OCELOT DENSITY AND HOME RANGE IN BELIZE, CENTRAL AMERICA: CAMERA-TRAPPING AND RADIO TELEMETRY

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(ABSTRACT)

Historically, ocelots (*Leopardus pardalis*) were hunted in large numbers for their fur, causing declines in population abundance across their range. In recent decades protection measures (e.g. CITES) and decreased public demand for ocelot fur resulted in declines in hunting pressure. Do to their elusive nature there is little known about ocelot population size, structure or general ecology. This lack of information hampers our ability to provide protection for this endangered species.

Remote cameras were deployed in 7 grids across the landscape to estimate the density of ocelots in 2 habitat types; the broadleaf rainforest and pine forest of western Belize. Camera trapping combined with mark-recapture statistics resulted in densities of 18.91 – 20.75 ocelots per 100 km^2 in the rainforest and 2.31 – 3.81 ocelots per 100 km^2 in the pine forest habitat. This study examined the issues of camera spacing and animals with zero distance moved and their effect on density estimation. Increased camera spacing resulted in larger buffer sizes (increasing the effective trap area) and decreased density estimates. Inclusion of zero distance animals decreased buffer sizes and increased density estimates. Regardless of these effects, ocelot density was higher in the broadleaf rainforest than the pine forest. The ocelot density estimates in Belizean forests were lower than those in other portions of their range. The camera trapping technique demonstrated ocelots to be mostly active at night, with peaks of activity after sunset and before sunrise, and to travel low-use roads in the wet season and high-use roads in the dry season.

Radio telemetry was used in this study to estimate the home range size and density of ocelots in the broadleaf rainforest of western Belize. Six collared ocelots (3 male, 3 female) were collared and tracked from September 2003 – August 2004. Male ocelots had an average home range size of 33.01 km^2 (95% fixed kernel) and 29.00 km^2 (100% MCP), and female ocelots had an average home range size of 21.05 km^2 (95% fixed kernel) and 29.58 km^2 (100% MCP). Most ocelots had larger home ranges in the dry season than the wet season. Ocelots showed a large amount of same sex home range overlap; with male-male overlap averaging 25% (100% MCP) and female-female overlap averaging 16% (100% MCP). Ocelot density determined using radio telemetry was 7.79 – 10.91 ocelots per 100 km^2. The radio telemetry ocelot densities were lower and their home ranges larger in the Belizean broadleaf rainforests than those in other portions of their range.

The camera trapping and radio telemetry techniques were compared against one another and combined in order to test which technique may be more successful in studying certain aspects of feline behavior. Activity budgets and density estimates determined from camera trapping were superior to radio telemetry, whereas camera trapping home ranges showed higher variation and lower resolution than radio telemetry. However, home range estimates determined from camera trapping captured long distance movements, a larger percent of territory overlap, and displayed potential for estimating an animal’s core use area. When radio telemetry data were used to create a buffer around camera traps based on the average radius of an ocelots' home range size, the resulting density estimates were smaller than those determined using the current camera trapping methodology.

This study provided much needed baseline information on ocelot abundance, home range size, activity patterns, and trail use. While sample sizes were small, this study had the largest number of ocelots captured in Central America to date. Although camera trapping is already a useful tool in felid research, this study highlights the importance of further standardization of the camera trapping methodology, increasing its potential for monitoring and conservation across habitats and study sites.

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Emma, I love you honey.

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CHAPTER 1 – OCELOT BACKGROUND AND ECOLOGY

Introduction

Historically, ocelots occurred in relatively large numbers from the southern United States to northern Argentina, but their populations have declined dramatically over the past half-century. From the 1950's to the mid 1980's, animal pelts were in high demand for international trade and ocelots were heavily exploited (Murray and Gardner 1997). Many countries exported large numbers of ocelot pelts, some approaching 100,000 annually (Myers 1973). The resulting decline in ocelot numbers prompted the Convention on International Trade in Endangered Species (CITES) to list the species as endangered on Appendix II in 1973 (Murray and Gardner 1997). Following the CITES listing, many countries passed laws banning the hunting and trade of ocelot and other felid pelts in the mid 1970s (Myers 1973). In July of 1982, the United States listed the ocelot as an endangered species (Murray and Gardner 1997), and in 1989 CITES moved ocelots to Appendix I (Sunquist and Sunquist 2002). However, enforcement of these laws is practically non-existent and ocelots are still hunted today, but in much lower numbers due to a decreased demand for their fur.

Although ocelot populations have declined throughout their range due to past hunting and current habitat loss (Broad 1987), no population estimates exist for ocelots in Central America (Sunquist and Sunquist 2002). In addition, there is very little known about their ecology. For example, in Central America our knowledge of ocelot biology comes from 1 study with 2 radio collared ocelots (Konecny 1989). This lack of data makes it difficult to design appropriate plans for ocelot conservation.

Current Status

Although hunting has had a severe effect on ocelot populations, the largest threat to ocelot survival currently is habitat destruction (Sunquist and Sunquist 2002). The dense forests they prefer are being converted to pastures and cropland in much of South America (Murray and Gardner 1997). In south Texas, which supports an ocelot population of roughly 100 animals, much of their preferred thorn scrub habitat has been converted to agricultural land, leaving only 1.6% of the region as potential ocelot habitat (Tewes and Everett 1986). To combat this loss of habitat, restoration projects are underway to return native woody thorn scrub habitat to the area (Shindle and Tewes 1998). The Rio Grande Wildlife Corridor Project has also been set up to facilitate ocelot movement and dispersal between Mexico and south Texas (Tewes and Blanton 1998). However, throughout the ocelot's range, habitat is being fragmented or destroyed, which will eventually lead to further population declines (Mondolfi 1986, Tewes and Everett 1986).

Distribution

Although ocelots historically ranged as far north as Arizona, Arkansas, and Louisiana, they currently range from the southern areas of Texas in North America, to the northern areas of Argentina in South America (Figure 1.1) (Murray and Gardner 1997, Sunquist and Sunquist 2002). They have also been observed on the Venezuelan Island of Margarita and the Island of Trinidad (Bisbal 1986). Ten subspecies of ocelot are recognized within this range, but molecular analysis shows only 4 separate phylogeographic groups: Central America, northern-northeastern South America (French

Guyana, northern Brazil), northern-northwestern South America (Venezuela, Panama, Trinidad, northern Brazil), and southern South America (Figure 1.2) (Murray and Gardner 1997, Eizirik et al. 1998). Large rivers such as the Amazon, Negro, and Branco, along with other natural barriers, separate these 4 regions, and mitochondrial DNA analysis shows little to no gene flow between these sub-populations (Eizirik et al. 1998, Sunquist and Sunquist 2002).

Habitat

Ocelots occur in a wide variety of habitats, residing in the thorn scrubs of Texas (Navarro 1985, Tewes 1986), the deciduous forests of Jalisco, Mexico (de Villa Meza et al. 2002), the subclimax moist, tropical forests of Belize (Konecny 1989), the lowland tropical rainforests of Peru (Emmons 1987a, Emmons 1987b, Emmons 1988), the savannas of Venezuela (Bisbal 1986, Mondolfi 1986, Ludlow and Sunquist 1987, Sunquist et al. 1989), and the semi-deciduous forests, subtropical forests, and Atlantic forests of Brazil (Crawshaw and Quigley 1989, Crawshaw 1995, Facure and Giaretta 1996, Trolle and Kery 2003). Throughout their extensive range ocelots inhabit elevations from sea level to 1,200 m (Mondolfi 1986, Sunquist and Sunquist 2002), and show strong association with dense cover (Emmons 1987a, Emmons 1988, Sunquist 1992).

Morphology

Ocelots are one of the largest of the small cats, comparable in size to bobcats. They average between 10 and 15 kg with males typically weighing more than females (Table 1.1) (Murray and Gardner 1997, Sunquist and Sunquist 2002). Body and tail lengths range from 70-100 cm and 25-45 cm respectively, resulting in a total length of 95-140 cm (Murray and Gardner 1997). Pelage color varies greatly between individuals, with each animal possessing a unique coat pattern (Figure 1.3) (Trolle and Kery 2003). The base color, which can appear tawny yellow, reddish gray, or gray, is marked with dark black spots, swirls, and stripes running from the neck down along the sides and back, leaving the underside of the coat white and spotted with black (Sunquist and Sunquist 2002). Their forepaws are larger than their hind paws, giving them the local name in some areas of South America of manigordo or "fat hands" (Sunquist and Sunquist 2002).

Reproductive Behavior

Ocelots can live up to 20 years in captivity, but their average life span in the wild, although unknown, is likely closer to 10 years (Table 1.1) (Cisin 1967, Eaton 1977, Laack 1991). Most ocelots achieve adult size after 2 years of growth, with females achieving full size earlier than males (Tewes 1986). Female ocelots may begin breeding at 18 months, but usually do not have their first litter until after 24 months (Mondolfi 1986, Laack 1991). Most male ocelots become sexually active after 30 months, however some have been known to produce viable sperm as early as 24 months (Mondolfi 1986). Laack (1991) suggested that nutrition and the local density of other adult females may influence a female's age of first reproduction.

Ocelots are considered to be polyestrous, although they have shown seasonal breeding in the northern sections of their range (Denis 1964, Tewes 1986). A female ocelot's estrus cycle is usually between 7 and 10 days in duration, but is halted at 5 days if conception occurs (Eaton 1977). Although estrus can occur every 6 weeks in captivity, estrus cycles in the wild occur every 4 to 6 months (Eaton 1977). The average gestation period is between 78 and 82 days (Mondolfi 1986), and newborn ocelots weigh approximately 200 g. They open their eyes at 15 to 18 days, begin walking at 3 weeks, leave the den to hunt at 4 to 6 weeks, start taking solid food at 8 weeks, and acquire their permanent canines at 8 months (Cisin 1967, Laack 1991, Mansard 1991). In the first few months, kittens' eyes turn from blue to brown and they slowly gain adult coloration (Cisin 1967, Mansard 1990). Although they are not known to hybridize in the wild, ocelots have hybridized with puma, margay, tiger cat, and Geoffrey's cat in captivity (Newman et al. 1985, Dubost and Royere 1993).

In the wild, ocelots average a litter of 1 to 2 kittens every other year, but they can produce larger litters more rapidly in captivity (Eaton 1977, Mondolfi 1986, Emmons 1988). Unlike domestic cats that have 8 mammae, ocelots have 4 mammae, possibly reflecting the upper limit of their litter size (Cisin 1967). Once kittens are born, the mother alone tends to them, moving them to a variety of different dens during lactation, which lasts from 3 to 9 months (Eaton 1977, Tewes 1986). Since female ocelots have sole responsibility of rearing kittens, their energy demands increase by 50-150% during lactation (Emmons 1988). Consequently ocelot mothers must increase their hunting activity during kitten rearing (Emmons 1987a). Since wild ocelots only produce 1 to 2 kittens every other year, mature at 2 years of age, and potentially live to 10 years, an individual's lifetime reproductive output is approximately 5 offspring (Sunquist and Sunquist 2002). Taking into account estimated mortality, only 2 of these 5 young will be expected to reach reproductive age (Sunquist and Sunquist 2002).

When compared with other small felids, ocelots have a longer gestation period and a slower growth rate (Sunquist and Sunquist 2002). These characteristics, as well as small litter size and slow sexual maturation are possible evolutionary adaptations for living in habitats where the availability of prey items is unreliable (Mondolfi 1986). However, these characteristics also make it hard for their population numbers to recover after an increase in mortality caused by hunting or habitat loss for example.

Feeding Behavior

Ocelots are solitary, terrestrial animals that may be active at any hour of the day, but are predominantly nocturnal (Murray and Gardner 1997). They are opportunistic hunters that feed primarily on small mammals, reptiles, and ground birds. They will prey upon any animal they can subdue, from spiny pocket mice (*Heteromys desmarestianus)*, opossums (*Didelphis marsupialis* and *Philander opossum)*, and armadillos (*Dasypus novemcinctus)*, to iguanas (*Iguana iguana)* and porcupines (*Coendou mexicanus, Coendou prehensilis, Coendou rothschildi)* (Bisbal 1986, Mondolfi 1986, Emmons 1987a, Konecny 1989, Farrel et al. 2000). Almost 90% of their diet consists of prey weighing < 1 kg, but given the opportunity they will take larger prey such as red brocket deer (*Mazama americana)*, collared peccaries (*Pecari tajacu)*, or howler monkeys (*Alouatta caraya)* (Murray and Gardner 1997). Since males are 20-25% larger than females they may be more successful capturing larger prey (de Villa Meza et al. 2002). Although an ocelot's diet may change depending on the habitat, they appear to hunt smaller prey in proportion to their availability (Emmons 1987a, Ludlow and Sunquist

1987). Since prey abundance can change seasonally, ocelot hunting habits may change seasonally as well.

In much of the ocelot's range it is sympatric with other carnivores such as jaguars (*Panthera onca)*, pumas (*Puma concolor)*, margays (*Leopardus weidi)*, and gray foxes (*Urocyon cinereoargenteus)*. However many studies have shown evidence of ecological separation between these animals (Bisbal 1986, Mondolfi 1986, Emmons 1987a, Konecny 1989, Sunquist et al. 1989, Facure and Giaretta 1996). The majority of prey taken by larger felids is > 1 kg in size, whereas the majority of prey taken by ocelots and other smaller carnivores is < 1 kg (Emmons 1987a, Ludlow and Sunquist 1987, Farrel et al. 2000). In addition to dietary separation, the ocelot may also separate itself from other competitors through its hunting behavior. The margay is an almost exclusively arboreal predator, whereas the ocelot is predominantly a terrestrial predator (Mondolfi 1986). Furthermore ocelots are mostly nocturnal, while other carnivores, such as the tayra (*Mustela barbara),* jaguarundi (*Herpailurus yaguarundi)*, and gray fox (*Urocyon cinereoargenteus*) are diurnal predators (Emmons 1988, Sunquist et al. 1989). These differences in hunting behavior and dietary separation are thought to release interspecific competition pressure and enable coexistence.

The separation of prey at approximately 1 kg coincides with a switch in prey ecology. Prey weighing < 1 kg demonstrate high reproductive rates, short generation times, and continuous breeding, whereas prey > 1 kg demonstrate lower reproductive rates, longer generation times, and discrete breeding (Emmons 1987a, Emmons 1988). This suggests ocelot biomass is not supported by a high standing biomass of prey, but rather the high productivity of their prey (Emmons 1987a, Emmons 1988). In research conducted by Emmons (1987a) in Peru, ocelot biomass was estimated at 6 kg/km^2, and the average adult ocelot was estimated to eat 550-850 g of meat per day (60-90 g of meat per day per kg of ocelot). Considering the average weight of their prey, ocelots must kill approximately 3 small (< 1 kg) prey items per day (Emmons 1988).

Since ocelots prey on live animals that are widely distributed and hard to detect, they must travel long distances and hunt intensively to acquire sufficient food (Emmons 1987a). Ocelots have 2 main hunting strategies; they either walk for long periods of time until they encounter a prey item, or sit in one spot and wait until they detect prey (Sunquist and Sunquist 2002). Usually ocelots consume their entire prey immediately following a kill, but if the prey is too large they will return the next day to consume the remains (Kitchener 1991).

Olfactory cues are considered relatively unimportant in ocelot hunting, especially when compared with visual cues (Emmons 1988). Since ocelots are mostly visual predators, both sunlight and the moonlight affect their hunting behavior. The more light available, the easier it is to detect prey. For this reason, ocelots are most active in the hours following sunset, and can often be seen hunting during the day when it is rainy or overcast (Konecny 1989). During evenings of bright moonlight, ocelots will still hunt actively, but much of their time is spent in dense habitats searching for hidden prey instead of on open trails (Emmons et al. 1989).

Home Range and Habitat Use

Both male and female ocelots establish home ranges although the ranges of adult male ocelots are larger, overlapping the ranges of 2 or 3 females (Murray and Gardner

1997). Female home ranges are thought to be entirely within a single male's range and show little overlap with neighboring females (Murray and Gardner 1997). The ranges of both sexes are often reduced (11-38%) during the wet season, presumably due to higher prey density (Tewes 1986, Ludlow and Sunquist 1987, Sunquist et al. 1989). Ocelots patrol the boundaries of their home range more heavily than the interior, and often avoid open areas (Emmons 1987a). Both males and females are active between 12 and 14 hours of the day and rarely spend 2 days in the same spot (Emmons 1987a). Sub-adult ocelots usually do not establish their own home range until 2 to 4 years of age, and there is little chance of ocelots breeding until they establish a territory (Emmons 1988, Laack 1991). Since male ocelots defend larger territories and multiple mates, Emmons (1987a) suggests that ocelot mothers may allow sons to remain in their natal ranges longer, affording them more time to grow strong before dispersing and acquiring their own territory.

Ocelots patrol their home range almost constantly, covering their entire range every 2 to 4 days (Emmons 1988). They may travel up to 6.5 km in a 24 hour period (Konecny 1989), often leaving scrapes on fallen logs or nearby trees, and marking the boundaries of their territory by spraying, urinating or defecating (Murray and Gardner 1997). Such signs of activity likely encourage temporal avoidance by competing predators, reducing the chance of direct interactions. Although these behaviors are important in establishing home ranges throughout the year, they are especially prominent during the breeding period (Emmons 1987a, Murray and Gardner 1997). Females may overlap with neighboring females, but when a female has kittens she patrols her territory intensely and no overlap is permitted (Emmons 1988). Since males overlap with many females, they must travel greater distances to check the reproductive status of females and meet their energy requirements (Ludlow and Sunquist 1987). Due to this extensive traveling by the resident male, neighboring males may occasionally have access to the breeding females, allowing females some mate choice (Emmons 1988).

Since ocelots prefer dense habitats and are elusive by nature, they are especially difficult to observe. A handful of research projects have used radio telemetry and the Minimum Convex Polygon (MCP) to study the ocelot's home range in various regions of its distribution (Table 1.2). Konecny (1989) collared 2 cats and estimated male and female home ranges in the subclimax rainforests of Belize to be 31.25 km^2 and 14.68 km^2 respectively. While Crawshaw (1995) estimated the largest male and female home ranges in the subtropical forests of northeastern Argentina and southwestern Brazil to be 38.80 km^2 and 17.40 km^2 respectively, Emmons (1988) estimated the smallest female home range in the rainforests of Peru to be 1.98 km^2. Although it is not known exactly why ocelots possess small home ranges in certain habitats, it is assumed that the smaller home range of ocelots in Venezuela and Peru is the result of prime habitat (Konecny 1989). Better habitat conditions may support more prey, allowing ocelots to travel less in order to meet their energy requirements.

Density

In addition to home range size, ocelot density has also been estimated in sections of its range (Table 1.3). Crawshaw (1995), Ludlow and Sunquist (1987), and Emmons (1988) all captured ocelots and equipped them with radio collars. After determining each animal's home range, the total area of all the collared ocelots was divided by the number of ocelots captured to estimate ocelot density. Crawshaw (1995) estimated the lowest ocelot density of 13.7 ocelots/100 km^2 in the subtropical forests of northern Argentina and southern Brazil, whereas Emmons (1988) estimated the highest ocelot density of 80 ocelots/100 km^2 in the rainforests of Peru. This method of density estimation is often inaccurate due to variation in home range estimates, small sample sizes, and not all animals in the study area being captured.

Recently studies have been conducted using a relatively new technique to estimate the density of ocelots. Instead of radio collaring ocelots as previous studies have done, individual ocelots were detected and identified using infrared remote cameras. Cameras were placed so that the movement of each identified ocelot could be mapped and an overall population size of the study area could be determined using mark-recapture statistics. With this technique Trolle and Kery (2003) determined an ocelot density of 62 ocelots/100 km^2 in the Pantanal region of southeastern Brazil, while Di Bitetti et al. (Under Review) found a density of 12.9 to 19.1 ocelots/100 km^2 in the Atlantic forest of Argentina, Haines et al. (Under Review) found a density of 30 ocelots/100 km^2 in the thorn scrub forests of Texas, and Maffei et al. (Under Review) found a density of 24.0 to 66.0 ocelots/100 km^2 in the various dry forests of eastern Bolivia. These density estimates are based on mark-recapture statistics, which are likely more accurate than estimates of density from telemetry studies.

Dispersal and Mortality

Ocelots begin dispersing after 2 years of age, with females possibly being forced to leave their natal range earlier than males (Emmons 1987a, Ludlow and Sunquist 1987).

Female ocelots may establish a territory within the home range of a resident male, but males must establish their own territory in order to attract mates and breed (Emmons 1987a). Dispersing from their natal range and establishing their own territory can be extremely taxing on male ocelots, and may be the main source of mortality (Crawshaw 1995). Males will travel long distances in erratic patterns to find available habitat, often encountering and fighting other males (Crawshaw 1995). In their search for a home range, male ocelots often come in contact with roads and civilization, increasing their risk of being shot by poachers or hit by automobiles (Tewes 1986, Emmons 1987a, Crawshaw 1995). Other than humans, ocelots have few predators, but can occasionally be taken by harpy eagles (*Harpia harpyja*), pumas, jaguars or boa constrictors (*Boa constrictor constrictor*) (Murray and Gardner 1997).

In Texas, 4 of the 8 ocelots that dispersed died shortly after leaving their natal ranges, 3 from suspected automobile collisions (Navarro 1985, Tewes 1986, Tewes and Everett 1986). Crawshaw (1995) documented an ocelot that was killed by a bus while dispersing, and Emmons (1988) documented an animal that had dispersed 5 km before being killed in a fight with another ocelot. Crawshaw (1995) calculated the daily mortality rates for collared ocelots in northeastern Argentina and southwestern Brazil to be 0.0056, and Tewes (1985) estimated the annual mortality rate of the ocelots in south Texas to be 29%.

In the past 20 years, knowledge of ocelot ecology, behavior, and status has slowly increased due to the field studies that have been conducted throughout their range, however there is still little known about their demographics or movement. The objective of this study is to use remote cameras to determine the first ocelot density estimate in

Central America from 2 neighboring habitats of western Belize, the rainforest and pine forest, and to estimate ocelot home range size in the rainforest using radio telemetry. Furthermore this study examines the impact of camera spacing and animal movement on camera trapping density estimates, and compares the density estimates, home range sizes, and activity budgets determined from each separate technique.

Study Site

This research was conducted within the 1775 km^2 Chiquibul Forest Reserve and National Park (CFRNP) (16˚ 44' N, 88˚ 59' W; 500 m elevation) of Western Belize (Figure 1.4) (Penn et al. 2004). This area of western Belize, along with the Peten regions of northern Guatemala and southern Mexico make up La Selva Maya (the Mayan Forest) (Figure 1.5), the largest tropical broadleaf forest remaining in Central America (Carr and de Stoll 1999). Rainfall in the Chiquibul averages 1500 mm/year with a rainy season from June to January (Johnson and Chaffey 1973). The vegetation is a mosaic of broadleaf tropical moist rainforest, deciduous semi-evergreen, deciduous seasonal forest, and stands of pine (Wright et al. 1959). Some blocks of the Chiquibul Forest Reserve are selectively logged for commercially important species on a > 40-year rotational basis. Besides the currently used logging roads, there are numerous old logging roads, making the area conducive to setting up camera stations. The study took place in 2 dominant habitat types of the Chiquibul Forest Reserve, the broadleaf rainforest and the pine forest. The research was conducted in an area of La Selva Maya centered around the Las Cuevas Research Station (LCRS). At the time of this study, the LCRS was jointly administered by the Belize Forest Department and British Natural History Museum.

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Table 1.1 Average ocelot vital statistics (Murray and Gardner 1997).

Adult Weight	10 – 15 kilograms
Birth Weight	200 grams
Body Length	70 – 100 centimeters
Total Length	95 – 140 centimeters
Life Span in the Wild	10 years
Age of Male Sexual Maturity	30 months
Age of Female Sexual Maturity	24 months
Estrus Cycle	5 – 10 days
Gestation Period	78 – 82 days
Litter Size	1 – 2
Lactation Period	3 – 9 months
Eyes Open	15 – 18 days
Walking	3 weeks
Permanent Canines	8 months

Table 1.2 Average ocelot home range (km^2) in various habitats with the corresponding method and sample size (n).

Location	**Habitat**	**Method**	**Male (n)**	**Female (n)**
Belize[1]	Subclimax Rainforest	MCP	31.25 (1)	14.68 (1)
Brazil[2]	Subtropical Forest	MCP	43.25 (11)	16.03 (10)
Peru[3]	Tropical Rainforest	MCP	------	1.98 (1)
Texas[4]	Thorn Scrub	Minimum Area	2.50	2.10
Texas[5]	Thorn Scrub	Harmonic – Contour	17.67	11.04
Texas[6]	Thorn Scrub	MCP	6.25 (3)	2.87 (3)
Venezuela[7]	Llanos	Minimum Area	10.40 (2)	3.35 (6)
Venezuela[8]	Llanos	MCP	9.70 (1)	2.54 (2)

[1] Konecny 1989
[2] Crawshaw 1995
[3] Emmons 1988
[4] Navarro 1985
[5] Tewes 1986
[6] Laack 1991
[7] Ludlow and Sunquist 1987
[8] Sunquist et al. 1989

Table 1.3 Estimated ocelot density (individuals per 100 km^2) in various habitats with corresponding method.

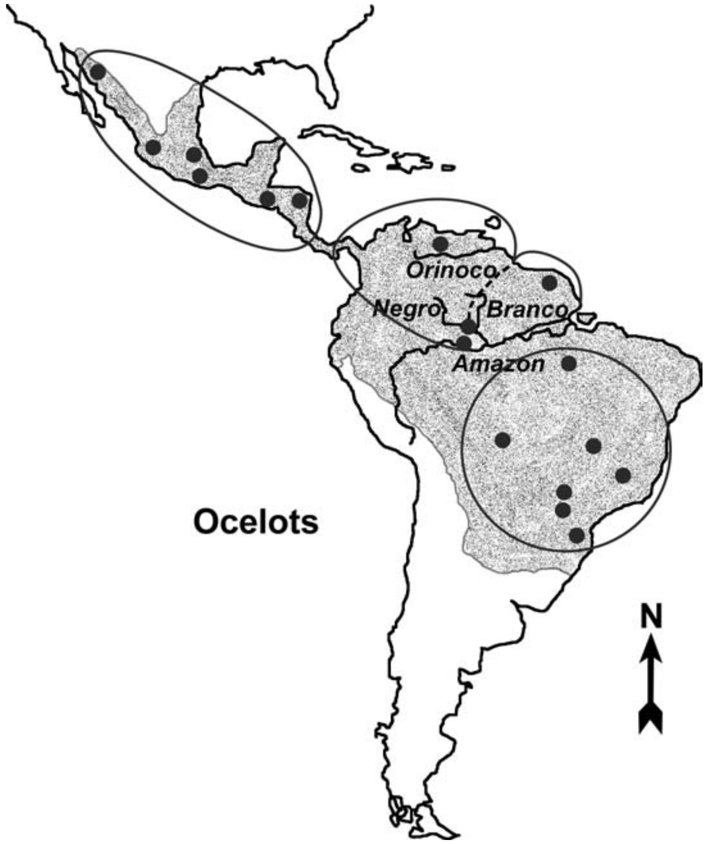
Location	**Habitat**	**Method**	**Density**
Argentina[1]	Atlantic Forest	Remote Camera	12.9 – 19.1
Bolivia[2]	Dry Forests	Remote Camera	24.0 – 66.0
Brazil[3]	Subtropical Forest	Radio Telemetry	13.7
Brazil[4]	Pantanal	Remote Camera	62.0
Peru[5]	Tropical Rainforest	Radio Telemetry	80.0
Texas[6]	Thorn Scrub Forest	Remote Camera	30
Venezuela[7]	Llanos	Radio Telemetry	40.0

[1] Di Bitetti et al. Under Review
[2] Maffei et al. Under Review
[3] Crawshaw 1995
[4] Trolle and Kery 2003
[5] Emmons 1987a
[6] Haines et al. Under Review
[7] Ludlow and Sunquist 1987

Figure 1.1 Ocelot distribution from the southern United States to northern Argentina.

From Sunquist and Sunquist 2002

Figure 1.2 Ocelot subspecies distribution.



From Eizirik et al. 1998

Figure 1.3 Examples of distinct ocelot coat patterns from the broadleaf rainforest habitat of western Belize.

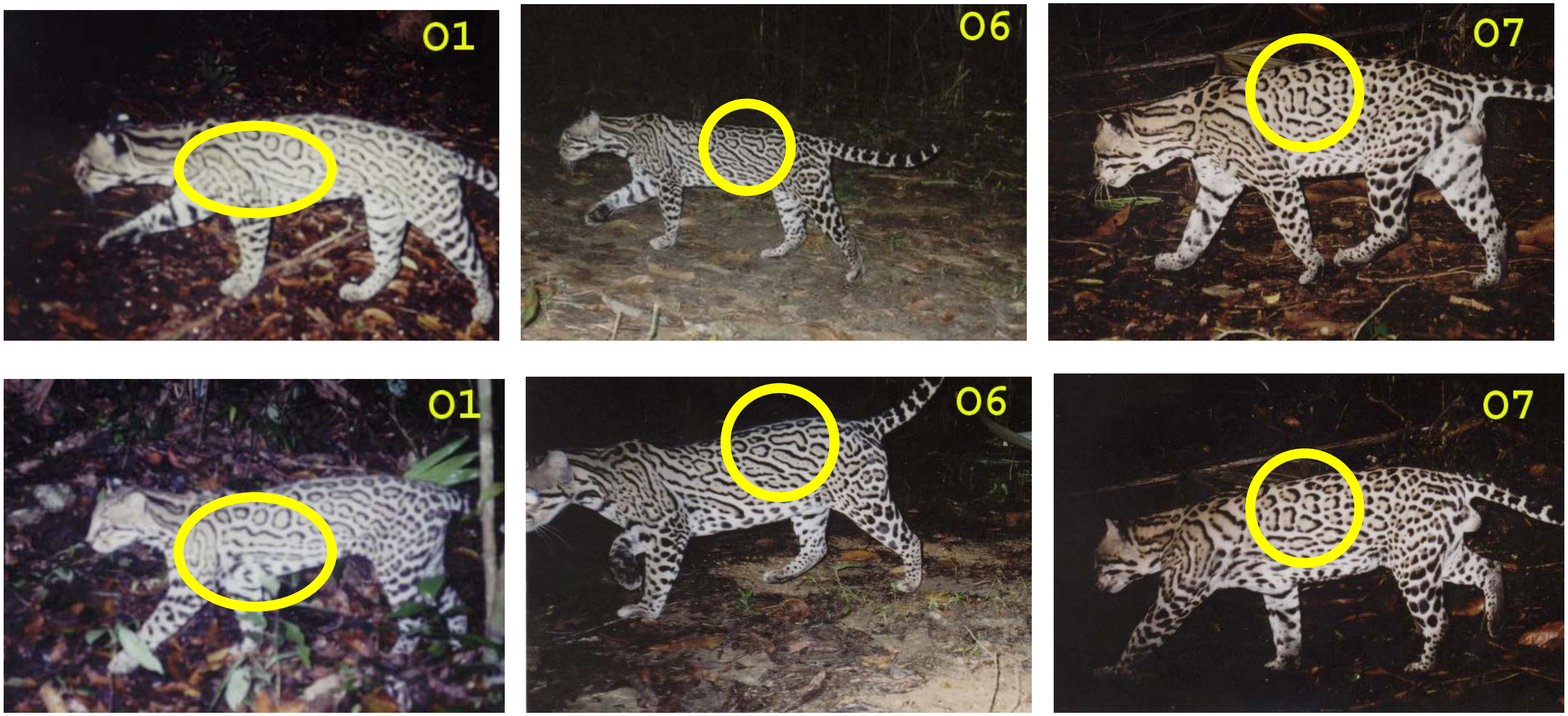


Figure 1.4 Belize and the Las Cuevas Research Station (LCRS).

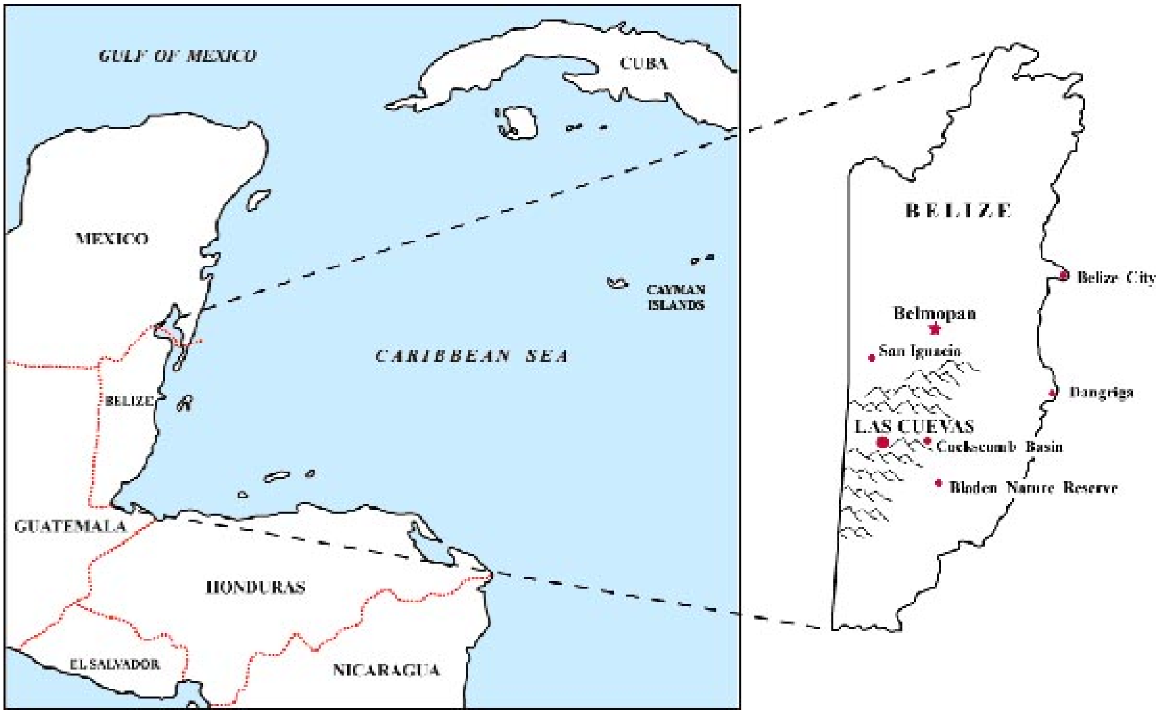
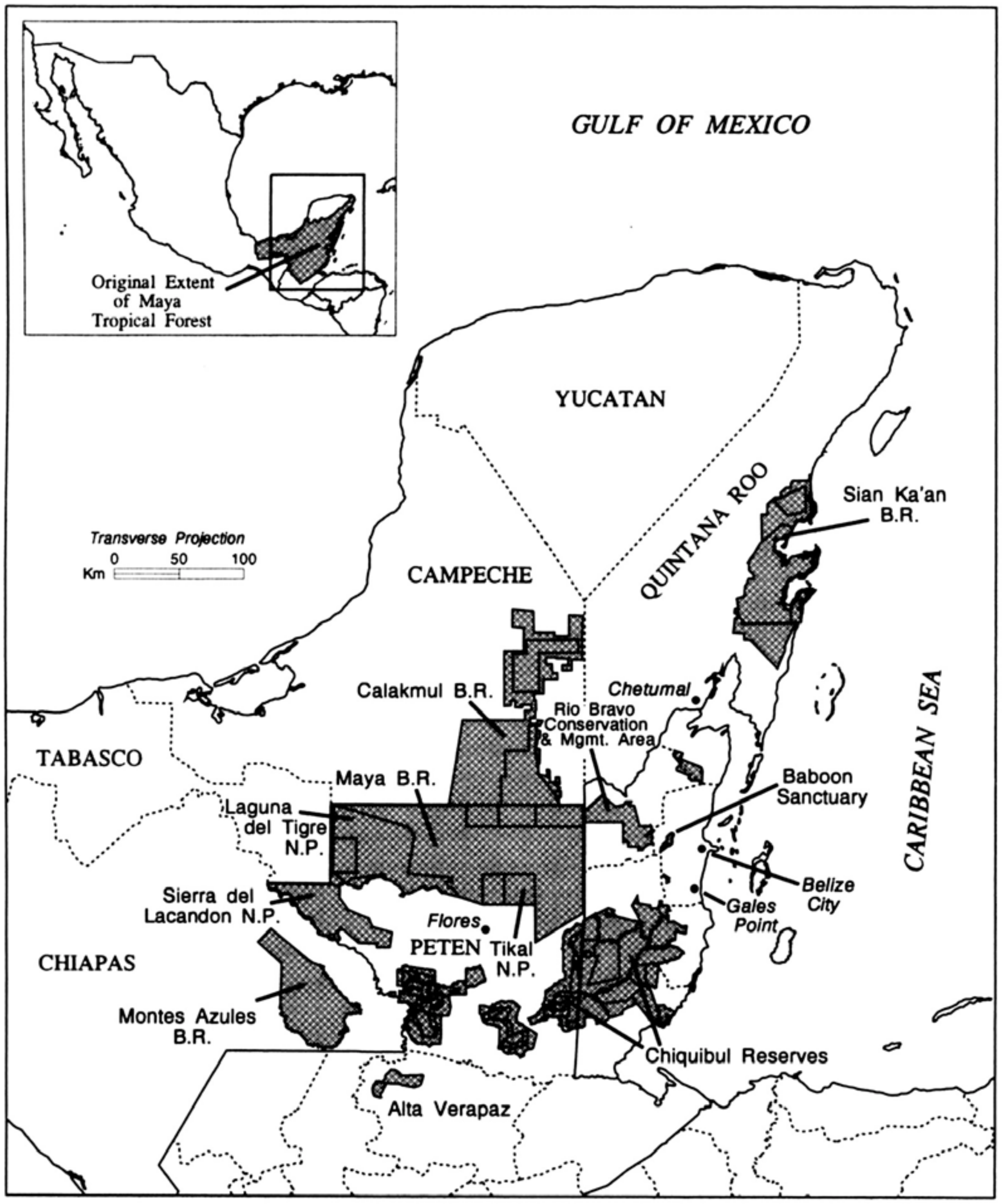


Figure 1.5 La Selva Maya (The Mayan Forest).



From Nations et al. 1998

CHAPTER 2 – CAMERA TRAPPING: OCELOT TRAP SUCCESS, ACTIVITY PATTERNS, AND DENSITY

Abstract

The elusive nature of ocelots makes them difficult to study and as a result little is known about their ecology, population size or structure. In this study, remote cameras were used to determine trap success, activity and trail use patterns, as well as to identify individuals and estimate ocelot density in the broadleaf rainforest and pine forest habitats of western Belize. Five camera trapping grids using varying camera spacing were established and monitored in the rainforest while 2 grids were established and monitored in the pine forest. Ocelot trap success from remote cameras was relatively high at 2.11 - 6.20 captures per 100 trap nights in the broadleaf rainforest habitat and demonstrated that ocelots were active mostly at night with peaks of activity just after sunset and before sunrise. Ocelots were shown to travel low-use roads in the wet season and high-use roads in the dry season. Camera trapping combined with mark-recapture statistics resulted in ocelot densities of 18.91 – 20.75 per 100 km^2 in the rainforest and 2.31 – 3.81 per 100 km^2 in the pine forest habitat. In addition, the effect of camera spacing on density estimation was examined. Increased camera spacing resulted in lower density estimates due to the increase in buffer size surrounding camera traps (increasing the effective trap area). In addition, inclusion of animals with a zero distance moved decreased the effective trap area which increased density estimates. Ocelot density was higher in the broadleaf rainforest than in the pine forest, possibly implying that ocelots exhibit preference for more dense cover. When compared with other portions of their range, ocelot densities were much lower in Belizean forests.

Introduction

Many species of endangered felids inhabit the dense rainforests of Central and South America. The secretive and elusive nature of these cats, along with the often remote and dense habitat in which they live, makes them difficult to study. Historically, track surveys and scat analyses have been used to study neotropical felids, but there are many limitations to these methods (Bisbal 1986, Emmons 1987). Although these techniques have provided some insight into felid diet and behavior, they have not been successful in estimating population size or density (Farrell et al. 2000). More recently, radio telemetry has been used to study these felids, but their nocturnal habits, dense habitat, and wide-ranging behavior make application of this technique difficult. In addition, radio telemetry is often expensive, time intensive, and stressful to the animal. Despite these problems, data collected using this method has resulted in density and home range estimates for ocelots (Table 1.2 and Table 1.3) (Ludlow and Sunquist 1987, Emmons 1988, Crawshaw 1995).

Recently, “camera-trapping” has been developed to study elusive felids (Karanth 1995, Karanth and Nichols 1998). For animals possessing unique coat patterns, infrared cameras “capture” them using photography and a capture-recapture history is established for each individual (Karanth 1995, Karanth and Nichols 1998). By positioning the cameras in a specific arrangement, density is determined through mark-recapture analysis (Karanth 1995, Karanth and Nichols 1998). This camera trapping technique was used to estimate the density of tigers (*Panthera tigris*) in Southeast Asia (Karanth 1995, Karanth and Nichols 1998, Carbone et al. 2001, Karanth et al. 2004), jaguars (*Panthera onca)* in Central and South America (Silver et al. 2004), and recently ocelots (*Leopardus pardalis*) in the Southern United States (Haines et al. Under Review), the dry forest of Bolivia (Maffei et al. Under Review), the Pantanal of Brazil (Trolle and Kery 2003), and the Atlantic forests of Argentina (Di Bitetti et al. Under Review).

The camera trapping technique has a relatively high start-up cost, but once established, is relatively inexpensive to maintain and can be managed by a few personnel. This technique is non-invasive and does not alter the animal's natural behavior. It can be used to collect data on a variety of species simultaneously and is currently the most successful technique for determining abundance of elusive felids (Karanth 1995, Karanth and Nichols 1998). In addition to estimating population densities, there is potential for this technique to be used over the long term to research aspects of animal behavior and population ecology such as home range, mortality, survival, and recruitment (Karanth 1995, Karanth and Nichols 1998).

The main objective of the camera trapping portion of this study is to estimate ocelot density in the tropical broadleaf rainforest and the tropical pine forest of western Belize, and to determine a difference if any between them. This study also examines the effect of camera spacing and ocelot movement on density estimation and determines ocelot trap success, activity budgets, trail use patterns and home range estimates using this remote camera technique.

Study Site

This research project was conducted within the 1775 km^2 Chiquibul Forest Reserve and National Park (CFRNP) (16° 44' N, 88° 59' W; 500 m elevation) of western Belize (Figure 1.4) (Penn et al. 2004). This area of Belize, along with the Peten regions of northern Guatemala and southern Mexico, make up La Selva Maya (the Mayan Forest) (Figure 1.5), the largest tropical broadleaf forest remaining in Central America (Carr and de Stoll 1999). Rainfall in the Chiquibul averages 1,500 mm/year with a rainy season from June to January (Johnson and Chaffey 1973). The vegetation is a mosaic of broadleaf tropical moist rainforest, deciduous semi-evergreen, deciduous seasonal forest, and stands of pine (Wright et al. 1959). Some blocks of the Chiquibul Forest Reserve are selectively logged for commercially important species on a > 40-year rotational basis. This research was based out of the Las Cuevas Research Station (LCRS) (Figure 1.4), which was jointly administered by the Belize Forest Department and the British Natural History Museum at the time of the study.

Camera trapping surveys were conducted in 2 dominant habitats within the Chiquibul Forest Reserve, the broadleaf rainforest and the tropical pine forest (Figure 2.1). The broadleaf rainforest is a secondary rainforest subjected to frequent natural disturbance in the form of hurricanes. Tall canopy trees such as the cohune palm (*Orbigyna cohune*), ironwood (*Dialium guinense*), quamwood (*Schizolobium parahybum*), sapodilla (*Manilkara zapota*), nargusta (*Terminalia amonzonia*) and ceiba (*Ceiba pentandra*) trees frequently occur in this dense rainforest habitat (Beletsky 1999). The tropical pine forest is less dense than the broadleaf habitat and is dominated by the Caribbean pine (*Pinus caribaea*), mountain pine (*Pinus oocarpa*), and the palmetto palm (*Acoelorrhaphe wrightii*) (Beletsky 1999). From 1999 to 2003, the Southern pine beetle (*Dendroctonus frontalis*) decimated a large percent of the pine trees, creating a more open overstory which is growing back rapidly (Billings et al. 2004), resulting in a dense understory of small pine trees and other vegetation (personal observation).

Methods

Camera Trapping Grids:

Five separate remote camera models, manufactured by 3 companies, were used for this research; TrailMaster 1550 and 550, CamTrakker, and DeerCam 100 and 200. The TrailMaster 550, CamTrakker, and DeerCams 100 and 200 are passive infrared cameras which function independently and measure motion and temperature in a targeted area via a heat and motion sensor. When an animal passes in front of the area, motion and temperature changes are detected by the sensor and the camera is triggered to take a photograph. The TrailMaster 1550 is an active infrared camera model. This model includes a transmitter placed on one side of the path which emits an invisible infrared beam to a receiver placed on the other side of the path. When an animal moves through the invisible beam the cameras attached to the receiver are triggered. Each photograph is marked with the date and time.

During the course of this study (August 2002 – August 2004), 3 separate remote camera grids were established specifically to estimate ocelot density (Table 2.1). Two of these grids were set up in broadleaf rainforest habitat and the third was set up in pine forest habitat. When setting up the 3 ocelot-specific camera trapping grids (named: ocelot rainforest pilot, ocelot rainforest, ocelot pine forest) the distance between camera stations was based on the smallest estimate of an ocelot's home range (2 km^2) (Emmons 1988). Camera stations were placed closer together than the diameter of this smallest estimated ocelot home range (1.6 km). This increased the probability of capture for each ocelot in the surveyed area. Camera stations were set up along newly cut trails, established trails, and roads. To photograph both sides of the ocelot for positive identification, each station contained 2 cameras, one on either side of the trail. Cameras were placed 25-40 cm high and programmed to run continuously. Once mounted, all cameras were tested in the field to ensure that an ocelot sized animal would be detected and photographed as it passed by the camera station.

Camera trapping mark-recapture analysis assumes the population is closed (no births, deaths, immigration or emigration) during the time period of the survey (Karanth and Nichols 1998). To meet this assumption each trapping grid was active for ≤ 90 days, a short trapping period relative to the lifespan of an ocelot and similar to previous methods used for felids (Karanth and Nichols 1998, Trolle and Kery 2003, Silver et al. 2004). Data on vegetative cover, path width, and trail type were collected at each camera station during set up. During the trapping session each camera was checked on average every 10 days to replace batteries or film, and to check for camera malfunctions.

In addition to the 3 ocelot-specific grids, data from 4 grids set up to estimate jaguar density (Jan 2002 – Apr 2004) were analyzed for ocelot density (Table 2.1). Three of these grids were located in the broadleaf rainforest habitat (named: jaguar rainforest 1, jaguar rainforest 2, jaguar rainforest 3), and one was located in the pine forest habitat (named: jaguar pine forest). To determine jaguar density, the average camera spacing for these grids was twice as large as for ocelots, at approximately 3000 m (Table 2.1).

Trapping Success:

The trapping success (number of animal captures per 100 trap nights) was determined separately for each camera trapping grid and for every species photographed. For a single camera trapping grid the number of photographic captures was determined for each species. Photographs of animals that were not individually identifiable and taken within an arbitrarily assigned 20 minute time period were considered the same event and not counted as multiple captures unless a distinguishing feature enabled individual identification. The total number of trap nights was determined for the entire camera trapping grid. The number of photographic captures of each species was divided by the total number of trap nights multiplied times 100, resulting in a trapping success for each animal species.

Since the pine forest habitat is currently more open than the rainforest and ocelots have shown preference for dense habitat (Murray and Gardner 1997), I hypothesize that ocelot trap success will be higher in the rainforest than the pine forest.

Activity Budget:

Ocelot photograph captures from all 5 of the rainforest camera grids were combined and separated by each hour of the day. The total number of ocelots captured in each hour was divided by the total number of ocelot captures to determine the percentage of activity for ocelots throughout the day. An activity budget was determined for male ocelots, female ocelots, and all ocelots combined.

Some ocelot studies have shown ocelots to demonstrate nocturnal activity patterns (Emmons 1988), whereas other studies have shown higher rates of daytime activity (Konecny 1989). For this study I hypothesize that ocelots will demonstrate more activity at night than during the day.

Trail Use:

Four trail types were determined; newly cut trails, established trails, low-use roads (traveled < once a week), and high-use roads (traveled > once a week). The number of ocelot photographs taken in each trail type for all 5 rainforest camera grids was divided by the total number of ocelot photographs to determine percent use. A 95% confidence interval of percent use was determined for each trail type. The number of camera stations in each trail type for all 5 rainforest camera grids was divided by the total number of camera stations to determine percent availability. The percent use and percent availability was determined was for the wet season, dry season, and all rainforest grids combined.

Data from previous jaguar camera surveys in Belize (Silver et al. 2004) and ocelot camera surveys in Brazil (Trolle and Kery 2003) lead me to hypothesize that ocelots will show a preference for roads over trails.

Home Range:

Camera trapping has recently been used to estimate minimum home range size (Di Bitetti et al. Under Review, Maffei et al. Under Review). A 100% Minimum Convex Polygon (MCP) home range was calculated for all ocelots captured ≥ 3 separate camera stations from the rainforest camera grids conducted from Aug 2002 – Sept 2004. An average home range size was determined for male ocelots, female ocelots, and all ocelots combined.

Since male ocelots have been shown to have larger territories than female ocelot (Murray and Gardner 1997), I hypothesize that males will have a larger average camera trapping home range than females.

Population Size:

For each trapping grid, every photographed ocelot was identified by its spot pattern (Figure 2.2). The camera data was divided into 3-day periods, each constituting a single trapping occasion. A capture history, which consists of a string of 0s and 1s, indicating if an animal was or was not caught respectively for each trapping occasion, was created for each ocelot. The capture histories of all ocelots in a single camera grid were combined and analyzed with CAPTURE to estimate the population size (Otis et al. 1978, White et al. 1982, Rexstad and Burnham 1991). Both geographic and demographic closure were assumed and the program CAPTURE statistically tested these assumptions.

Within program CAPTURE there are 3 sources of variation affecting capture probability: time variation (M_t), behavior variation (trap-response) (M_b), and heterogeneity variation (M_h). Time variation (M_t) allows for the ocelot probability of capture to change over time, whereas behavior variation (M_b) allows the ocelot probability of capture to change after its first capture (trap-happy or trap-shy) and heterogeneity variation (M_h) allows the ocelot probability of capture to be unique for each animal captured. There are also combinations of all three sources of variation (e.g. M_{tb}, M_{th}, M_{bh}, M_{tbh}).

Theoretically the camera trapping methodology should reduce the likelihood that time or behavior will affect ocelot capture probability, and since ocelots are territorial and male ocelots have larger territories than female ocelots, I hypothesize that heterogeneity will be the largest source of variation in ocelot capture probability. The program CAPTURE used goodness of fit tests, between model tests, and discriminate function analysis to rank the variety of model estimators provided (White et al. 1982). This model selection was used to determine the most appropriate population estimator for the camera trapping surveys.

There were not enough ocelot captures in the pine forest habitat to use the program CAPTURE. To estimate a population size for each pine forest grid Equation 1 was used.

$$\text{Equation 1:} \quad N_{pf} = n_{pf} / p_{pf}$$

The number of ocelots captured for each separate pine forest camera grid (n_{pf}) was divided by the probability of capture for ocelots in the pine forest (p_{pf}) to determine the estimated population size of each pine forest grid (N_{pf}). Since the probability of capture for ocelots in the pine forest is unknown the probability of capture for ocelots in the rainforest was substituted. This assumes that ocelot capture probability is similar in the rainforest and the pine forest, an assumption that cannon be tested by this study. The probability of capture for ocelots in the rainforest was determined using Equation 2.

$$\text{Equation 2:} \quad p_{rf} = n_{rf} / N_{rf}$$

The total number of ocelots captured across all 5 rainforest grids (n_{rf}) was divided by the estimated ocelot population size across all rainforest grids (N_{rf}) to determine the probability of capture for ocelots in the rainforest (p_{pf}).

Effective Trap Area:

To determine the effective trap area of each camera grid, the maximum distance moved between any 2 cameras was determined for each ocelot. The maximum distances of all ocelots in a single camera grid were averaged to determine the mean maximum distance moved (MMDM). Half of this MMDM value was used as a buffer around each camera station in ArcView. The area of all buffers combined determined the total effective trapping area for each camera survey (Figure 2.3) This method followed other felid camera trapping studies (Maffei et al. 2004, Silver et al. 2004) and has been determined to be robust in simulation studies (Wilson and Anderson 1985).

Ocelots captured once do not have a maximum distance moved and were excluded from the MMDM analysis, but ocelots captured repeatedly at a single camera station have a maximum distance of zero. Some studies include these zeros in calculating MMDM (Silver et al. 2004) and others do not (Trolle and Kery 2003, Maffie et al. Under Review). In this study the MMDM was calculated both ways and the effect these "zero animals" had on the resulting density estimates was examined.

In addition to determining a unique MMDM value for each camera grid, the maximum distances of ocelots were pooled across all 5 rainforest grids to determine a single average mean maximum distance moved (AMMDM) value for the rainforest habitat. This AMMDM value was then halved and used as a buffer around each camera station to determine the final effective trap area of each rainforest camera grid. The AMMDM was determined both excluding and including animals with maximum distances of zero.

There were not enough ocelot captures in the pine forest to determine a unique MMDM or AMMDM value. To determine the effective trap area of each pine forest camera grid the AMMDM value from the rainforest habitat, determined both excluding and including animals with a maximum distance of zero, was substituted. The rainforest AMMDM value was halved and used as a buffer around each pine forest camera station to determine the final effect trap area of each pine forest camera grid. This assumes that ocelot movement patterns are similar in the tropical rainforest and the pine forest, an assumption that cannot be tested by this study.

Density:

To estimate the ocelot density of each rainforest camera grid, the population estimate determined by CAPTURE was divided by the effective trap area. The effective trap area for each rainforest grid was determined 4 separate ways; unique MMDM value, both excluding and including animals with a maximum distance of zero, and the AMMDM value, both excluding and including animals with a maximum distance of zero. The standard error was determined for each rainforest density estimate following Nichols and Karanth (2002).

To determine a final pine forest density, the population estimate was divided by the effective trap area. The effective trap area for each pine forest grid was determined 2 separate ways; rainforest AMMDM value, both excluding and including animals with a maximum distance of zero.

Since the pine forest habitat is currently more open than the rainforest and ocelots have shown preference for dense habitat (Murray and Gardner 1997), I hypothesize that ocelot density will be higher in the rainforest than the pine forest.

Results

Trap Success:

The trapping success for each species was determined for each separate camera trapping grid (Table 2.2, Figure 2.4). Jaguars, pumas, and ocelots showed relatively high trapping success rates in the rainforest habitat, ranging from 1.14 to 8.09 captures per 100 trap nights (Figure 2.4a). Conversely jaguarundi (*Herpailurus yaguarondi*) and margay (*Felis wiedii*) showed extremely low trap success (Figure 2.4a). Social animals such as the white-lipped peccary, ocelated turkey and coati showed variation in trapping success from grid to grid. When the 2 habitats were compared, ocelots, white-lipped peccary, paca, agouti, tinamou and brocket deer all showed higher trap success in the rainforest, whereas the white-tailed deer and gray fox showed higher trap success in the pine forest. Although sample sizes were too small to statistically test if ocelot trap success was higher in the rainforest than the pine forest, the results strongly support this hypothesis.

Activity Budget:

A total of 145 ocelot photograph captures (115 male, 27 female) was used to construct activity budgets (Figure 2.5). Ocelots demonstrated more activity from 7 pm until 4 am than from 4 am until 7 pm, with peaks of activity just after sunset around 7 pm, and again at 1 am (Figure 2.5a). When activity budgets were separated by sex, both male and female ocelots showed similar activity trends with the majority of activity at night, but the difference in sample size affected the resolution of the activity pattern. These results support my hypothesis that ocelots exhibit more activity at night than during the day.

Trail Use:

When ocelot trail use was graphed against trail availability for all of the rainforest trapping grids, they used new and established trails less than available while using low use roads and high use roads more than available (Figure 2.6a), supporting my hypothesis. When ocelot trail use was graphed against trail availability for the wet season, new trails were avoided and low use roads were preferred (Figure 2.6b). When ocelot trail use was graphed against trail availability for the dry season, new and established trails were avoided while high use roads were preferred (Figure 2.6b).

Home Range:

The 100% MCP rainforest camera trapping home ranges for 15 ocelots (7 male, 8 female) demonstrated a large amount of same sex and opposite sex overlap (Figure 2.7). Individual ocelots demonstrated high variation in the size of camera trapping home ranges (Table 2.3). The average camera trapping home range was 20.09 ± 20.05 km^2 for all male ocelots, 4.35 ± 3.41 km^2 for all female ocelots and 11.70 ± 15.63 km^2 for all ocelots combined. Although the variation of home range estimates within each sex was too great to determine a significant difference in size between them, males tended to show larger home range estimates than female ocelots.

Population Size:

Three of the camera grids (ocelot rainforest pilot, ocelot rainforest, jaguar rainforest 3) had roughly 20 ocelot captures (Table 2.4). Jaguar rainforest 1 had a low number of ocelot captures (10) and individuals (4), whereas jaguar rainforest 2 had a large number of ocelot captures (82). Both the ocelot pine forest and jaguar pine forest grids had a small number of ocelot captures, 1 and 2 respectively.

Program CAPTURE tested the assumption of population closure for each of the rainforest camera grids and the resulting z-scores and p values did not reject this assumption (Table 2.5). Both the heterogeneity model (M_h) and null model (M_o) showed high model selection values in program CAPTURE (Table 2.5), but White et al. (1982) cautioned against using the null model (M_o) when sample sizes are small, as is the case in this study. As hypothesized the heterogeneity model (M_h) is the appropriate model to estimate the population size of each rainforest camera grid. There are 2 heterogeneity estimators (M_h) provided by CAPTURE; the jackknife estimator (Otis et al. 1978) and the Chao estimator (Chao 1987), but the Otis jackknife estimator was given priority because it demonstrated lower standard error values and less variation in population estimates.

The estimated number of ocelots varied from 6 in the ocelot rainforest pilot grid and jaguar rainforest grid 1 to 26 in the jaguar rainforest grid 3 (Table 2.6). The ocelot captures were too low to use the program CAPTURE for the pine ridge grids. The estimated population size for the ocelot and jaguar pine ridge grid was 1 and 3 respectively (Table 2.6).

Effective Trap Area:

The ½ mean maximum distance moved (MMDM) value, both excluding and including ocelots with a maximum distance of zero, varied from 0.93 km in the ocelot rainforest pilot grid to 2.43 km in the jaguar rainforest grid (Table 2.7). The total effective trap area determined using unique MMDM values ranged from 11.17 km^2 for the ocelot rainforest pilot grid, both excluding and including ocelots with a maximum distance of zero, to 227.10 km^2 for the jaguar rainforest grid 3, excluding ocelots with a maximum distance of zero (Table 2.7). Three of the camera grids (ocelot rainforest pilot, ocelot rainforest, jaguar rainforest) did not include animals with a maximum distance of zero and the MMDM values and effective trap area remained the same, but when ocelots with a maximum distance of zero were included in the jaguar rainforest grid 2 and jaguar rainforest grid 3, the MMDM values and effective trap area decreased.

As the average camera spacing of each trapping grid increased, the MMDM value increased and the resulting density estimate decreased. A Pearson's correlation was performed by plotting the average camera spacing of each rainforest camera grid against its respective estimated ocelot density (determined using unique MMDM values excluding animals with a maximum distance of zero), revealing a significant negative relationship (Figure 2.8: $n = 5$, $r^2 = 0.9138$, $p = 0.011$). As average grid spacing increased fewer ocelots were captured > 1 station and only long distance movements were recorded. A smaller number of ocelots with larger maximum distances were determining the MMDM value. This increased the buffer distance, substantially increasing the effective trap area and decreasing the density estimate.

The ½ average mean maximum distance moved (AMMDM) value for all rainforest camera grids was 1.56 km excluding ocelots with a maximum distance of zero and 1.24 km including ocelots with a maximum distance of zero (Table 2.7). The total effective trap area determined using AMMDM values ranged from 15.40 km^2 for the ocelot rainforest pilot grid, including ocelots with a maximum distance of zero, to 137.51 km^2 for the jaguar rainforest grid 3, excluding ocelots with a maximum distance of zero (Table 2.7).

When ocelots with a maximum distance of zero were included in the AMMDM analysis both the buffer value and the effective trap area of each camera grid decreased, but to less of a degree than using the unique MMDM method.

Density:

Ocelot density estimates for the broadleaf rainforest grids ranged from 10.79 – 53.72 ocelots per 100 km^2 using unique MMDM values to determine the effective trap area (Table 2.8, Figure 2.9). Since the ocelot rainforest pilot grid, ocelot rainforest grid, and jaguar rainforest grid did not contain any ocelots with a maximum distance of zero, the density estimates remained the same for these grids, but including ocelots with a maximum distance of zero in the jaguar rainforest grid 1 and 2 increased both the density estimate and the standard error for each estimate. The jaguar rainforest grid 3 only contained 1 ocelot with a maximum distance of zero while the jaguar grid 2 contained 5 ocelots with a maximum distance of zero, resulting in a larger difference between the density estimates.

Ocelot density estimates for the broadleaf rainforest grids ranged from 11.74 – 29.78 ocelots per 100 km^2 when ocelots with a maximum distance of zero were excluded from the AMMDM analysis and 17.84 – 38.96 ocelots per 100 km^2 when ocelots with a maximum distance of zero were included in the AMMDM analysis. Including ocelots with a maximum distance of zero increased the density and standard error for each estimate (Table 2.8, Figure 2.9).

Ocelot density estimates ranged from 2.31 – 3.01 ocelots per 100 km^2 when ocelots with a maximum distance of zero were excluded in the AMMDM analysis and 3.38 – 3.80 ocelots per 100 km^2 when ocelots with a maximum distance of zero were included in the AMMDM analysis (Table 2.8, Figure 2.9).

Although the ocelot density estimates determined for the pine forest are less accurate than those of the rainforest the difference in ocelot density between the two habitats is evident and supports my hypothesis.

Discussion

Over the course of this study the remote cameras functioned adequately for most trapping grids, with the exception of jaguar rainforest 1 and ocelot rainforest pilot. The jaguar rainforest 1 grid was the first camera trapping survey done in the area and while the cameras were set at a height appropriate for jaguars there is question about whether they were low enough to capture ocelots. If the cameras did not detect all of the ocelots in the area it would result in an underestimate of the actual ocelot population size and an underestimate of the actual ocelot density in the area. During the ocelot rainforest pilot survey many camera stations malfunctioned, either completely or in displaying the correct date and time. Stations that completely malfunctioned were eliminated from the analysis, which led to holes in the grid. These cameras were spaced close together (500 m) so it is unlikely that the holes in the grid would contain an ocelot that had no chance of being captured at another camera station, but incorrect dates may lead to inaccurate population estimates from program CAPTURE. In addition, the small effective trap area of this camera grid may not be larger enough to capture maximum ocelot movements and would therefore result in an artificially high density estimate.

The remote camera technique collects data on a wide variety of animals simultaneously, allowing us to determine a trap success for each species photographed. The trap success for species photographed in this study followed what is generally known about the abundance of different prey and predator species in the rainforest versus pine forest, and as hypothesized, ocelots showed higher trap success in the rainforest than the pine forest habitat. Although there is current debate as to whether indices of abundance such as trap success, can track population trends over time (Anderson 2001, Carbone et al. 2001, Jennelle et al. 2002, Carbone et al. 2002, Anderson 2003, Engelman 2003), with further research camera trapping shows potential to not only track population trends through time but to assess the habitat preference of certain species.

The extent to which ocelots exhibit nocturnal behavior has been variable from site to site (Ludlow and Sunquist 1987, Emmons 1988, Konecny 1989, Sunquist et al. 1989, Crawshaw 1995, Di Bitetti Under Review). The camera trapping results from this study demonstrated that although ocelots may be active at any time of the day or night, they generally exhibit more nocturnal behavior. This trend was consistent with other ocelot research (Ludlow and Sunquist 1987, Emmons 1988, Di Bitetti et al. Under Review).

When ocelot trail use was analyzed, ocelots were shown to avoid new and established trails, while preferring low and high use roads. Ocelots may use established roads as territory boundaries and may therefore use them more than trails. This highlights the importance of using currently existing trail and/or road systems, or of establishing a permanent system, such that over time ocelots may come to use such paths, as has been noted in other studies (Maffei et al. 2004). Ocelots preferred high-use roads during the dry season and low-use roads during the wet season. During the dry season ocelots' home ranges are likely to increase and it is thought that they must travel father to meet their energy requirements (Ludlow and Sunquist 1987). This may account for why they travel more along high-use roads, which may be easier to traverse, during the dry season.

When estimating ocelot density, camera grids with average camera spacing of 3000 m contained ocelots that were repeatedly caught at one station, resulting in a maximum distance moved of zero. When camera spacing is large relative to the radius of the animal's home range, as is the case in the large 3000 m grids, only a few animals displaying long distance movement are captured at more than one station. The resulting buffer value may be artificially inflated due to the large spacing of the cameras, rather than actual animal movements, which would result in a decreased density estimate. Including animals with a maximum distance of zero would reduce this artificially inflated buffer value. Although the currently accepted method is to exclude animals with a maximum distance of zero from the MMDM analysis, some studies do include these animals. These data suggest that when camera spacing is large relative to the radius of the animal's home range and animals are being repeatedly captured at one station, animals with a maximum distance of zero should be included in the MMDM analysis.

When unique MMDM values were used to determine ocelot density a > 5-fold difference separated the largest and smallest estimate. Since the rainforest camera grids were conducted in the same area and within 22 months, the variation in density estimates seemed more a factor of average camera spacing rather than actual changes in ocelot density. When the maximum ocelot distances were pooled across all rainforest grids to determine the AMMDM value, the sample size used to determine the buffer value increased, the standard error of each density estimate was lowered, and the spread of density estimates across all grids was much smaller. Hence using the AMMDM value to determine density estimates rather than unique MMDM value is preferred if repeated surveys are conducted in the same area over a short time period.

When ocelot density estimates are compared between the 2 habitats there is a dramatic difference between the broadleaf and pine forest habitats, and as hypothesized ocelots showed a higher density in the rainforest than the pine forest habitat. Although ocelots have a wide range of habitats, they may require more dense cover than is currently available in the pine forest. Since the bark beetle infestation, much of the understory has returned, but the canopy cover is still open. Perhaps the destruction of the pine forest by the bark beetle has affected ocelot prey density, resulting in a decrease in ocelot population. Further research should be conducted in the pine forest over the following years as the understory and canopy cover return to determine if ocelot numbers increase as the pine forest habitat returns.

Due to the camera malfunctions of the jaguar rainforest 1 and ocelot rainforest pilot camera grids, I am most confident in an estimated density of 18.91 – 20.75 ocelots per 100 km^2 in the rainforest habitat and 2.31 – 3.81 ocelots per 100 km^2 in the pine forest. Although the rainforest density estimates were low compared to those in other areas of its range (Table 1.3), they do coincide with estimates found by Crawshaw (1995) in the subtropical forests of Brazil and by Di Bitetti et al. (Under Review) in the Atlantic forests of Argentina, as well as the larger home range estimates that Konecny (1989) found in Belize (Table 1.2).

This study has shown the effects camera spacing has on density estimation. If camera spacing is kept small it detects more animal movements and results in a more precise buffer value, but if camera spacing becomes too large many animals will only be captured at a single camera station and only a few animals exhibiting long distance movements will be captured at more than one camera station. This will result in an artificially large buffer value and a decreased density estimates.

In addition to average camera spacing, the area a camera grid covers is extremely important. If average camera spacing and grid area are small in relation to an animal's home range, the true maximum distance of the animal may be impossible to detect. This would result in an inaccurately small buffer value and an overestimation of the density. With a finite number of cameras, there is a balance between camera spacing and area sampled. The survey area should be maximized while maintaining an average camera spacing comparable to the radius of the animal's home range.

Although the start-up costs of camera trapping can be prohibitive, it is relatively inexpensive to maintain and with proper training and maintenance, can produce valuable data. The information provided by camera trapping can be collected over a relatively short time span, in a variety of habitats and areas, and can be performed by only a few individuals.

This study shows the importance of camera spacing and the affect animals with a maximum distance of zero have on density estimates. This is particularly important as the number of studies employing camera trapping has rapidly increased. Even current studies on the same species use different camera spacing and some include animals with a maximum distance of zero while others exclude them. The buffer determination technique and camera spacing therefore require further standardization if we are to use these data for comparison across study sites. Due to the variation in ocelot home range size across different habitats, camera trapping specifications should be tailored to the habitat and area being studied, but as a guideline I recommend a camera spacing of approximately 1.5 km apart with a minimum of 20 camera stations to encompass an area of at least 50 km^2. If this spacing results in a large portion of animals being captured at only 1 camera station, then camera spacing is too large and subsequent camera grids should have closer camera spacing. While it would be economic and efficient to estimate several animal densities (i.e. jaguars and ocelots) simultaneously during camera trapping studies, issues of camera spacing may make these estimates unreliable. If ocelot densities are to be determined from a grid set up for other animals such as jaguars and pumas, then zero distance animals should be included in the MMDM calculations, otherwise distances moved are artificially inflated by long distance movers and density estimates are unrealistically low. Camera trapping studies should be repeated in the same area to obtain estimates of variance on density estimates.

This study provides the first density estimate of ocelots in Central America, both from a relatively intact rainforest habitat and from an adjacent pine forest habitat. These estimates can provide a baseline of comparison for ocelot density in the future at this same site, as well as across sites once estimate techniques become further standardized. In addition, the information provided here is important for forest reserve and protected area design.

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Table 2.1 Habitat description, dates conducted, average camera spacing (m), number of camera stations, number of nights active, and the total number of trap nights for each camera trapping grid.

Camera Grid	Habitat	Dates	Spacing (m)	Stations	Nights Active	Total Trap Nights
Ocelot Rainforest Pilot	Rainforest	Jul 3 – Aug 15, 2002	500	13	44	730
Ocelot Rainforest	Rainforest	Aug 21 – Sep 21, 2003	1500	15	32	442
Jaguar Rainforest 1	Rainforest	Jan 12 – Mar 18, 2002	3100	7	65	528
Jaguar Rainforest 2	Rainforest	Jan 4 – Apr 10, 2003	3000	17	97	1575
Jaguar Rainforest 3	Rainforest	Jun 16 – Jul 22, 2003	2800	14	37	598
Ocelot Pine Forest	Pine Forest	Apr 26 – Jun 27, 2004	1000	13	62	855
Jaguar Pine Forest	Pine Forest	Jan 11 – Apr 4, 2004	3000	19	83	1533

Table 2.2 Camera trap success (number of animal photograph captures per 100 trap nights) for each species across all trapping grids.

	Trap Success (# of Captures / 100 Trap Nights)						
	Rainforest Grids					Pine Forest Grids	
	Ocelot Pilot	Ocelot	Jaguar 1	Jaguar 2	Jaguar 3	Ocelot	Jaguar
TOTAL TRAP NIGHTS	730	442	528	1575	598	855	1533
CARNIVORES							
Jaguar *Panthera onca*	4.11	4.35	3.02	6.88	8.09	0.20	3.93
Puma *Puma concolor*	3.82	1.37	1.14	3.17	4.80	0.44	1.14
Ocelot *Leopardus Pardalis*	5.71	6.20	2.11	5.60	4.37	0.15	0.13
Jaguarundi *Herpailurus yaguarondi*	0.00	0.24	0.00	0.17	0.00	0.00	0.06
Margay *Felis wiedii*	0.00	0.00	0.15	0.00	0.00	0.00	0.06
Tayra *Eira barbara*	0.68	0.46	0.21	0.24	0.00	0.28	0.13
Coati *Nasua narica*	1.03	0.36	0.70	0.98	0.17	0.66	0.44
Skunk *Conepatus semistriatus*	0.51	0.24	0.35	0.45	0.71	0.64	0.25
Gray fox *Urocyon cinereoargenteus*	0.81	4.13	1.08	0.80	0.15	2.66	11.73
HERBIVORES							
Tapir *Tapirus bairdii*	0.33	1.46	1.22	1.60	0.62	0.00	1.46
White-Tailed Deer *Odocoileus virginianus*	0.00	0.00	0.00	0.00	0.39	0.12	0.38
Brocket deer *Mazama americana*	0.77	0.97	0.55	1.09	1.98	0.10	0.38
White-lipped peccary *Dicotyles pecari*	0.00	0.00	6.12	2.26	0.00	0.00	0.00
Collared peccary *Tayassu tajacu*	0.45	0.18	0.75	1.40	0.99	0.31	0.19
Paca *Agouti paca*	0.36	0.18	0.88	0.00	0.10	0.00	0.00
Agouti *Dasyprocta punctata*	0.30	0.24	0.00	0.50	0.36	0.00	0.00
Squirrels *Sciurus deppi*	0.67	0.00	0.31	0.24	0.10	0.00	0.00
Mouse *Heteromys sp.*	0.51	1.06	0.57	0.00	0.00	0.00	0.00

	Trap Success (# of Captures / 100 Trap Nights)						
	Rainforest Grids					**Pine Forest Grids**	
	Ocelot Pilot	Ocelot	Jaguar 1	Jaguar 2	Jaguar 3	Ocelot	Jaguar
TOTAL TRAP NIGHTS	730	442	528	1575	598	855	1533
BIRDS							
Ocelated turkey	4.79	2.47	0.77	4.22	7.60	0.00	5.86
Meleagris ocellata							
Currasow	1.04	0.68	2.07	1.35	3.26	0.00	0.57
Crax rubra							
Guan	0.00	0.00	0.00	0.25	0.71	0.00	0.13
Penelope p. purpurascens							
Chachalaca	0.00	0.20	0.15	0.06	0.74	1.00	0.56
Ortalis vetula							
Tinamou	1.97	0.00	0.58	0.00	0.29	0.00	0.00
Crypturellus boucardi							
Ground doves	1.96	0.93	0.19	0.12	0.57	0.12	0.13
Columbina sp.							
Other Birds	0.22	1.12	0.00	0.06	0.14	0.12	0.25
OTHERS							
Armadillo	0.59	0.37	1.22	0.07	0.70	0.54	0.06
Dasypus novemcinctus							
Opossum	1.55	6.08	7.65	2.19	5.64	2.17	2.54
Didelphis sp.							
Tamandua	0.00	0.00	0.15	0.00	0.00	0.00	0.00
Tamandua mexicana							
Raccoon	0.00	0.00	0.00	0.00	0.14	0.00	0.00
Procyon lotor							

Table 2.3 100% MCP camera trapping home ranges (km^2) for each individual ocelot in the rainforest habitat. Average home range (km^2) and standard deviation for all male ocelots, all female ocelots, and all ocelots combined.

Ocelot	**100% MCP Camera Trapping Home Range (km^2)**
Males	
O3	21.81
O7	58.39
O8	6.01
O16	3.64
O17	33.31
O26	13.3
O29	4.19
Average Male Home Range	20.09 ± 20.05
Females	
O1	9.24
O2	3.56
O4	3.76
O5	2.11
O6	4.78
O13	0.19
O23	9.52
O32	1.63
Average Female Home Range	4.35 ± 3.41
Average Ocelot Home Range	11.70 ± 15.63

Table 2.4 Number of ocelot captures, recaptures, individuals captured, and sex for each camera trapping grid.

Camera Grid	Total Captures	Total Recaptures	Number of Individuals	Males	Females	Unknown Sex
Ocelot Rainforest Pilot	23	18	5	1	4	0
Ocelot Rainforest	21	12	9	4	5	0
Jaguar Rainforest 1	10	6	4	2	2	0
Jaguar Rainforest 2	82	63	19	9	10	0
Jaguar Rainforest 3	20	6	14	8	5	1
Ocelot Pine Ridge	1	0	1	1	0	0
Jaguar Pine Ridge	2	0	2	0	1	1
Total	159	105	54	25	28	2

Table 2.5 CAPTURE program closure test z-scores and p values, and model selection ranking for all rainforest camera trapping grids.

Camera Grid	**Closure Test**		**Model Selection**							
	Z-Scores	**P Value**								
			$\mathbf{M_o}$	$\mathbf{M_h}$	$\mathbf{M_b}$	$\mathbf{M_{bh}}$	$\mathbf{M_t}$	$\mathbf{M_{th}}$	$\mathbf{M_{tb}}$	$\mathbf{M_{tbh}}$
Ocelot Rainforest Pilot	0.98	0.84	0.92	0.91	0.83	1.00	0.00	0.56	0.73	0.92
Ocelot Rainforest	0.55	0.71	0.95	1.00	0.64	0.71	0.00	0.41	0.80	0.74
Jaguar Rainforest 1	-0.31	0.38	0.96	1.00	0.39	0.57	0.00	0.23	0.52	0.61
Jaguar Rainforest 2	-0.01	0.50	0.96	1.00	0.39	0.56	0.00	0.32	0.43	0.62
Jaguar Rainforest 3	0.36	0.64	1.00	0.95	0.66	0.92	0.00	0.52	0.60	0.92

Table 2.6 Estimated population size and standard error (SE) for each rainforest camera grid using the Otis heterogeneity estimator (M_h) from program CAPTURE, and the estimated population size for both pine forest camera grids.

Rainforest Camera Grids	Estimated Population Size (SE)
Ocelot Rainforest Pilot	6 (1.49)
Ocelot Rainforest	10 (2.74)
Jaguar Rainforest 1	6 (1.97)
Jaguar Rainforest 2	21 (3.27)
Jaguar Rainforest 3	26 (7.02)

Pine Forest Camera Grids	Estimated Population Size
Ocelot Pine Ridge	1
Jaguar Pine Ridge	3

Table 2.7 Buffer value (km) and effective trap area (km^2) of each rainforest camera grid using both MMDM and AMMDM, excluding and including ocelots with a maximum distance of zero. Buffer value (km) and effective trap area (km^2) of each pine forest camera grid using the rainforest AMMDM, excluding and including ocelots with a maximum distance of zero.

Camera Grid	Buffer Value (km)	Total Area (km^2)
Ocelot Rainforest Pilot		
MMDM Excluding Zeros	0.93	11.17
MMDM Including Zeros	0.93	11.17
AMMDM Excluding Zeros	1.56	20.15
AMMDM Including Zeros	1.24	15.40
Ocelot Rainforest		
MMDM Excluding Zeros	1.23	38.64
MMDM Including Zeros	1.23	38.64
AMMDM Excluding Zeros	1.56	48.20
AMMDM Including Zeros	1.24	38.73
Jaguar Rainforest 1		
MMDM Excluding Zeros	1.64	55.63
MMDM Including Zeros	1.64	55.63
AMMDM Excluding Zeros	1.56	51.11
AMMDM Including Zeros	1.24	33.64
Jaguar Rainforest 2		
MMDM Excluding Zeros	1.56	109.06
MMDM Including Zeros	1.02	54.59
AMMDM Excluding Zeros	1.56	105.89
AMMDM Including Zeros	1.24	76.22
Jaguar Rainforest 3		
MMDM Excluding Zeros	2.43	227.10
MMDM Including Zeros	1.95	182.30
AMMDM Excluding Zeros	1.56	137.51
AMMDM Including Zeros	1.24	94.39
Ocelot Pine Ridge		
AMMDM Excluding Zeros	1.56	33.18
AMMDM Including Zeros	1.24	26.32
Jaguar Pine Ridge		
AMMDM Excluding Zeros	1.56	129.59
AMMDM Including Zeros	1.24	88.68

Table 2.8 Ocelot density estimate (ocelots per 100 km^2) and standard error (SE) of each rainforest camera grid using both MMDM and AMMDM excluding and including ocelots with a maximum distance of zero. Ocelot density estimates (ocelots per 100 km^2) of each pine forest camera grid using the rainforest AMMDM, excluding and including ocelot with a maximum distance of zero.

Camera Grid	**Density (per 100 km^2)**	**SE**
Ocelot Rainforest Pilot		
MMDM Excluding Zeros	53.72	15.23
MMDM Including Zeros	53.72	15.23
AMMDM Excluding Zeros	29.78	8.85
AMMDM Including Zeros	38.96	11.99
Ocelot Rainforest		
MMDM Excluding Zeros	25.88	7.92
MMDM Including Zeros	25.88	7.92
AMMDM Excluding Zeros	20.75	6.09
AMMDM Including Zeros	25.82	7.67
Jaguar Rainforest 1		
MMDM Excluding Zeros	10.79	3.82
MMDM Including Zeros	10.79	3.82
AMMDM Excluding Zeros	11.74	4.04
AMMDM Including Zeros	17.84	6.25
Jaguar Rainforest 2		
MMDM Excluding Zeros	19.26	3.49
MMDM Including Zeros	38.47	7.81
AMMDM Excluding Zeros	19.83	3.40
AMMDM Including Zeros	27.55	4.84
Jaguar Rainforest 3		
MMDM Excluding Zeros	11.45	4.07
MMDM Including Zeros	14.26	5.13
AMMDM Excluding Zeros	18.91	5.24
AMMDM Including Zeros	27.55	7.71
Ocelot Pine Ridge		
AMMDM Excluding Zeros	3.01	-
AMMDM Including Zeros	3.80	-
Jaguar Pine Ridge		
AMMDM Excluding Zeros	2.31	-
AMMDM Including Zeros	3.38	-

Figure 2.1 a) Photograph of dense broadleaf rainforest habitat b) Photograph of open canopy tropical pine forest habitat.

Figure 2.2 Example of how ocelots are identified by their unique coat pattern.

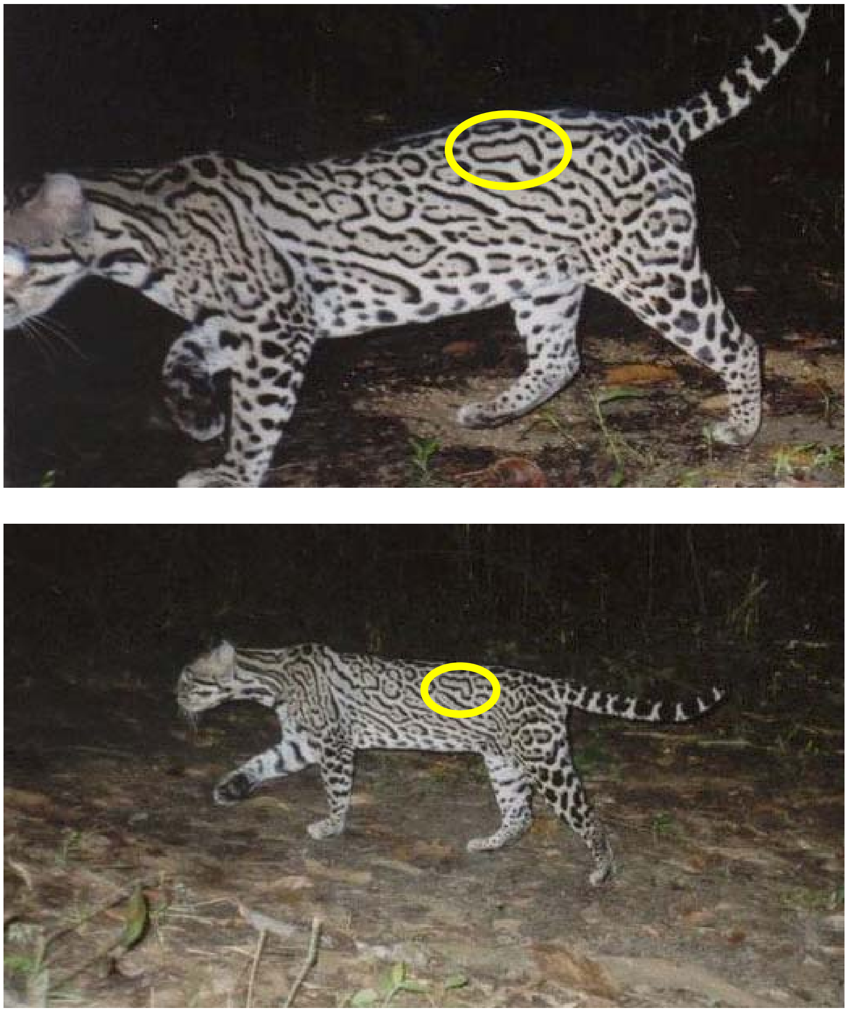


Figure 2.3 Ocelot rainforest camera grid with a ½ MMDM buffer added to each station to determine the effective trap area.

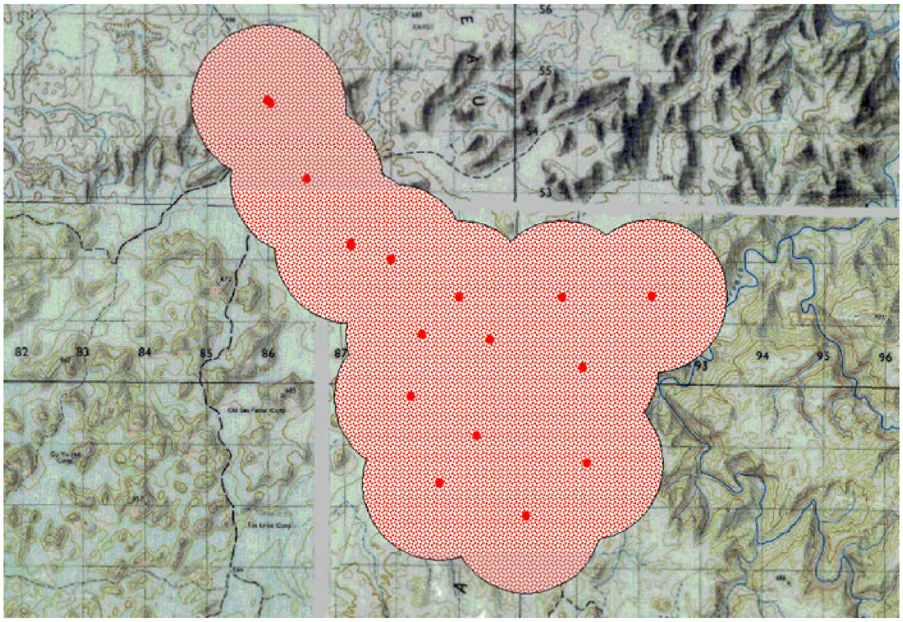
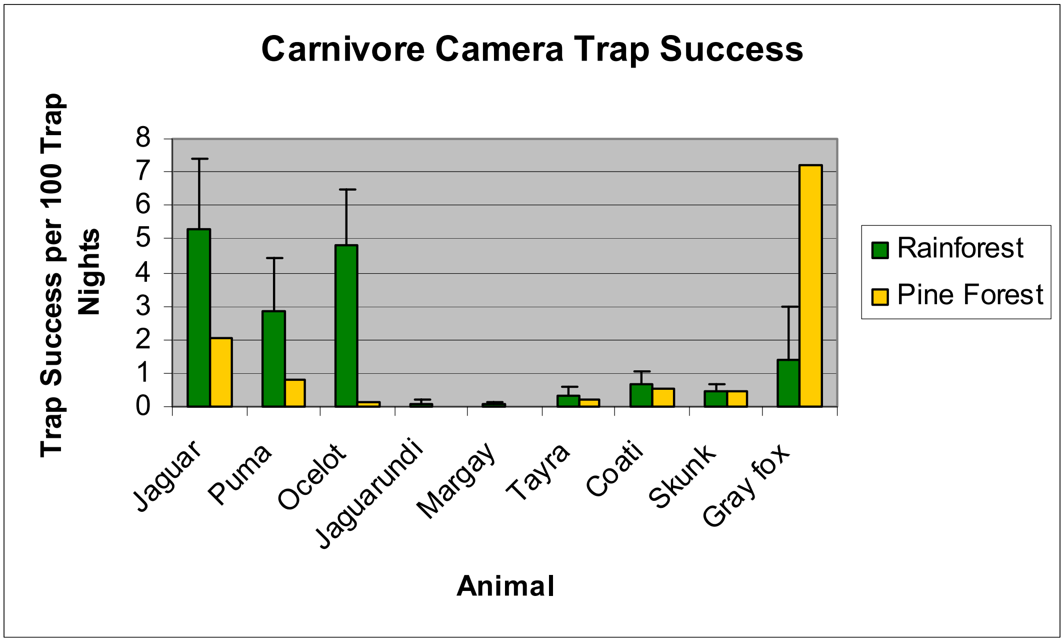
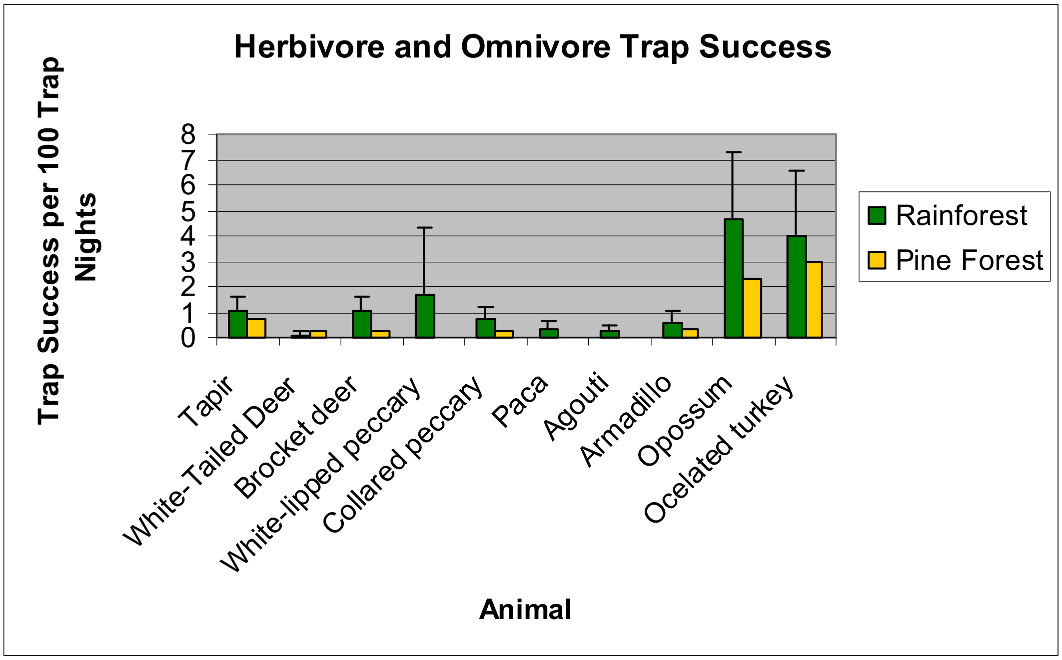


Figure 2.4 a) Carnivore trap success and standard deviation in the rainforest and carnivore trap success in the pine forest b) Herbivore and omnivore trap success and standard deviation in the rainforest and herbivore and omnivore trap success in the pine forest.



a)



b)

Figure 2.5 a) Ocelot camera trapping activity budget with sample size per hour b) Male and female ocelot camera trapping activity budgets with sample size per hour.

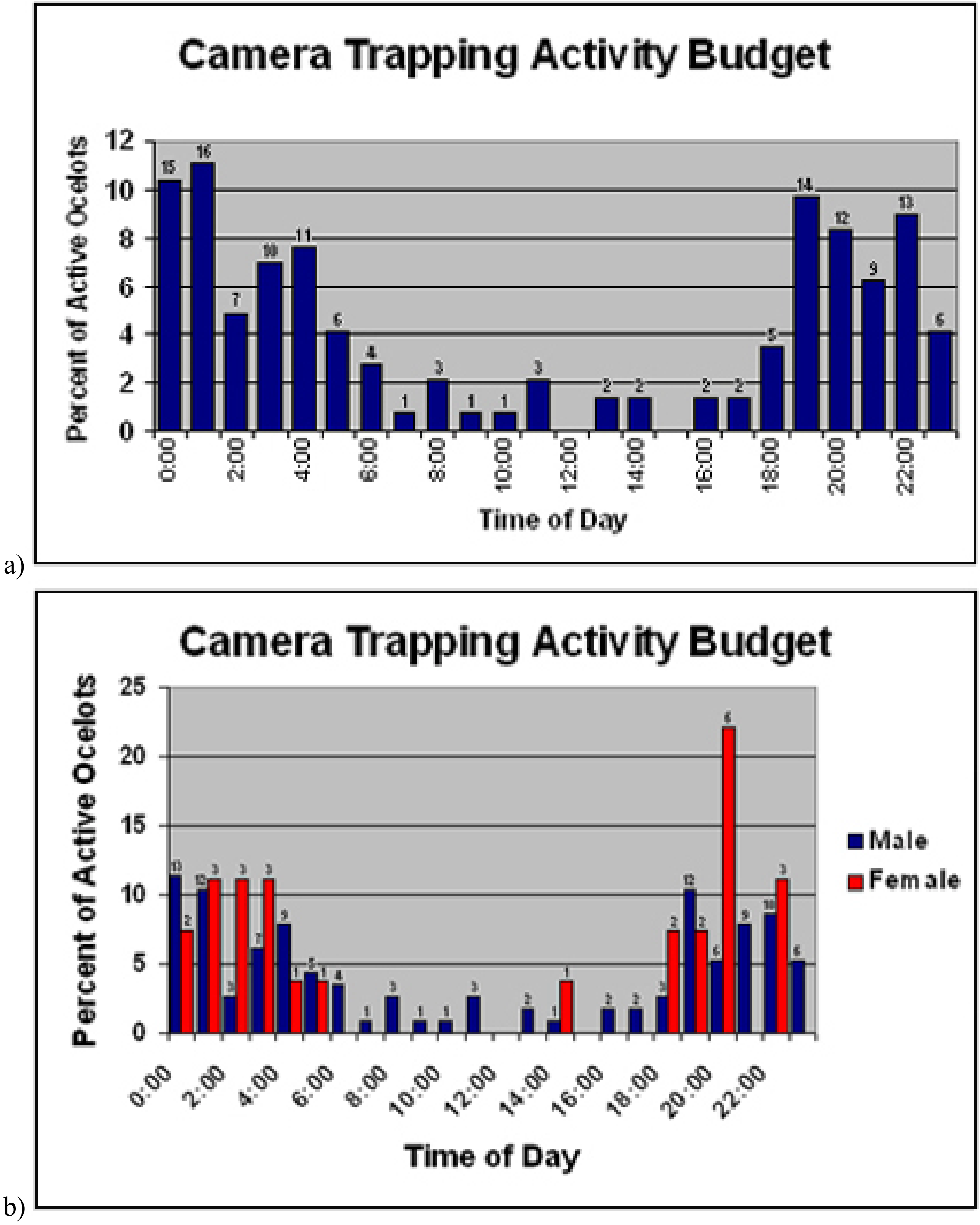
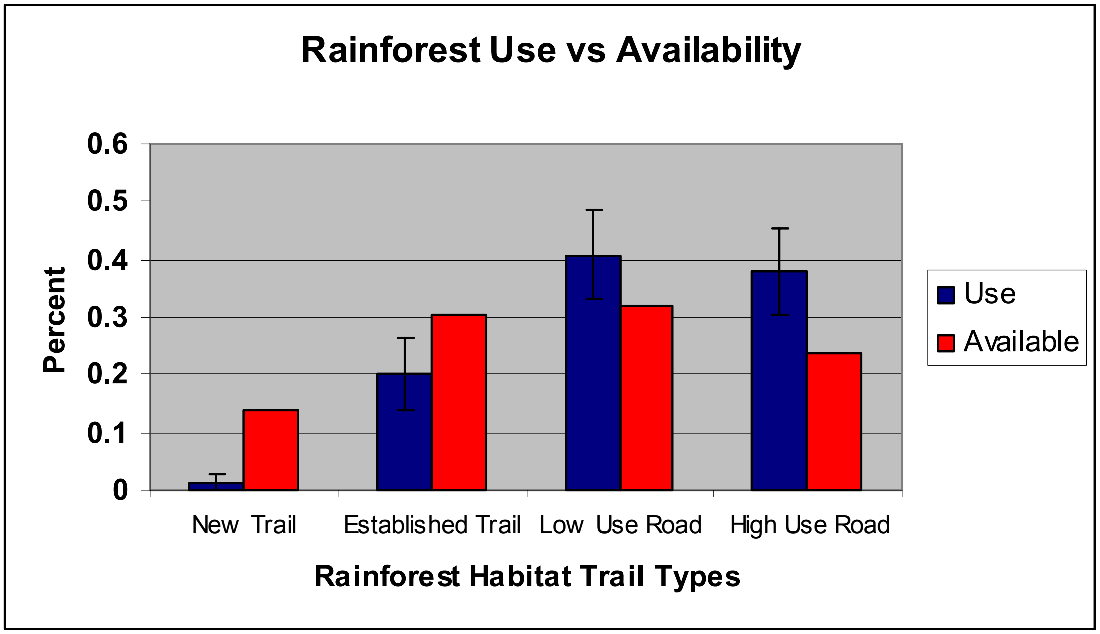
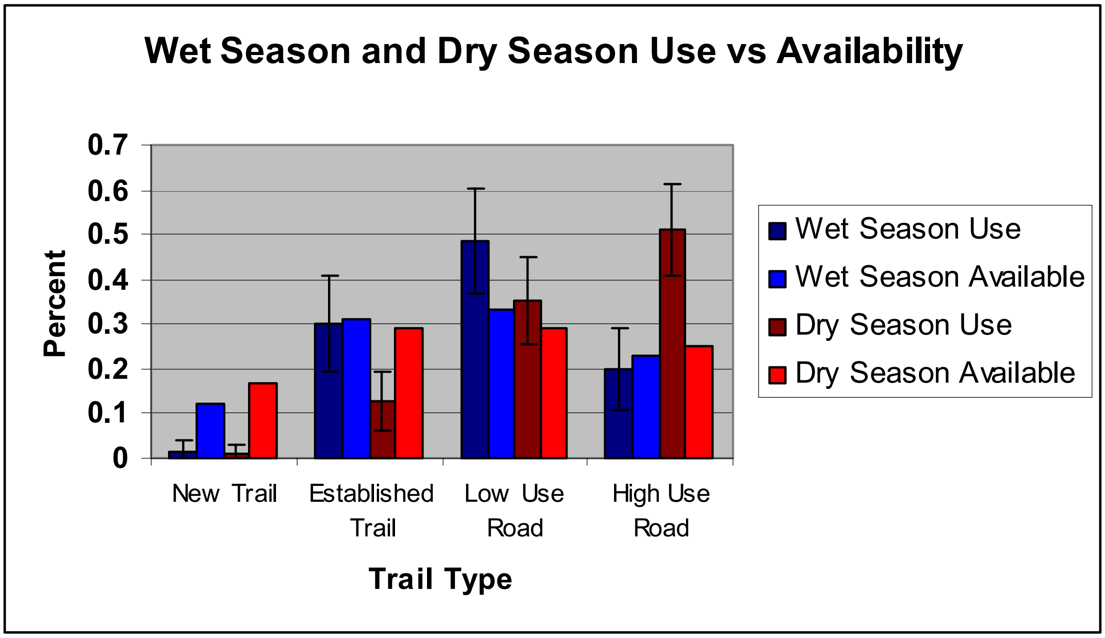


Figure 2.6 a) Ocelot trail use and 95% confidence interval versus trail availability for all rainforest grids b) Ocelot trail use and 95% confidence interval versus trail availability for the wet and dry seasons.



a)



b)

Figure 2.7 100% MCP rainforest home ranges (km^2) for all ocelots determined from camera trapping surveys.

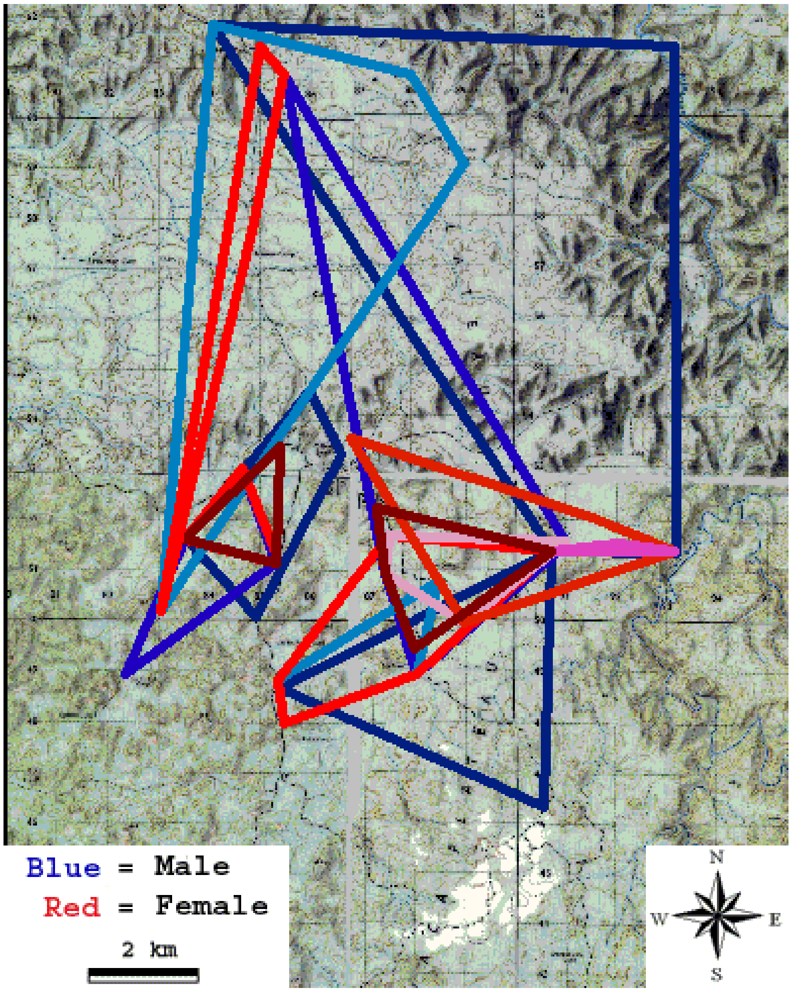


Figure 2.8 Average rainforest camera spacing versus estimated rainforest ocelot density determined using unique MMDM excluding ocelots with a maximum distance of zero.

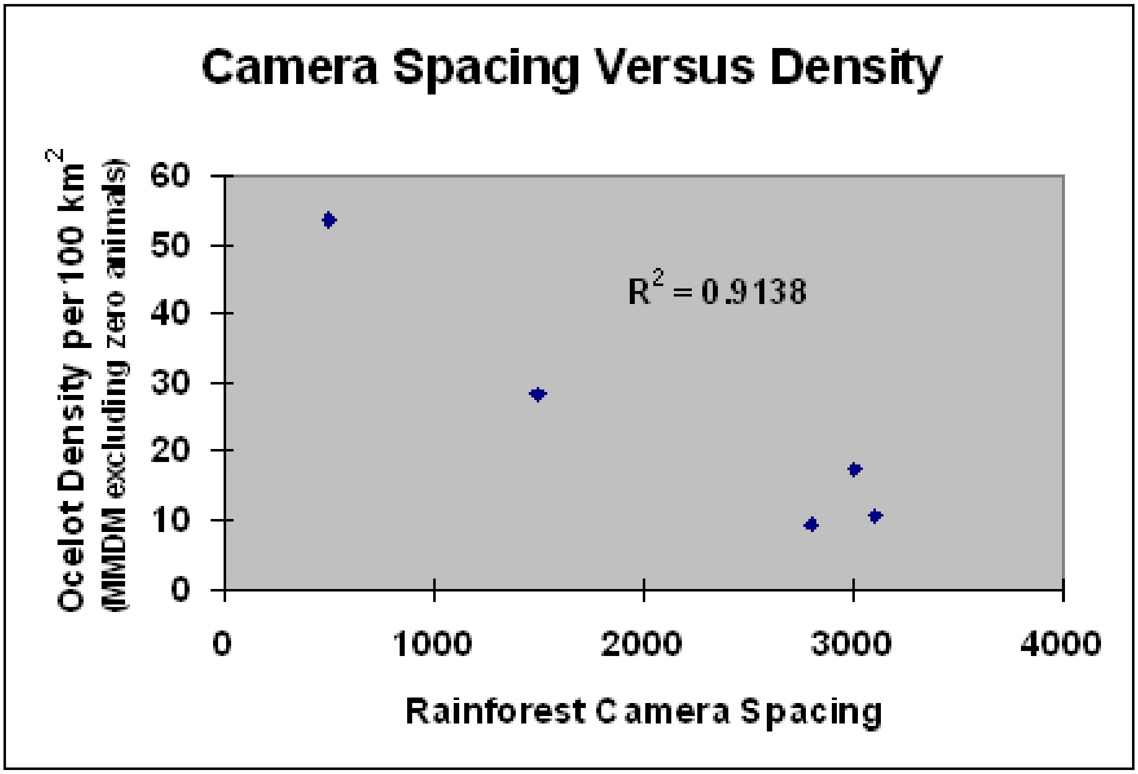
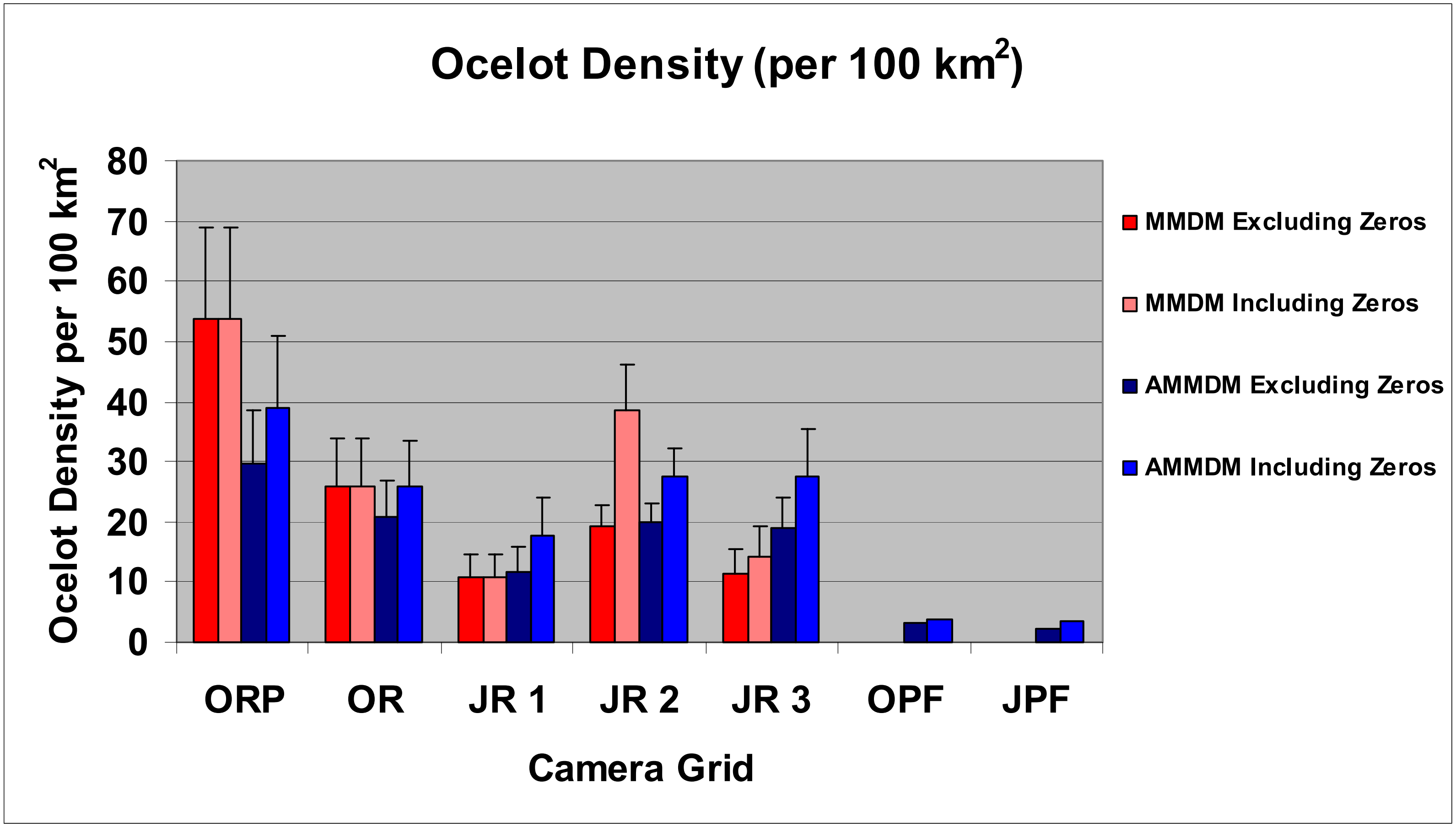


Figure 2.9 Ocelot density estimate (ocelots per 100 km^2) and standard error (SE) of each rainforest camera grid using both MMDM and AMMDM, excluding and including ocelots with a maximum distance of zero. Ocelot density estimate (ocelots per 100 km^2) of each pine forest camera grid using the rainforest AMMDM, excluding and including ocelot with a maximum distance of zero.



CHAPTER 3 – RADIO TELEMETRY: OCELOT TRAP SUCCESS, ACTIVITY PATTERNS, HOME RANGE AND DENSITY

Abstract

Due to the elusive nature of ocelots they are hard to study and, as a result, little is known about their home range size and space use patterns. This study used radio telemetry to estimate the home range size and density of ocelots in the broadleaf rainforest of western Belize. Overall trap success for ocelots in live traps was low, ranging from 0.80 to 2.42 captures per 100 trap nights. Seven ocelots were captured, but only 6 ocelots, 3 males and 3 females, were collared and tracked from September 2003 – August 2004, with the number of locations ranging from 18 to 165. Twenty-four hour radio telemetry monitoring was used to measure ocelot activity patterns across. The average home range size for male ocelots was 33.01 km^2 using 95% fixed kernel and 29.00 km^2 using 100% MCP; whereas, the average home range size for female ocelots was 21.05 km^2 for 95% fixed kernel and 29.58 km^2 using 100% MCP. Most ocelots, both male and female, had larger home ranges in the dry season than the wet season. Female ocelots showed a smaller percent of same sex home range overlap (100% MCP: 16%) than males (100% MCP: 25%), and were often overlapped by more than a single male. Radio telemetry was used to determine the daily distance moved for male (2551 ± 209 m) and female ocelots (1762 ± 162 m), and to estimate density (7.79 – 10.91 ocelots per 100 km^2). Ocelots of the western rainforest of Belize demonstrated larger home ranges sizes and lower density estimates than those in other portions of their range.

Introduction

Like many neotropical felids, ocelots have been historically difficult to study. Recently camera trapping has been successful in estimating population sizes and densities (Trolle and Kery 2003, Di Bitetti et al. Under Review, Haines et al. Under Review, Maffei et al. Under Review, this study), but radio telemetry is still the primary means of obtaining information on home range size and spatial organization of this species (Ludlow and Sunquist 1987, Emmons 1988, Konecny 1989). Some density estimates have been obtained from radio telemetry data (Ludlow and Sunquist 1987, Emmons 1988, Crawshaw 1995); however, until now no study has compared density estimates from remote cameras to those of radio telemetry at the same study site during the same time period.

Only a handful of studies have been conducted on ocelot home range throughout their distribution (Tewes 1986, Ludlow and Sunquist 1987, Emmons 1988, Crawshaw 1995). A single study in Belize (Konecny 1989), containing 1 collared male and 1 collared female, provides the only information on ocelot home range in Central America. Lack of data on home range size, movement, and spatial arrangement makes it difficult to implement conservation measures for this species.

The main objective of the radio telemetry portion of this study is to estimate ocelot home range in the tropical broadleaf rainforest of western Belize. Average home range sizes will be determined for male ocelots, female ocelots, and all ocelots combined. This study also determines ocelot density estimates, activity budgets, and daily distances moved using radio telemetry.

Study Site

Trapping and radio telemetry were conducted within the broadleaf rainforest habitat of the 1775 km^2 Chiquibul Forest Reserve and National Park (CFRNP) (16˚ 44' N, 88˚ 59' W; 500 m elevation) of Western Belize (Penn et al. 2004). The broadleaf rainforest habitat is a secondary rainforest accustomed to relatively frequent disturbance. Tall canopy trees such as the cohune palm (*Orbigyna cohune*), ironwood (*Dialium guinense*), quamwood (*Schizolobium parahybum*), sapodilla (*manilkara zapota*), nargusta (*Terminalia amonzonia*) and ceiba (*Ceiba pentandra*) trees, dominate this dense rainforest habitat (Beletsky 1999).

Methods

Error Testing:

In January 2003, five Advanced Telemetry Systems, Inc. (ATS) radio telemetry collars (M2140) were placed throughout the prospective study area and their locations were determined with GPS (Global Positioning System) units. The bearing and signal strength of each collar was estimated 3 separate times from a number of hilltop locations throughout the study site using a 3-element hand-held Yagi antennae and ATS receiver (R2000). The collars were moved to new locations and the process was repeated a second time. The location of the collar and the researcher were used to determine the true bearing. The difference between each estimated bearing and true bearing (bearing error) was determined. This process was repeated throughout the study year (August 2003 – August 2004) as new technicians joined the project and the overall average bearing error and its standard deviation were determined (White and Garrott 1990, Millspaugh and Marzluff 2001).

Once the standard deviation of the bearing error was determined for the study site, it was entered into the LOAS (Location Of A Signal – Ecological Software Solutions) program and used to determine final ocelot locations. Testing collars throughout the study site revealed certain areas that demonstrated consistently biased estimates and these areas were avoided as telemetry stations during the study.

Trapping:

There is very little information on techniques for trapping ocelots, so our trapping protocol is discussed in detail. Seven single-door 42” x 15” x 20” wire box traps (Tomahawk Trap Co. Model 109.5) were used to capture ocelots. New traps were rubbed with raw chicken and left in the field for 2–3 days. This masked the new trap odor and potentially provided time for ocelots to examine these novel objects before the traps were set. The 7 Tomahawk traps were clustered in one area in order to target the resident male and female. Traps were spaced roughly 500 m apart along the sides of roads and trails where ocelot sign was present. Traps were padlocked around trees to deter theft and to keep them from being dragged away by jaguars or pumas.

Two baiting and trapping systems were used throughout the study year. From August until December of 2003, the Tomahawk traps were baited and set using the following system (Animal Care and Use Committee #03-055-F&W). One medium sized adult chicken was placed in a plastic or wooden crate and the opening was covered with chicken wire. The crate was then attached to the rear side of the Tomahawk trap using cable ties (Figure 3.1a). Food and water dishes were fastened to the inside of the crate. Once the crate was attached to the Tomahawk trap, the entire cage was set in place along the road or trail. The trap was covered with vegetation to provide camouflage and shelter for the chicken and trapped animals. A small pile of bait (sardines or chicken parts) was placed at the back of the trap behind the foot treadle and in front of the trap door. The floor of the trap was covered with leaf litter and the trap was set. The traps were checked every morning and the live chicken was given food and water as necessary. Once an ocelot was successfully trapped it was not able to kill the chicken due to the wire separation.

From February until August of 2004, the Tomahawk traps were baited and set using the following system (Animal Care and Use Committee #04-115-F@W). The same 7 wire Tomahawk traps were used and a chick was placed in a temporary compartment inside the cage (Figure 3.1b). The edges of the wire mesh were fastened to the cage with cable ties and water and food dishes were fastened inside the light wire mesh compartment. A hole was cut in the top of the Tomahawk box trap so a chick could be placed into the mesh compartment and the traps were covered with vegetation. A combination of lures (Marak Lures: Bobcat, Coyote, Gray Fox, Raccoon) was used at each trapping station. A fishing line was thrown over a branch in a tree that was overhanging the road or trail. A stick with a few cotton balls was attached to one end of the fishing line and the lure was placed on the cotton balls. The other end of the fishing line was pulled until the stick was raised into the air and then tied to a tree. A stick that had been dipped into the lure was placed through the wire trap so it hung down inside the cage. Once inside the cage the captured ocelot could destroy the mesh compartment and eat the chick. The traps were checked every morning and the chicks were given food and water as necessary.

During both techniques, when a female ocelot was caught the traps were moved to a location assumed to be out of her range but still within the resident male's range. When a male ocelot was captured, the traps would remain until the resident female was captured. When both the resident male and female had been trapped, all of the traps would be moved to a new location to capture new male and female ocelots.

The location of each trap was recorded and each day the trap status (open or tripped) was recorded along with any animal species that may have been trapped. The available trap nights were determined, as well as the trapping success for each species captured.

Immobilization:

When an ocelot was trapped, it was immobilized and fit with a radio telemetry collar. To aid in the immobilization process, a push plate was created. A hardwood tree trunk approximately 3 inches in diameter was nailed to a solid rectangle of plywood (13" x 18") slightly smaller than the Tomahawk trap door to create the push plate.

When an ocelot was trapped, a 0.5 ml syringe containing 25 mg of Telazol, 15 mg of Xylazine, and 1 mg of Butorphanol was prepared before approaching the trap. This dose was appropriate for an average adult ocelot (no juveniles were caught) weighing approximately 10 kg. One person would pull the Tomahawk trap out and set it on its end. The trap door would be opened slightly as the push plate was placed inside the trap. The weight of the tree trunk attached to the push plate would push the ocelot to the bottom of the cage and hold it in place, lowering the chance of trap injury. The syringe would be hand-injected into the ocelot's rear flank and the times of injection and induction were recorded. This method allowed accurate and full injection of the immobilization drugs and was safer than using a jab stick.

Once the ocelot was immobilized it was weighed and sex was determined. Eye ointment was applied to each eye and a bandana was placed around the eyes. Body temperature and breathing rate were recorded every 10-15 minutes. Water was rubbed against its belly, feet pads, and genitals in order to maintain a low body temperature. If the animal's temperature exceeded 105° F, 500 ml of dextrose/saline was administered through a syringe directly into the stomach of the animal to cool it down quickly. Body measurements and body condition were recorded. Between 5 and 10 ml of blood were drawn from the femoral vein of each ocelot, and a hair sample was collected. A rabies vaccine (1 ml), a feline leukemia vaccine (Panoleukopenia – 1 ml), and a dewormer (Ivermectin – 0.1 ml per 10 pounds) were administered. If the animal had cuts or abrasions, 1 ml of Ceftiofur (antibiotic) was administered. A radio telemetry collar (ATS M2140) was fitted on the animal, and digital pictures were taken to identify each ocelot with previous camera captures. If additional drugs were needed during the processing 0.2 ml of Ketamine (20 mg) would be administered and the time recorded. When the animal was completely processed it was moved to a safe area and 1 ml of the reversal drug Yohimbine was administered. The time was recorded and researchers remained at a distance until the ocelot left the area under its own power.

Radio Telemetry Locations:

To detect the radio signal transmitted from the ocelot collar, researchers hiked to hilltops that contained a good line of sight. A minimum of 3 and a maximum of 4 technicians would hike to separate hilltops to obtain bearings on the collared ocelots. Technicians communicated with hand-held radios while conducting telemetry to help determine location and strength of signal. Once all technicians were in position, simultaneous bearings were taken on all possible ocelots. For each reading, the hilltop location, date, time, ocelot ID, radio collar frequency, signal strength and compass bearing were recorded. If an animal's location was difficult to determine, rough locations were determined in the field and bearings were taken again after 10 minutes. To avoid autocorrelation, locations were a minimum of 4 hours apart.

The standard deviation of the bearing error determined from the error testing was entered into the LOAS program which was then used to analyze all simultaneous bearings, resulting in an estimated location and error ellipse for each ocelot reading. If the error ellipse was larger than an arbitrarily determined 0.2 km^2, the estimated location was recorded but not used in the home range analysis. An error ellipse of 0.2 km^2 seemed a reasonable amount of error in proportion to the total size of the ocelot's home range. Once all of the bearings were run through the LOAS program the final location and average time between consecutive readings was determined for each ocelot.

Activity Budget:

To determine what time of day ocelots are most active, an activity budget was constructed. Researchers recorded bearings on all ocelots every half hour, in shifts ranging from 4 to 13 hours. Each ocelot was determined to be active or inactive for each 60 minute period throughout the 24-hour day. The determination of active or inactive was based on changes in signal strength and/or changes in consecutive locations. Ocelots were tracked for a total of ten 24-hour periods to construct the activity budget. For each individual ocelot and each hour of the day, the number of times it was determined as active was divided by the number of times it was detected. To determine an overall activity budget, all ocelots were averaged together and their standard deviation determined. Activity budgets were also determined for all male and female ocelots.

Some ocelot studies have shown ocelots to demonstrate nocturnal activity patterns (Emmons 1988), whereas other studies have shown higher rates of daytime activity (Konecny 1989). For this study I hypothesize that ocelots will demonstrate more activity at night than during the day.

Home Range Analysis:

Radio telemetry triangulation locations were combined with activity budget locations (minimum of 4 hours apart), visual locations and trapping locations to determine each ocelot's home range. The locations for each ocelot were separated into 3 time periods; 2003 wet season (Aug – Dec), 2004 dry season (Jan – Apr) and 2004 wet season (May – Aug). Home ranges were determined for each separate season and all seasons combined. The Home Range Extension (Rodgers and Carr 1998) in ArcView 3.2 was used to estimate each ocelot's home range, both by the fixed kernel and minimum convex polygon (MCP) methods. The fixed kernel home ranges were determined using an arbitrary 95% contour, as is commonly used on kernel analysis (Worton 1989), while the MCP home ranges were determined using 100% contour of the locations for each animal. The fixed kernel home range method was used because it gives a more representative depiction of home range use and area than other home range methods, while being less affected by outliers and sample size (Worton 1987). Although the MCP method lacks many properties of fixed kernel it was used because it is simple, can be compared between different studies, and can be used to determine percent overlap.

When determining kernel home ranges the unit variance option was used as the standardization method, the least squares cross validation method was used to determine the smoothing factor, and a raster resolution of 70 was used (Seaman and Powell 1996, Rodgers and Carr 1998).

A 2003 wet season home range, 2004 dry season home range, 2004 wet season home range, and a combined home range was determined for each individual ocelot. When the home ranges were averaged across sex, those home ranges with a low number of locations (O7 2003 wet season with 12 locations, O16 2004 dry season with 18 locations, O35 2004 dry season with 14 locations) were not included.

Other ocelot studies have shown males to have larger territories than females (Emmons 1987, Ludlow and Sunquist 1987, Crawshaw 1995), therefore I hypothesize that male ocelots will have a larger average home range than female ocelots. Ocelots have also been shown to have larger territories in dry season than the wet season (Ludlow and Sunquist 1987, Sunquist et al. 1989), therefore I hypothesize that ocelots will have larger home ranges in the dry season than the wet season.

Home Range Overlap:

Percent overlap is 2-dimensional analysis and since kernel home ranges are 3-dimensional, MCP home ranges were used. Home range overlap was determined with collared ocelots only. To determine the percent of male ocelot overlap the 100% MCP home ranges of all male ocelots were joined using the union function in ArcView and the percent of each home range used exclusively, used by a neighboring male, and used by both neighboring males was determined. Overlap was determined for each male ocelot during the 2003 wet season, 2004 dry season, 2004 wet season, and all seasons combined. This was repeated to determine female-female and male-female overlap. Ocelots with a low number of locations (O16 2004 dry season with 18 locations, O35 2004 dry season with 14 locations) were omitted from the average male and average female overlap analysis. Although male ocelot O7 only had 12 locations for the 2003 wet season, he was included in the male home range overlap analysis in order to estimate a difference in male overlap between the wet season and the dry season.

Since male ocelots have been shown to have larger territories than females (Emmons 1987, Ludlow and Sunquist 1987, Crawshaw 1995), and ocelots have been shown to have larger territories in the dry season (Ludlow and Sunquist 1987, Sunquist et al. 1989), I hypothesize that males will demonstrate more average overlap than females, and ocelots will demonstrate more overlap in the dry season than the wet season.

Density:

Radio telemetry was used to estimate ocelot density following previous studies (Emmons 1987, Ludlow and Sunquist 1987, Crawshaw 1995). The 95% fixed kernel and

100% MCP home ranges of all the collared ocelots were merged respectively to determine 2 separate values for total area. The total number of ocelots captured was divided by the total area occupied by the cats multiplied by 100 to determine a density estimate of ocelots per 100 km^2.

Daily Distance Moved:

A minimum distance ocelots traveled daily was determined using consecutive locations collected between 12 and 36 hours apart. The distance between 2 consecutive readings was calculated and averaged across all locations to determine a minimum daily distance moved for each individual ocelot. The average daily distance moved was determined for males, females, and all ocelots combined.

Since male ocelots have been shown to have larger territories than female ocelots (Murray and Gardner 1997), I hypothesize that males will have a larger daily distance moved than females.

Results:

Error Testing:

A total of 237 bearings was taken throughout the year, resulting in an average overall bearing error of 5.98 degrees and a standard deviation of 4.92 degrees. The standard deviation of the bearing error was entered into the program LOAS to determine final ocelot locations.

Trapping Success:

For the first trapping and baiting method, 6 ocelots were captured (2 males, 2 females, 2 recaptures) in a total of 751 trap nights, resulting in a trap success of 0.80 captures per 100 trap nights (1 ocelot capture every 125 trap nights) (Table 3.1). For the second method, 7 ocelots were captured (1 male, 2 female, 4 recaptures) in a total of 289 trap nights, resulting in a trapping success of 2.42 captures per 100 trap nights (1 ocelot capture every 42 trap nights) (Table 3.1). The overall capture total was 13 ocelots (3 males, 4 females, 6 recaptures) in 1,040 trap nights, resulting in an overall trapping success of 1.25 captures per 100 trap nights (1 ocelot every 80 trap nights) (Table 3.1). Ocelots experienced only minor trap-related injuries, consisting of scrapes or scratches on the face from rubbing on the inside of the trap and a cut foot pad from the trap treadle, which had healed by the time it was recaptured.

The first trapping and baiting session resulted in 44 Virginia and common possums (*Didelphis virginiana, Didelphis marsupialis*) and 1 turkey vulture (*Cathartes aura*), whereas 11 Virginia and common opossums, 1 collared forest falcon (*Micrastur semitorquatus*), 1 common black hawk (*Buteogallus anthracinus*) and 1 squirrel cuckoo (*Piaya cayana*) were captured during the second trapping and baiting method (Table 3.1).

Seven ocelots were captured, 3 males and 4 females, but only 6 were collared (Table 3.2). Female ocelot O1 was not collared because it was caught at the end of the study. Female ocelot O6 was trapped again after its collar was removed and female ocelot O35's collar was removed after the study had ended and its last location recorded.

Radio Telemetry:

The total number of nighttime, daytime, and overall radio telemetry locations was determined for each ocelot (Table 3.3). The average time between consecutive locations ranged from 26.7 – 40.0 hours, which seemed adequate for the ocelots to be located anywhere within their range.

Mortality:

During the course of the study ocelot O16 died. O16 was a male ocelot that showed signs of old age, starvation, tooth wear, and serious injuries when initially trapped (Figure 3.2a). O16 was found dead caught on a vine with additional injuries and very low body weight (Figure 3.2b). Although a home range was determined for this ocelot it was not used in the average home range analysis for all male ocelots or all ocelots combined.

Activity Budget:

Although the activity budget for all ocelots combined showed no clear behavior trend, it did show that ocelots could be active at any time of the day or night (Figure 3.3a). The difference in activity between male and female ocelots (Figure 3.3b) was due mostly to small sample size. Although 2 male and 3 female ocelots were collared, female ocelots were detected more often than males during the 10 24-hour samples. Again, no distinct behavior pattern was observed for male or female ocelots.

Home Range Analysis:

Individual male home ranges were 21.8 – 75.6 km^2 using 95% fixed kernel and 5.7 – 40.9 km^2 using 100% MCP, whereas individual females home ranges were 15.0 – 31.8 km^2 using 95% fixed kernel and 5.1 – 34.3 km^2 using 100% MCP (Table 3.4, Figure 3.4). When the home ranges were averaged for male and female ocelots, average male home ranges (95% fixed kernel: 33.6 – 36.5 km^2, 100% MCP: 19.9 – 35.7 km^2) were roughly 1.5 – 2 times larger than average female home ranges (95% fixed kernel: 16.0 – 25.9 km^2, 100% MCP: 10.9 – 24.8 km^2) for each separate season (Table 3.4). When the home ranges were averaged across all ocelots, the average home range for all seasons combined was 25.8 km^2 using 95% fixed kernel and 29.4 km^2 using 100% MCP. Although sample sizes were too small to statistical tests if male ocelots exhibited larger home ranges than females and if dry season home ranges were larger than wet season home range, the results supported the hypothesis of males having larger home ranges than females, while showing no indication that dry season home ranges were larger than wet season home ranges.

Home Range Overlap:

The percent of male same sex home range overlap was determined using 100% MCP home ranges for the 2003 wet season, 2004 dry season, 2004 wet season, and all seasons combined (Table 3.5, Figure 3.4). During the 2004 dry season, the ocelot that died (O16) overlapped 50% of O7's home range and 66% of O26's home range. The average percent of male home range overlap was smaller in the 2003 wet season (6%)

than in the 2004 dry season (12%) (Table 3.6). The overall average percent of male home range overlap for all seasons combined was 25%.

The percent of female home range overlap was determined using 100% MCP home ranges for the 2003 wet season, 2004 dry season, 2004 wet season, and all seasons combined (Table 3.7, Figure 3.4). The average percent of female home range overlap was larger in the 2004 dry season (25%) than either the 2003 wet season (10%) or the 2004 wet season (12%) (Table 3.8). The overall average percent of female home range overlap for all seasons combined was 16% with a standard deviation of 7, which was smaller than the average percent of male home range overlap.

The percent of a single female ocelot's home range overlapped by male ocelots was determined (Table 3.9). Female ocelot O6 had only a small percent of her home range not overlapped by male ocelots O7 and O26 (3 – 23%), with O26 overlapping a larger percent (77 – 96) than O7 (4 – 17%). Female ocelot O32 had a much larger percent of her home range not overlapped by male ocelots O7 and O26 (20 – 72%) than ocelot O6. Male ocelot O7 overlapped a larger percent of female ocelot O32's home range (48 – 72%) than male ocelot O26 (13 – 28%). Female ocelot O35 also had a larger percent of her home range not overlapped by male ocelots O7 and O26 (23 – 701%) than ocelot O6. Male ocelot O26 overlapped a larger percent of female ocelot O35's home range (30 – 77%) than male ocelot O7 (0%).

Although sample sizes were too small to test statistically, males showed a larger average percent overlap than females, thus supporting my hypothesis, and both males and females showed a larger average percent overlap in the dry season than the wet season.

Density:

The total area of all the merged 100% MCP home ranges was 93.7 km^2 and the total area of all the merged 95% fixed kernel home ranges was 93.8 km^2. Dividing the 6 ocelots that were radio collared by these total areas resulted in a density estimate of 6.4 ocelots per 100 km^2. When the 1 ocelot that was trapped in the area but not collared was included in the analysis the resulting density estimate was 7.5 ocelots per 100 km^2. Therefore, the ocelot density determined using radio telemetry was 6.4 – 7.5 ocelots per 100 km^2 using both the 100% MCP and 95% fixed kernel home ranges.

Daily Distance Moved:

The results of the daily distance moved analysis showed that on average, ocelots moved 2157 m per day with a standard deviation of 464 m (Table 3.10). Males moved a significantly larger distance (2551 ± SD 209) (T test: $n = 3$, $p = 0.007$) than females (1762 ± SD 162), thus supporting my hypothesis.

Discussion:

Although the second trapping and baiting method resulted in a 3-fold increase in trapping success, we cannot be sure it was a result of small chicks, of lures, or of a combination of both. Nonetheless our increased trapping efficiency allowed for a larger sample size and larger number of ocelot locations.

Although activity budgets were constructed for all male and female ocelots, no distinct behavioral pattern was revealed. Ocelots may exhibit nocturnal behavior but as the activity budget showed, both males and females can be active at any time of the day or night. One potential confounding factor is the arbitrary designation of active or inactive for each individual ocelot. Ocelots were considered active when their signal strength changed from one reading to the next and/or when the plotted locations for consecutive readings appeared to have moved. There is potential for this to create faulty "active" designation due to error in bearings and signal strength. Also, slight or small ocelot movements are not separated from larger movements which could increase the number of active designations.

Although the home range estimates resulting from this study are larger than most of those in other areas of their range, they are similar to those of Konecny (1989) in eastern Belize and of Crawshaw (1995) in the subtropical forests of Brazil (Table 1.2). Male ocelot O7 was collared and tracked for over 3 months and then dispersed to an inaccessible area over 10 km away. It had been previously caught in the same area using camera traps, suggesting its home range may be larger than reported or that it exhibited a range shift.

Radio telemetry revealed increases in ocelot home range size during the dry season, which was also shown in other studies (Ludlow and Sunquist 1987, Sunquist et al. 1989). As water becomes scarce during the dry season, an ocelot's prey population may decrease in numbers or travel further to obtain water. Thus, to meet their energy requirements, ocelots must travel further during the dry season in search of prey, not only increasing their home range size but potentially allowing for more territory overlap (Ludlow and Sunquist 1987).

The home range overlap analysis demonstrated that a large percent of both male and female home ranges are overlapped by neighboring ocelots. Although some studies have shown that same sex home ranges are practically exclusive (Emmons 1988), others have shown same sex overlap (Ludlow and Sunquist 1987.) This research indicates a large percent of same sex territory overlap, with an increase in territory overlap during the dry season. Although female ocelots were predominantly overlapped by a single male, smaller areas of their home range were overlapped by a second male, and some areas were overlapped by both males. This lends support to the hypothesis that female ocelots exhibit mate choice.

The home range overlap analysis also revealed a large amount of territory overlap for the male ocelot that died. During the month that this male ocelot was tracked, it was located in a large area, most of which was occupied by 2 other radio collared males. Although this home range analysis showed a large amount of territory overlap, the old male ocelot with a number of injuries provides evidence that there is strong territoriality and very likely avoidance behavior, as is shown in other studies (Ludlow and Sunquist 1987, Emmons 1988).

The density estimate produced for ocelots via radio telemetry is lower than any other density estimate for ocelots throughout their range, but does coincide with the larger home range estimates attained in this study area. This method of density estimation has been used for other studies (Emmons 1987, Ludlow and Sunquist 1987, Crawshaw 1995), but is likely inaccurate due to the low probability that all ocelots in the study area were captured.

As expected, male ocelots showed a higher daily distance moved than females. Since males have a larger home range size, and often overlap more than 1 female's territory, they must traverse more area per day and they would be expected to have a larger daily distance moved than female ocelots.

Through the use of radio telemetry, this study has provided the first ocelot home range and density estimates from western Belize. These estimates are based on a larger sample size than had previously been achieved anywhere else in Central America. The data from this study can be compared to ocelot studies in other areas of their range, provide a framework for expanded studies on ocelot habitat requirements, and provide important information for reservation design and conservation of the species.

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Table 3.1 Trap success per 100 trap nights of each species, for both trapping methods individually and combined.

Animal Trapped	Trapping Occasions	Trap Nights	Trap Success
Trapping Method 1 (adult chicken): Aug – Dec 2003			
Ocelot *Leopardus pardalis*	6	751	0.80
Opossum *Didelphis sp.*	44	751	5.86
Turkey Vulture *Cathartes aura*	1	751	0.13
Trapping Method 2 (chick plus lure): Mar – Jun 2004			
Ocelot	7	289	2.42
Opossum	11	289	3.81
Collared Forest Falcon *Micrastur semitorquatus*	1	289	0.35
Common Black Hawk *Buteogallus anthracinus*	1	289	0.35
Squirrel Cuckoo *Piaya cayana*	1	289	0.35
Trapping Methods Combined: Aug 2003 – Jun 2004			
Ocelot	13	1040	1.25
Opossum	55	1040	5.29
Collared Forest Falcon	1	1040	0.10
Common Black Hawk	1	1040	0.10
Squirrel Cuckoo	1	1040	0.10
Turkey Vulture	1	1040	0.10

Table 3.2 Sex, date of first capture, number of recaptures, date of last location, and date collar was removed for each ocelot.

Ocelot ID	Sex	Date of Capture	Recaptures	Date of Last Location	Date Collar Removed
O7	Male	11/30/2003	1	2/21/2004	-
O16	Male	3/14/2004	-	4/22/2004	4/22/2004
O26	Male	9/20/2003	-	8/8/2004	-
O1	Female	8/1/2004	2	Never Collared	-
O6	Female	9/20/2003	3	7/8/2004	6/29/2004
O32	Female	11/12/2003	-	8/5/2004	-
O35	Female	4/16/2004	-	8/8/2004	6/5/2005

<u>Table 3.3</u> Number of night locations, day locations, total locations, and average time between consecutive radio telemetry locations (hrs) for each ocelot.

Ocelot ID	**Night Locations**	**Day Locations**	**Total Locations**	**Average Time Between Readings (hrs)**
O7	1	44	45	35.7
O16	0	16	16	40.0
O26	41	123	164	36.3
O6	34	126	160	33.4
O32	35	123	158	32.5
O35	59	64	123	26.7

Table 3.4 Sex, 95% fixed kernel (FK) and 100% MCP home ranges (km^2) for the 2003 wet season, 2004 dry season, 2004 wet season and all seasons combined for each ocelot with the corresponding number of locations used to determine each home range. Average 95% fixed kernel (FK) and 100% MCP home ranges (km^2) for the 2003 wet season, 2004 dry season, 2004 wet season and all seasons combined for an average male, an average female, and for an average ocelot with the corresponding sample size.

		Home Range Size (km^2)							
Ocelot ID	**Sex**	**2003 Wet Season (n)**		**2004 Dry Season (n)**		**2004 Wet Season (n)**		**All Seasons Combined (n)**	
		95% FK	**100% MCP**	**95% FK**	**100% MCP**	**95% FK**	**100% MCP**	**95% FK**	**100% MCP**
O7	Male	21.8 (12)*	5.7 (12)*	29.9 (34)	14.9 (34)	-	-	28.8 (46)	17.1 (46)
O16	Male	-	-	75.6 (18)*	34.4 (18)*	-	-	75.6 (18)*	34.4 (18)*
O26	Male	33.8 (48)	22.2 (48)	42.1 (54)	24.9 (54)	36.5 (63)	35.7 (63)	37.2 (165)	40.9 (165)
O6	Female	17.0 (59)	11.2 (59)	27.0 (55)	17.7 (55)	31.8 (51)	21.1 (51)	23.4 (165)	25.6 (165)
O32	Female	15.0 (34)	10.5 (34)	24.9 (63)	16.1 (63)	17.1 (62)	19.3 (62)	17.6 (159)	28.9 (159)
O35	Female	-	-	18.0 (14)*	5.1 (14)*	20.8 (110)	33.9 (110)	22.2 (124)	34.3 (124)
Average Male		33.6 (1)	22.2 (1)	36.0 (2)	19.9 (2)	36.5 (1)	35.7 (1)	33.0 (2)	30.8 (2)
Average Female		16.0 (2)	10.9 (2)	25.9 (2)	16.9 (2)	23.2 (3)	24.8 (2)	21.1 (3)	30.0 (3)
Average Combined		21.9 (3)	14.6 (3)	31.0 (4)	18.4 (4)	26.5 (4)	27.5 (3)	25.8 (5)	29.4 (5)

* Ocelots with low numbers of locations were omitted from the average home range analysis

Table 3.5 Percent of each male ocelot's 100% MCP home range that it used exclusively, that was overlapped by a neighboring male, and that was overlapped by both neighboring males.

Ocelot ID	**Percent of 100% MCP Home Range**			
	Used by O7	**Used by O16**	**Used by O26**	**Used by All**
		2003 Wet Season		
O7	90	-	10	-
O16	-	-	-	-
O26	3	-	92	-
		2004 Dry Season		
O7	47	50	15	12
O16	22	36	48	5
O26	9	66	32	7
		2004 Wet Season		
O7	-	-	-	-
O16	-	-	-	-
O26	-	-	100	-
		All Seasons Combined		
O7	43	46	26	16
O16	23	31	54	8
O26	11	45	56	7

<u>Table 3.6</u> Percent of O7 and O26 100% MCP home range overlap and average percent of male 100% MCP home range overlap for the 2003 wet season, 2004 dry season, and all seasons combined.

Ocelot	**Percent of 100% MCP Home Range Overlap**
2003 Wet Season	
O7 Home Range Overlapped by O26	10
O26 Home Range Overlapped by O7	3
Average Male Home Range Overlap for 2003 Wet Season	6
2004 Dry Season	
O7 Home Range Overlapped by O26	15
O26 Home Range Overlapped by O7	9
Average Male Home Range Overlap for 2004 Dry Season	12
All Seasons Combined	
O7 Home Range Overlapped by O26	26
O26 Home Range Overlapped by O7	23
Average Male Home Range Overlap for All Seasons Combined	25

Table 3.7 Percent of each female ocelot’s 100% MCP home range that it used exclusively, that was overlapped by a neighboring female, and that was overlapped by both neighboring females.

Ocelot ID	**Percent of 100% MCP Home Range**			
	Used by O6	**Used by O32**	**Used by O35**	**Used by All**
		2003 Wet Season		
O6	90	10	-	-
O32	10	90	-	-
O35	-	-	-	-
		2004 Dry Season		
O6	73	24	4	-
O32	26	74	-	-
O35	14	-	86	-
		2004 Wet Season		
O6	73	11	19	4
O32	12	79	13	4
O35	12	7	83	2
		All Seasons Combined		
O6	62	25	18	5
O32	22	72	10	5
O35	13	9	82	4

Table 3.8 Percent of O6, O32, and O35 100% MCP home range overlap and average percent of female 100% MCP home range overlap for the 2003 wet season, 2004 dry season, and all seasons combined with corresponding standard deviation.

Ocelot	Percent of 100% MCP Home Range Overlap
2003 Wet Season	
O6 Home Range Overlapped by O32	10
O32 Home Range Overlapped by O6	10
Average Female Home Range Overlap for 2003 Wet Season	10
2004 Dry Season	
O6 Home Range Overlapped by O32	24
O32 Home Range Overlapped by O6	26
Average Female Home Range Overlap for 2004 Dry Season	25

Ocelot	**Percent of 100% MCP Home Range Overlap**
2004 Wet Season	
O6 Home Range Overlapped by O32	11
O6 Home Range Overlapped by O35	19
O32 Home Range Overlapped by O6	12
O32 Home Range Overlapped by O35	13
O35 Home Range Overlapped by O6	12
O35 Home Range Overlapped by O32	7
Average Female Home Range Overlap for 2004 Wet Season	12 (4)
All Seasons Combined	
O6 Home Range Overlapped by O32	25
O6 Home Range Overlapped by O35	18
O32 Home Range Overlapped by O6	22
O32 Home Range Overlapped by O35	10
O35 Home Range Overlapped by O6	13
O35 Home Range Overlapped by O32	9
Average Female Home Range Overlap for All Seasons Combined	16 (7)

Table 3.9 Percent of each female ocelot's 100% MCP home range that was used by no other male, used by male O7, used by male O26, and used by both male O7 and O26.

Ocelot ID	**Percent of 100% MCP Home Range**			
	No Male Overlap	**Used by O7**	**Used by O26**	**Used by O7 and O26**
		2003 Wet Season		
O6	3	4	96	3
O32	45	48	13	5
O35	-	-	-	-
		2004 Dry Season		
O6	19	16	77	12
O32	20	72	20	13
O35	23	-	77	-
		2004 Wet Season		
O6	23	-	77	-
O32	72	-	28	-
O35	70	-	30	-
		All Seasons Combined		
O6	21	17	77	15
O32	32	57	26	15
O35	69	-	31	-

Table 3.10 Daily distance moved (DDM) for each individual ocelot, all males, all females, and all ocelots combined (with corresponding standard deviation).

Ocelot ID	Sex	Individual DDM	DDM by Sex	Combined DDM
O7	Male	2314	2551(209)	2157 (464)
O16	Male	2709		
O26	Male	2631		
O6	Female	1859	1762(162)	
O32	Female	1575		
O35	Female	1852		

Figure 3.1 a) Ocelot trapping method 1. A live adult chicken is placed in a crate attached to the back of the Tomahawk live trap. The ocelot cannot reach the chicken through the cage. b) Ocelot trapping method 2. A chick is placed in a constructed compartment at the top and back of the Tomahawk live trap. Ocelots can destroy the mesh and eat the chick.

Figure 3.2 a) Ocelot O16's teeth, deep cut above ear, general condition, low weight. b) Mortality, new injuries.

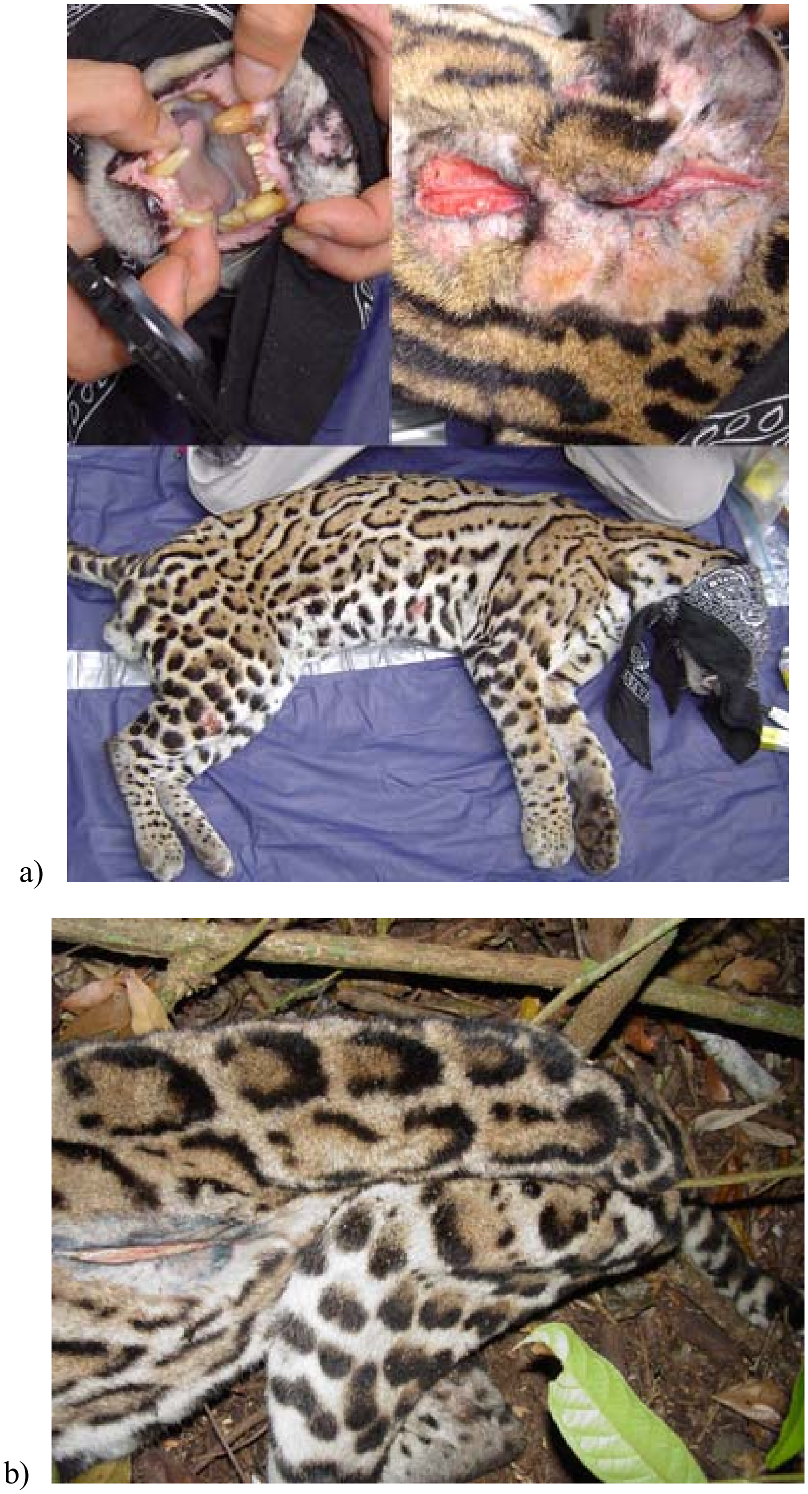
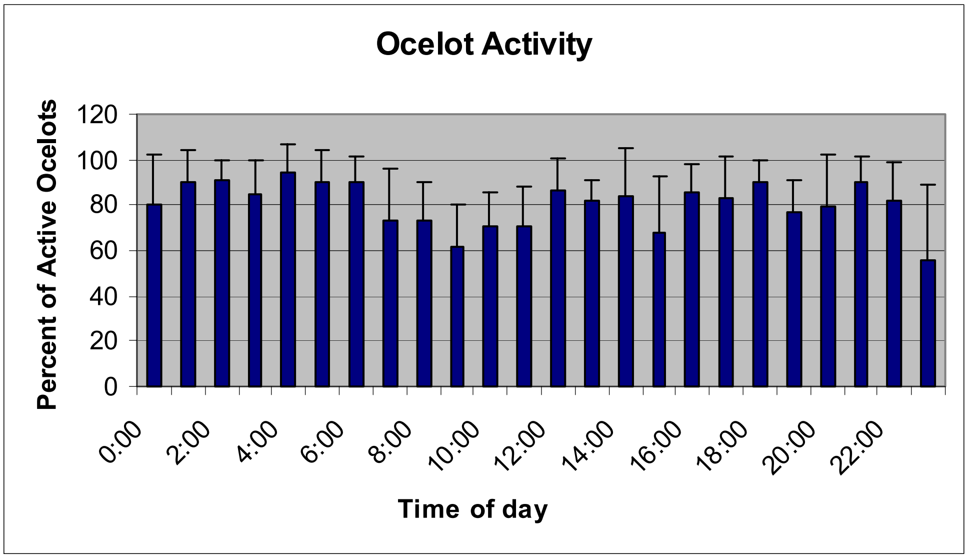
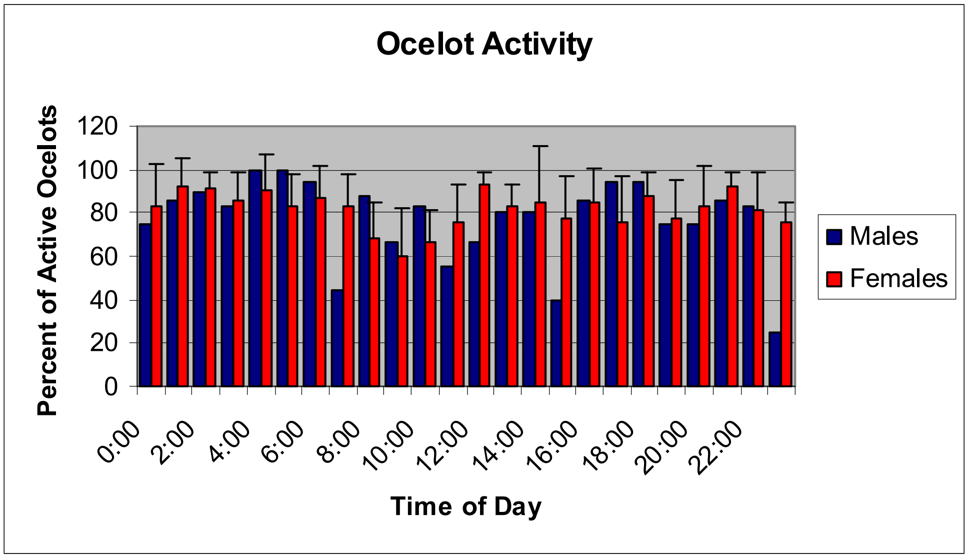


Figure 3.3 a) Radio telemetry activity budget and standard deviation for all ocelots combined. b) Radio telemetry activity budget for male ocelots and radio telemetry activity budget and standard deviation for female ocelots.

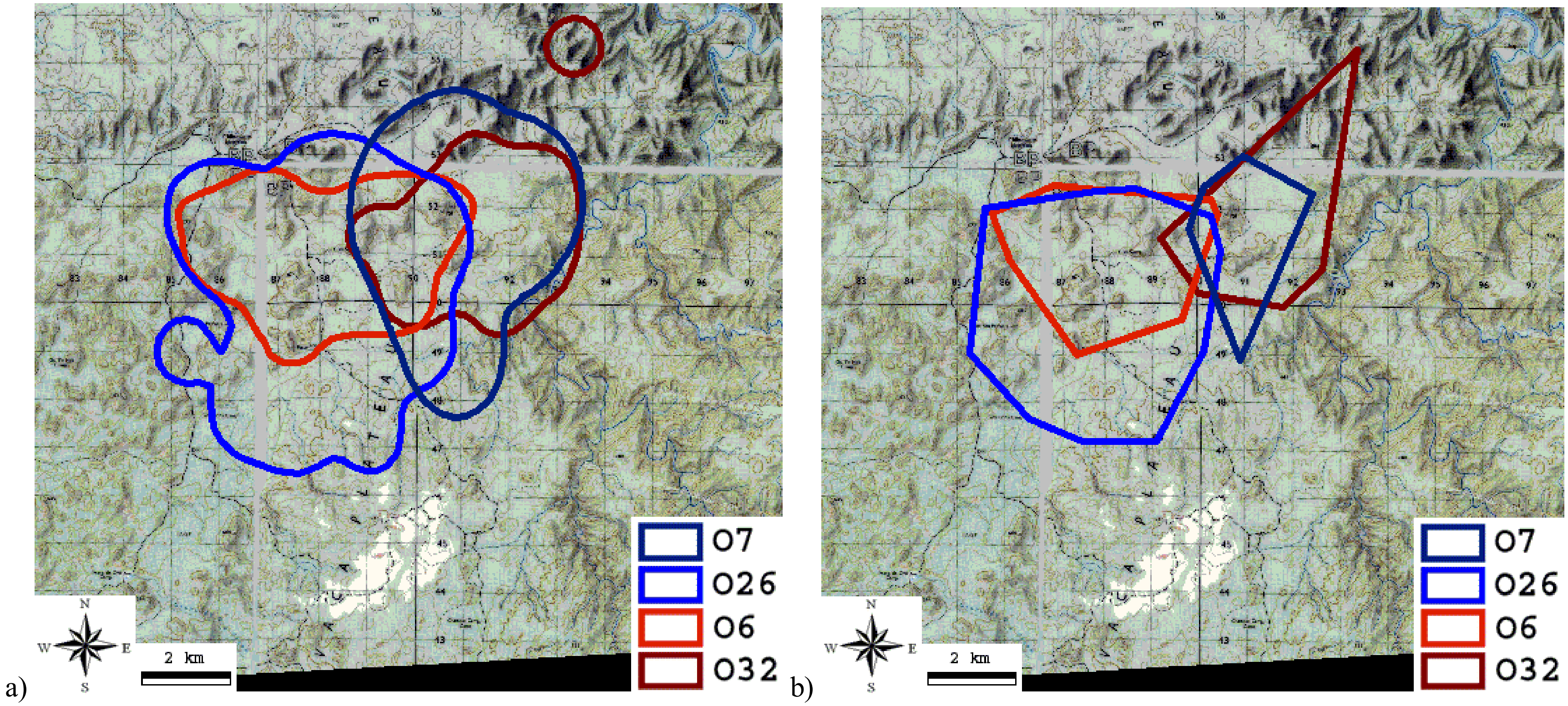


a)

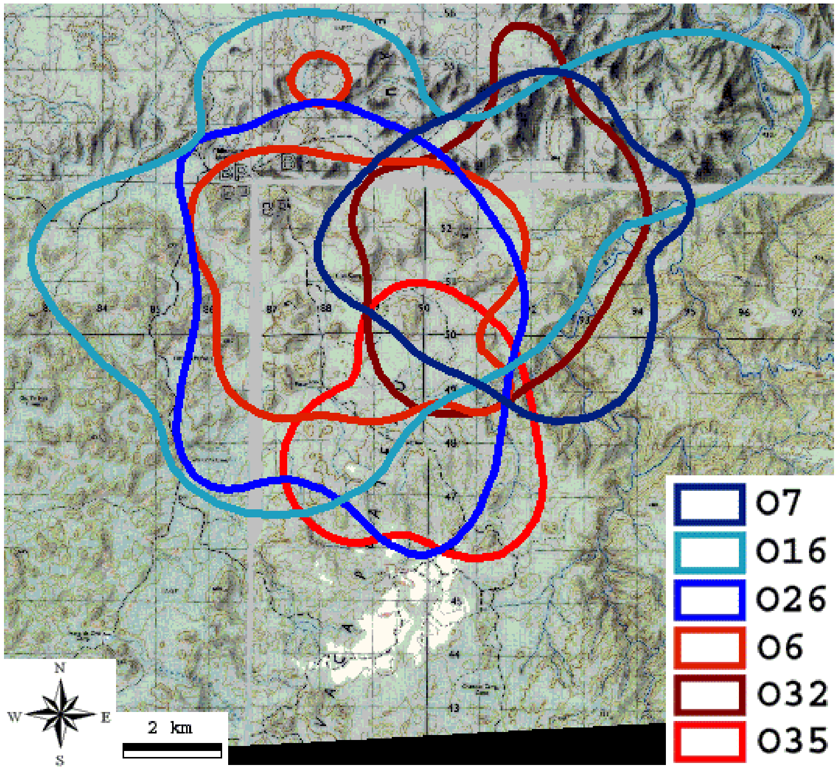


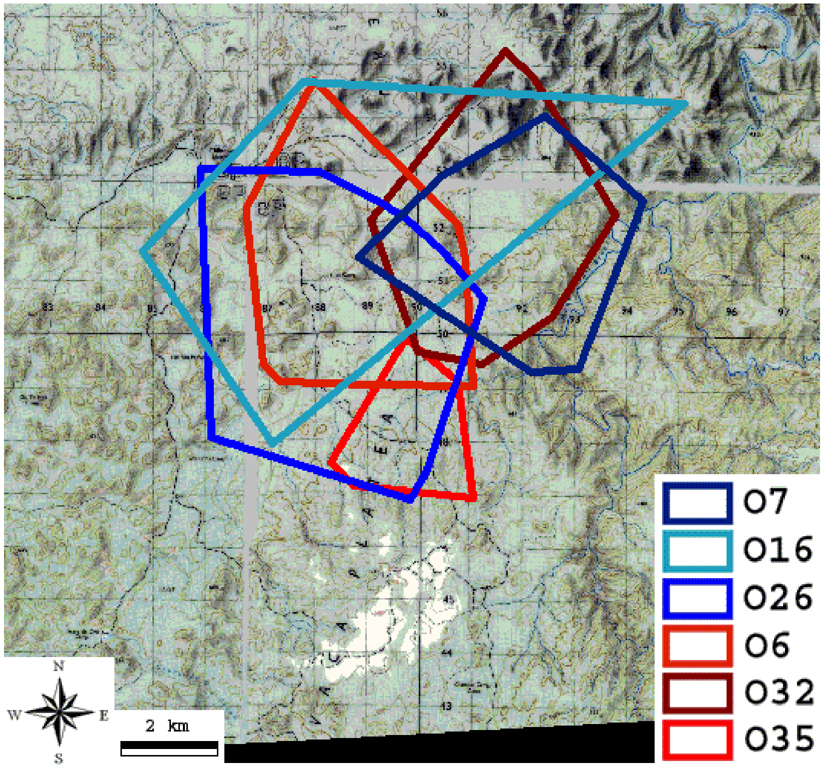
b)

Figure 3.4 a) 95% fixed kernel 2003 wet season home ranges b) 100% MCP 2003 wet season home ranges c) 95% fixed kernel 2004 dry season home ranges d) 100% MCP 2004 dry season home ranges e) 95% fixed kernel 2004 wet season home ranges f) 100% MCP 2004 wet season home ranges g) 95% fixed kernel combined season home ranges h) 100% MCP combined season home ranges.



a) b)

c) 

d) 

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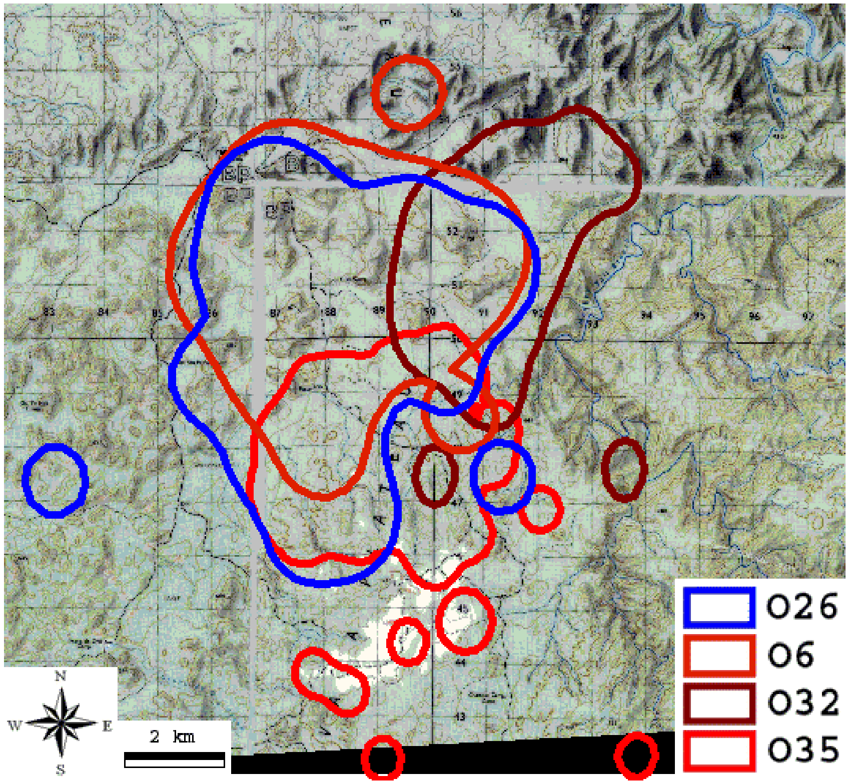

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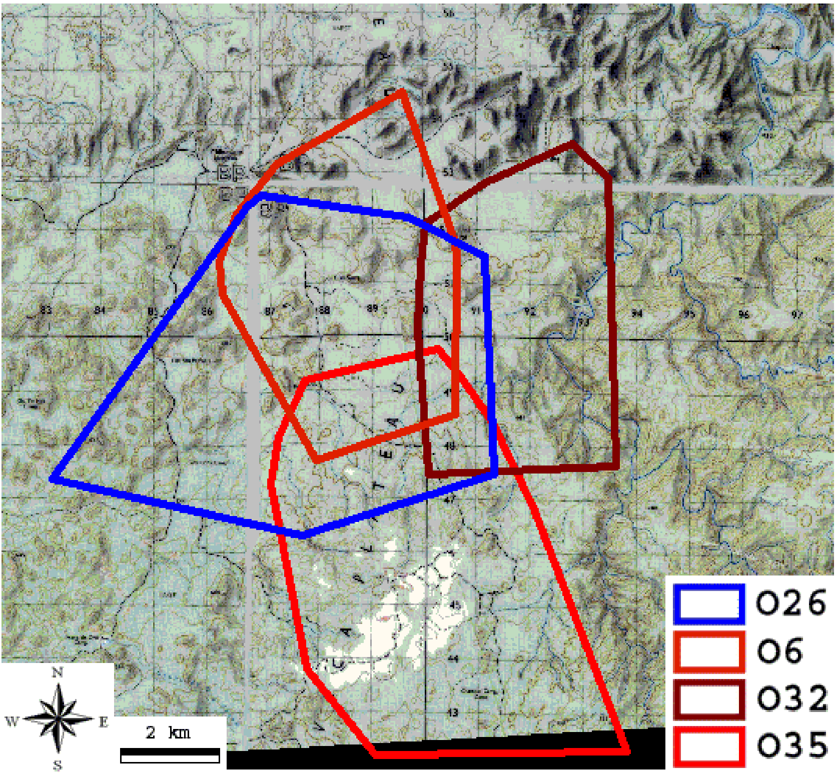

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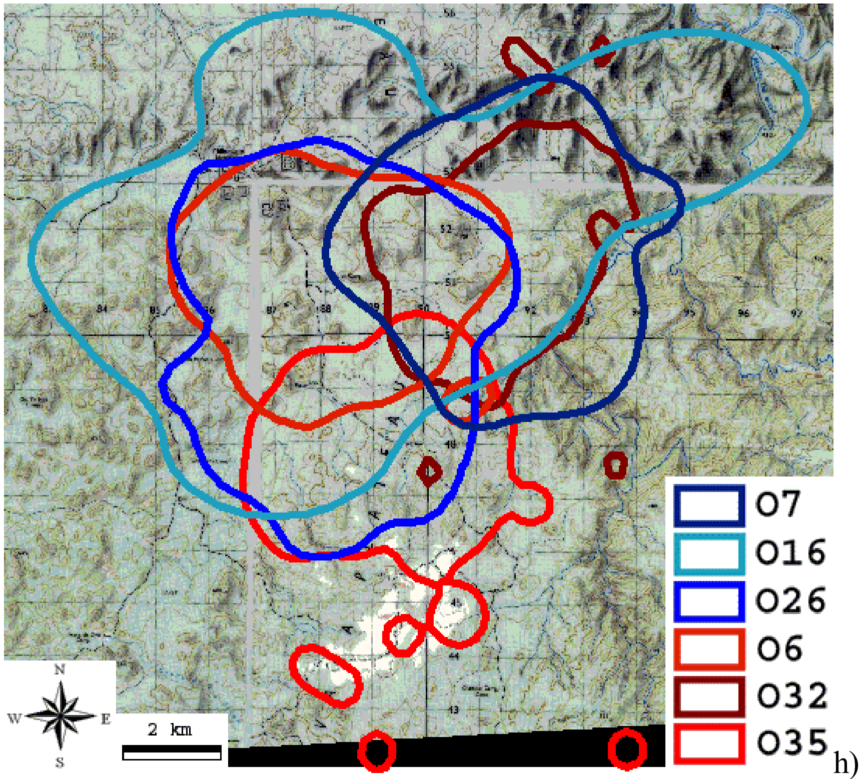
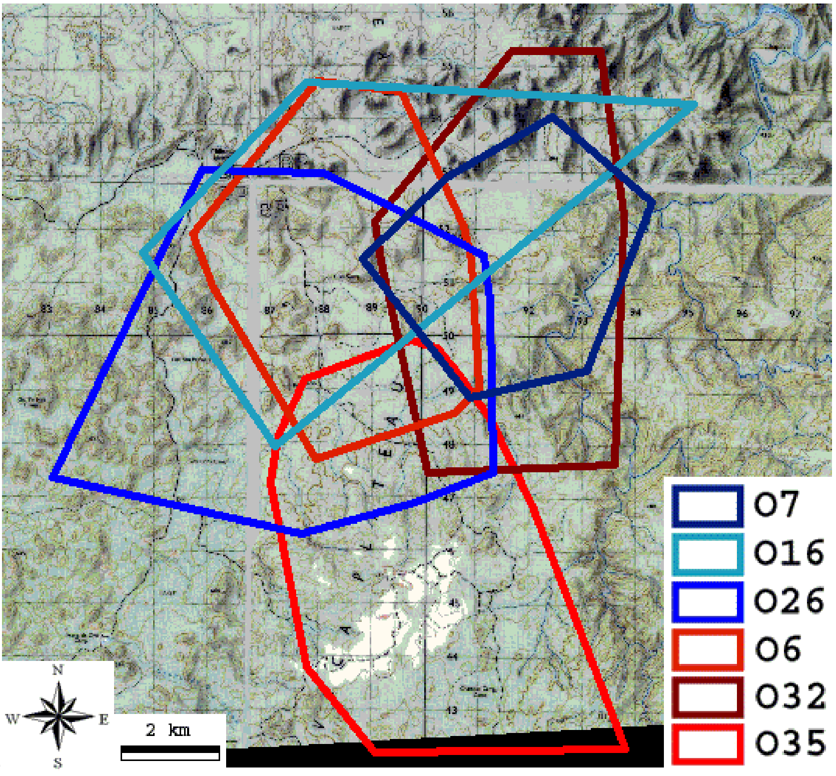


h)



CHAPTER 4 – COMPARING AND COMBINING CAMERA TRAPPING AND RADIO TELEMETRY

Abstract

Ocelots were studied in western Belize using both camera trapping and radio telemetry. These 2 techniques were conducted in the same habitat, at the same time and on some of the same individuals, allowing them to be compared against one another and combined. Activity budgets and density estimates determined from camera trapping were superior to those determined using radio telemetry. Although radio telemetry home range estimation demonstrated higher resolution, the home range estimates determined from camera trapping captured long distance movements, a larger amount of territory overlap, and demonstrated potential for estimating an animal's core use area. When radio telemetry data was combined with camera trapping methodology, by using the radius of the home range as a buffer around camera traps, the resulting density estimates were smaller than those determined using the current camera trapping methodology. Radio telemetry retains its strength as a home range estimation technique, while camera trapping provides more realistic density estimates. A combination of both methods produces much more information about the status and ecology of little known species, such as the ocelot, than either method alone.

Introduction

In the past 2 decades a handful of radio telemetry studies have been conducted on ocelots throughout their range (Tewes 1986, Ludlow and Sunquist 1987, Emmons 1988, Konecny et al. 1989, Crawshaw 1995). Recently new studies have been conducted on ocelots using remote cameras (Trolle and Kery 2003, Di Bitetti et al. Under Review, Haines et al. Under Review, Maffei et al. Under Review), but this study is the first to conduct both radio telemetry and remote camera trapping on ocelots in the same habitat, at the same time, and on some of the same individuals.

The main objective of this portion of the study is to compare the remote camera and radio telemetry techniques against one another to determine the benefits and shortcomings of each technique. Radio telemetry data will also be combined with remote camera data in order to test current camera trapping methodology.

Methods

Five camera trapping surveys (ocelot rainforest pilot, ocelot rainforest, jaguar rainforest 1, jaguar rainforest 2, jaguar rainforest 3) were conducted from August of 2002 until September of 2004, and 6 ocelots (3 male, 3 female) were trapped, collared and tracked from September 2002 until August 2003. Both of these techniques were conducted in the broadleaf rainforest habitat of the 1775 km^2 Chiquibul Forest Reserve and National Park (CFRNP) of Western Belize (Figure 1.4).

Comparing Remote Cameras and Radio Telemetry:

The ocelot activity budget across all rainforest camera trapping grids was compared to the ocelot rainforest activity budget determined using radio telemetry. The final ocelot density estimate determined across all rainforest camera trapping grids was compared to the ocelot rainforest density estimate determined using radio telemetry. The average camera trapping home ranges for males, females and all ocelots combined were compared to the average radio telemetry home ranges for males, females and all ocelots combined. Three ocelots (O7 – male, O26 – male, O6 – female) had both radio telemetry and camera trapping home ranges. Each ocelot's camera trapping home range was compared to its respective radio telemetry home range.

Combining Camera Trapping and Radio Telemetry:

Estimating density using remote cameras relies heavily on the estimation of a Mean Maximum Distance Moved (MMDM) between camera stations. Half of this value is used as a buffer around each camera, resulting in the total effective trap area of each camera grid. The maximum distance moved is meant to be a proxy for the maximum distance traversed across an animal's home range, unfortunately most camera studies lack any information on home range size in the selected habitat. Since this study used radio telemetry to determined ocelot home ranges in the same habitat and during the same time as the camera trapping surveys, the average radius of an ocelot's home range was determined and compared to the ½ MMDM camera trapping buffer value. Ocelot density was estimated using the average radius of radio telemetry home ranges and then compared with the estimated ocelot density determined from camera trapping surveys.

Since camera grids were conducted for 2-3 months during a single season, comparable home ranges were determined from a single wet season of similar duration. A 2-month period (5/1/04 – 7/1/04) that contained the most radio telemetry locations on the most ocelots was chosen and a 95% fixed kernel and 100% MCP home range was determined for each ocelot. This 2-month period included 1 male and 3 female ocelots. The radius was determined for each home range and an average radius was determined for all ocelots combined. This radius was used as a buffer around each camera station and the resulting density estimate was compared with that determined using camera trapping alone.

As a second method of comparison, a home range consisting of year-round locations but only 75% of the volume was determined for each ocelot. These 75% fixed kernel and 75% MCP home ranges may represent a comparable area that an ocelot would use during a 2-3 month camera survey. The radius of each home range was averaged across all ocelots and used as a buffer around each camera station. The resulting density estimate was compared with that determined using camera trapping alone.

Results

Activity Budgets:

The camera trapping activity budget (Figure 4.1a) revealed a much more distinct pattern for ocelot behavior than the radio telemetry activity budget did (Figure 4.1b). The camera trapping activity budget showed distinct increases in ocelot activity from 7 pm until 4 am; whereas there was no clearly observable trend in ocelot activity from the radio telemetry activity budget.

Density:

The density estimates determined from the 5 rainforest camera trapping grids ranged from 11.74 – 29.78 ocelots per 100 km^2 (Table 2.8), but due to complications the ocelot rainforest pilot and jaguar rainforest 1 grids were omitted, resulting in a density range of 18.91 – 20.75 ocelots per 100 km^2. Ocelot density estimates determined using radio telemetry data alone were 6.4 – 7.5 ocelots per 100 km^2. Although sample sizes were too small to perform statistical tests, ocelot density estimates determined from camera trapping were 2-3 times higher than density estimates determined using radio telemetry data.

Home Range:

Six ocelots were radio collared, but 1 ocelot (O16) had 18 radio telemetry locations and was omitted from the analysis. The 95% fixed kernel (Figure 4.2a) and 100% MCP (Figure 4.2b) home ranges were determined for each of the 5 ocelots (2 male, 3 female) using the radio telemetry data collected for the entire study year (Aug 2003 - Aug 2004). Fifteen ocelots (7 male, 8 female) were photographed ≥ 3 camera stations and their 100% MCP home ranges were determined from camera trapping surveys conducted from Aug 2002 – Sept 2004 (Figure 4.2c). All 3 methods of home range analysis demonstrated not only male-female territory overlap, but also male-male and female-female overlap.

The average home range size for both radio telemetry and camera trapping was determined for all male ocelots, all female ocelots, and all ocelots combined (Table 4.1). Although radio telemetry sample sizes were small and camera trapping home ranges showed a high degree of variation, the average camera trapping home range was smaller than the average radio telemetry home ranges.

When the 100% MCP camera trapping home range for male ocelot O7 was compared against the 95% fixed kernel and 100% MCP radio telemetry home ranges (Figure 4.3), the camera trapping home range showed a small percent of overlap with the radio telemetry home ranges, but it did capture long distance movements that were not detected using radio telemetry. These movements were picked up on the widespread camera trapping grids that were set up primarily for jaguars. When the 100% MCP camera trapping home range for male ocelot O26 (Figure 4.4a) and female ocelot O6 (Figure 4.4b) were compared against their respective 75% fixed kernel and 75% MCP radio telemetry home ranges they showed a larger percent overlap. Ocelot O26 showed roughly 50% overlap, and ocelot O26 showed almost complete home range overlap.

Combining Camera Trapping and Radio Telemetry:

The average radius for all 2-month 95% fixed kernel and 100% MCP home ranges and the average radius for all year-round 75% fixed kernel and 75% MCP home ranges were determined along with their corresponding standard deviations (Table 4.2). The average radius buffer values determined from radio telemetry were larger than all of the MMDM buffer values from camera trapping, except the jaguar rainforest 3 MMDM values, both excluding and including animals with a maximum distance of zero (Table 4.3, Figure 4.5). Ocelot density estimates, determined using the average radius of radio telemetry home ranges as a buffer, were compared to the camera trapping density estimates determined using MMDM values as a buffer (Table 4.4, Figure 4.6). Since almost every buffer value determined from the radius of radio telemetry home ranges was larger than the buffers determined from the camera trapping mean maximum distances moved, the resulting radio telemetry density estimates were all smaller than the camera trapping density estimates.

Discussion

Radio telemetry and camera trapping were compared in this study to examine the potential and limitations of each technique. Radio telemetry is time-intensive, invasive, and often results in data on a small subset of the population; whereas, camera trapping is relatively simple to maintain, usually obtains larger sample sizes, collects data on a variety of animals simultaneously, and uses mark recapture techniques to estimate a population size and density.

Radio telemetry and camera trapping have each been used in previous studies to determine ocelot activity patterns (Ludlow and Sunquist 1987, Emmons 1988, Di Bitetti et al. Under Review, Maffei et al. Under Review). When activity budgets were compared between these 2 techniques camera trapping resulted in a more distinct ocelot behavior pattern than radio telemetry. Although camera trapping may not capture all active ocelots at all hours of the day, the ocelots it does capture are accurately identified as active, thus providing an accurate subset of ocelot behavior. On the other hand radio telemetry provides the opportunity to determine if an ocelot is active or inactive at any time of the day, but the designation of activity is often subjective, increasing potential bias into the ocelot behavior data. Although not implemented for this study, activity collars, which send separate radio telemetry signals depending on the activity of the animal, could be used to lower this observer bias. For this study camera trapping activity budgets were superior to radio telemetry activity budgets.

Both radio telemetry and camera trapping divide population size by a sampled area to estimate density, but the population size determined from radio telemetry is often small and only represents a subset of the population. In addition there is the potential for animals within the study area not to be counted because they were not successfully trapped. Camera trapping only the other hand likely “captures” a larger percent of the animals in an area and uses mark-recapture statistics to estimate a population size for the area surveyed. The sampled area determined by radio telemetry is the sum total of the area used by all collared individuals (Ludlow and Sunquist 1987, Emmons 1988, Konecny 1989, Crawshaw 1995). The home range size of each individual is highly dependent the number of locations per animal (Seaman et al. 1999) and the method used to determine home range (Worton 1989, Seaman and Powell 1996); whereas, camera trapping uses the movements of photographed animals to determine a buffer value, which is placed around each camera to determine the effective trap area (Silver et al. 2004, Maffei et al. Under Review). For this study camera trapping density estimates were superior to radio telemetry density estimates.

Although radio telemetry has been used to estimate animal home range for years (Ludlow and Sunquist 1987, Emmons 1988, Konecny 1989, Crawshaw 1995), camera trapping has only recently been used to estimate an animal’s range (Di Bitetti et al. Under Review, Maffei et al. Under Review). When home ranges were compared between these 2 techniques camera trapping resulted in higher home range variation and lower home range size than radio telemetry. However, camera trapping captured more ocelots than radio telemetry and recorded long distance movements that radio telemetry did not. Minimum home range estimates determined from camera trapping displayed a large percent of territory overlap and demonstrated its potential in estimating a common or core use area for certain ocelots. The cameras in this study were not set up specifically to estimate an animal's home range, but if camera stations were moved to new locations in quick succession, animals could be captured at multiple locations, increasing the resolution of the camera trapping home range estimate. More research should be done to extend camera trapping home range estimation.

A critical aspect to estimating an animal's density using camera trapping methodology is determining the effective trap area. This study had the unique ability to compare the current ½ MMDM buffer method of determining effective trap area to buffers based on the average radius of an animal's radio telemetry home range. Radio telemetry buffers were larger than those determined using camera trapping ½ MMDM values. If the radius of an average ocelot's home range is a more accurate measure of how far away ocelot are captured by cameras, then the ½ MMDM buffer values in this study were too small, resulting in artificially inflated density estimates. More research should be conducted to determine if the currently used method of camera trapping buffer determination is an accurate measure of how far animals are being trapped by remote cameras. If more radio telemetry studies demonstrate, as this study has, that the average radius of an animal's home range is larger than the buffers that are currently being used to determine density, than the buffer distance may need to be increased (e.g. ¾ MMDM, MMDM including animals with a maximum distance of zero) to more accurately estimate density.

Although radio telemetry contains some benefits over camera trapping, especially in the area of home range estimation, for elusive and hard to study animals such as the ocelot, the camera trapping technique is more practical for obtaining population size and density estimates, which may be of more immediate conservation relevance. In addition, repeated camera trapping surveys in the same area can lead to estimates of survival and recruitment (Pollock 1982). Since radio telemetry studies will not always be conducted at the same time and location as camera trapping studies, standardizing camera trapping methodology is an important priority in ocelot (and other felid) monitoring and conservation.

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Table 4.1 Average home range size for male ocelots, female ocelots, and all ocelots combined with respective standard deviation and (sample size), determined using 95% fixed kernel (km^2) and 100% MCP (km^2) from radio telemetry (RT) data and 100% MCP from camera trapping (CT) data.

Ocelot	**95% Kernel (km^2) RT**	**100% MCP (km^2) RT**	**100% MCP (km^2) CT**
Males (n)	33.01 (2)	29.00 (2)	20.09 ± 20.05 (7)
Female (n)	21.05 ± 3.09 (3)	29.58 ± 4.39 (3)	4.35 ± 3.41 (8)
Combined (n)	25.83 ± 7.52 (5)	29.35 ± 8.98 (5)	11.70 ± 15.63 (15)

Table 4.2 Radius (km) of 2-month 95% fixed kernel and 100% MCP home ranges for each ocelot and the average 2-month home range radius (km) with its corresponding standard deviation. Radius (km) of year-round 75% fixed kernel and 75% MCP home ranges for each ocelot and the average year-round home range radius (km) with its corresponding standard deviation.

2-Month Home Range Radius (km)

Ocelot ID	95% Fixed Kernel	100% MCP
O26 (M)	2.73	3.09
O6 (F)	3.28	2.59
O32 (F)	2.34	2.47
O35 (F)	2.67	2.69
Average (SD)	**2.75 (0.39)**	**2.71 (0.27)**

Year-Round Home Range Radius (km)

Ocelot ID	75% Fixed Kernel	75% MCP
O7 (M)	2.08	1.43
O26 (M)	2.49	2.17
O6 (F)	1.89	1.66
O32 (F)	1.57	1.42
O35 (F)	1.81	1.58
Average (SD)	**1.97 (0.34)**	**1.65 (0.31)**

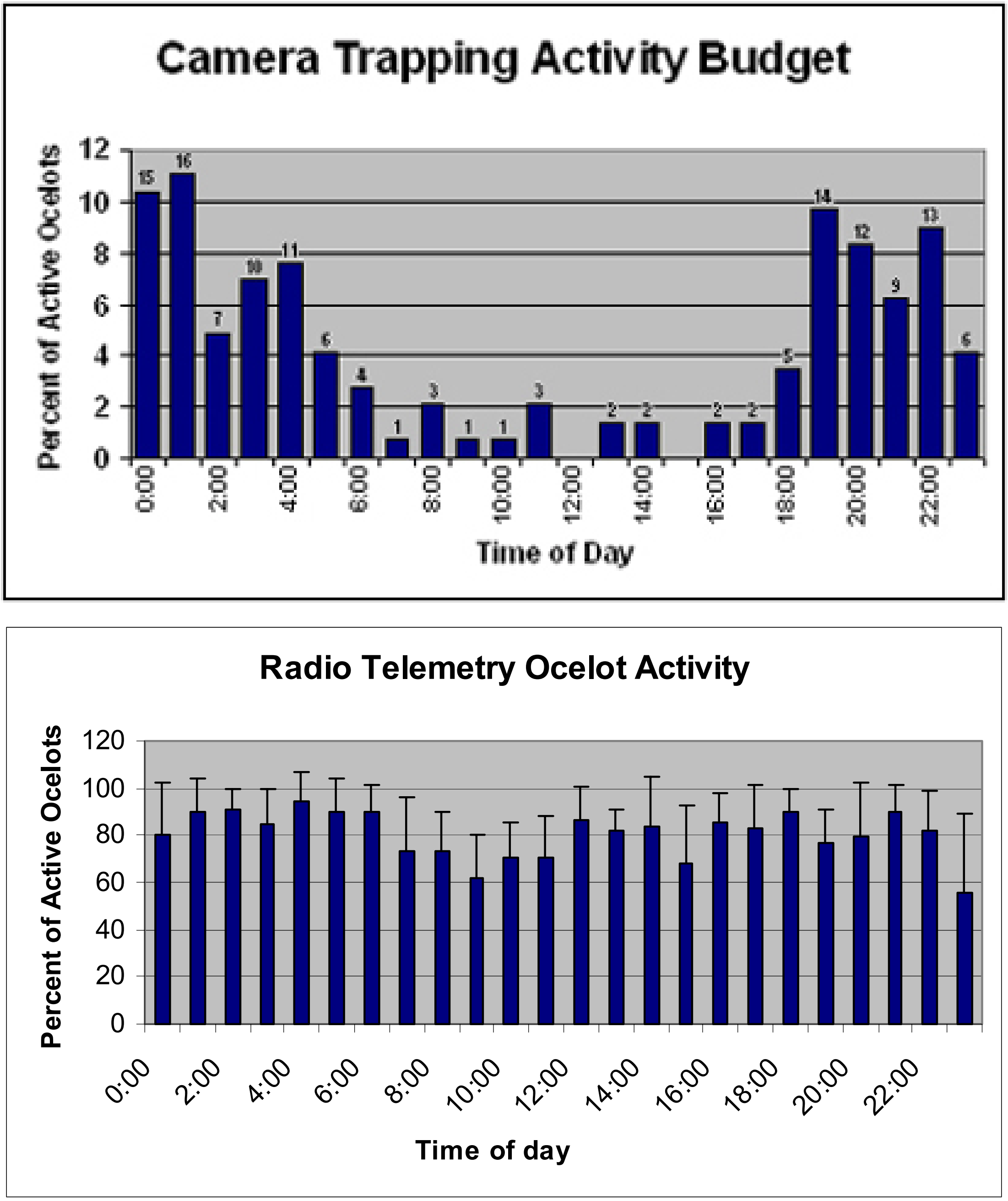
Table 4.3 Buffer value (km) of each rainforest camera trapping grid (ocelot rainforest pilot (ORP), ocelot rainforest (OR), jaguar rainforest 1 (JR1), jaguar rainforest 2 (JR2), jaguar rainforest 3 (JR3)) determined using the average radius of a 2-month 95% fixed kernel, 2-month 100% MCP, year-round 75% fixed kernel, and year-round 75% MCP radio telemetry home range, and determined using the ½ MMDM excluding zeros, ½ MMDM including zeros, ½ AMMDM excluding zeros, and ½ AMMDM including zeros values from camera trapping.

Buffer Type	**Rainforest Camera Grid Buffer Value (km)**				
	ORP	**OR**	**JR1**	**JR2**	**JR3**
Radio Telemetry					
Average 2-Month 95% Fixed Kernel Radius	2.75	2.75	2.75	2.75	2.75
Average 2-Month 100% MCP Radius	2.71	2.71	2.71	2.71	2.71
Average Year-Round 75% Fixed Kernel Radius	1.97	1.97	1.97	1.97	1.97
Average Year-Round 75% MCP Radius	1.65	1.65	1.65	1.65	1.65
Camera Trapping					
½ MMDM Excluding Zeros	0.93	1.23	1.64	1.56	2.43
½ MMDM Including Zeros	0.93	1.23	1.64	1.02	1.95
½ AMMDM Excluding Zeros	1.56	1.56	1.56	1.56	1.56
½ AMMDM Including Zeros	1.24	1.24	1.24	1.24	1.24

Table 4.4 Estimated ocelot density (per 100 km^2) of each rainforest camera trapping grid (ocelot rainforest pilot (ORP), ocelot rainforest (OR), jaguar rainforest 1 (JR1), jaguar rainforest 2 (JR2), jaguar rainforest 3 (JR3)), determined using the average radius of a 2-month 95% fixed kernel, 2-month 100% MCP, year-round 75% fixed kernel, and year-round 75% MCP radio telemetry home range as buffers, and determined using ½ MMDM excluding zeros, ½ MMDM including zeros, ½ AMMDM excluding zeros, and ½ AMMDM including zeros values from camera trapping as buffers.

Buffer Type	**Rainforest Camera Grid Density (ocelots per 100 km2)**				
	ORP	**OR**	**JR1**	**JR2**	**JR3**
	Radio Telemetry				
Average 2-Month 95% Fixed Kernel Radius	13.58	11.15	6.05	11.07	10.23
Average 2-Month 100% MCP Radius	13.92	11.37	6.15	11.25	10.38
Average Year-Round 75% Fixed Kernel Radius	21.81	16.19	8.62	15.36	14.10
Average Year-Round 75% MCP Radius	27.56	19.50	10.72	18.44	17.32
	Camera Trapping				
½ MMDM Excluding Zeros	53.72	25.88	10.79	19.26	11.45
½ MMDM Including Zeros	53.72	25.88	10.79	38.47	14.26
½ AMMDM Excluding Zeros	29.78	20.75	11.74	19.83	18.91
½ AMMDM Including Zeros	38.96	25.82	17.84	27.55	27.55

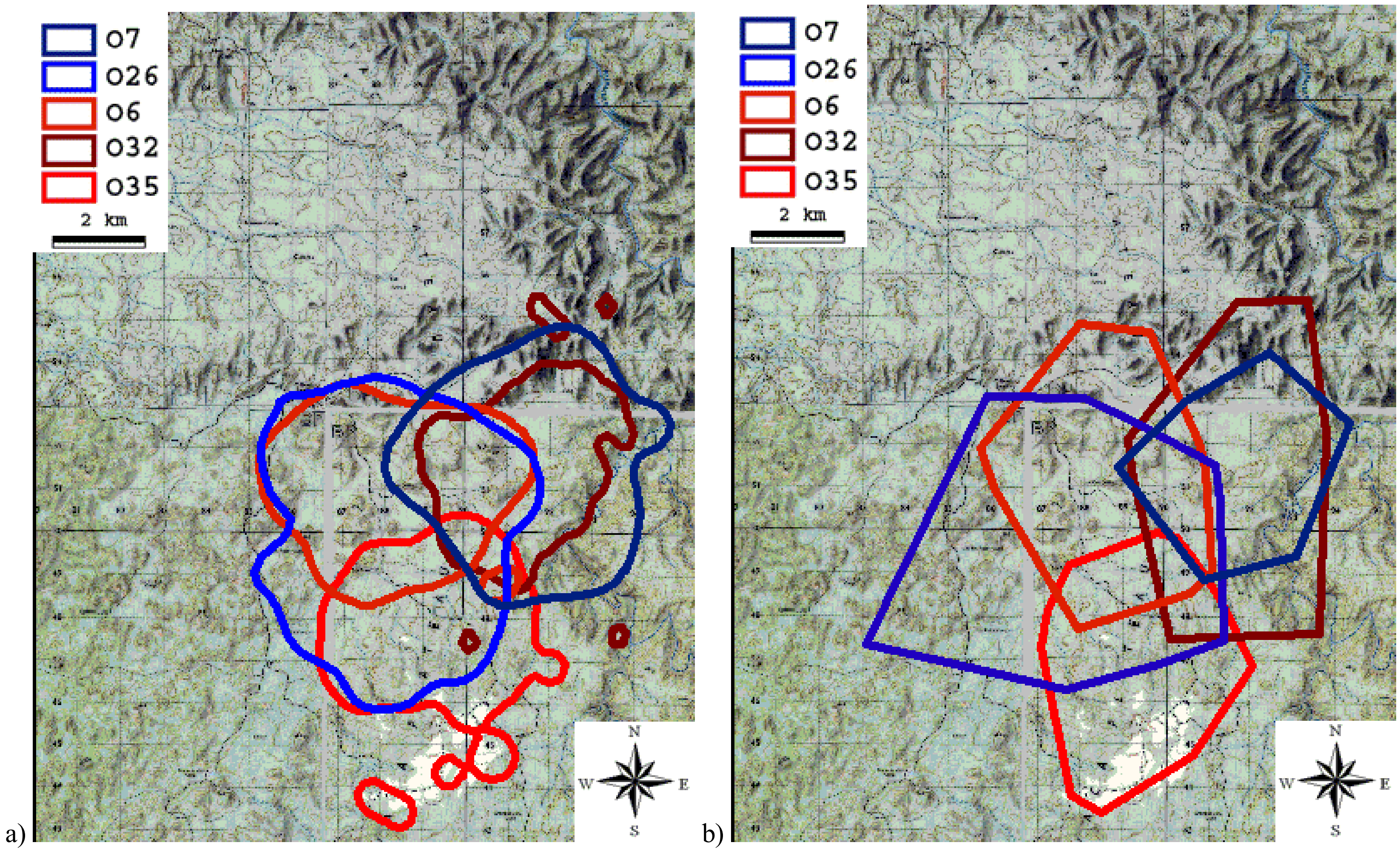
Figure 4.1 a) Camera trapping activity budget for all ocelots combined. b) Radio telemetry activity budget for all ocelots combined.



a)

b)

Figure 4.2 a) 95% fixed kernel home range (km^2) for all ocelots using radio telemetry. b) 100% MCP home range (km^2) for all ocelots using radio telemetry. c) 100% MCP home range (km^2) for all ocelots using camera trapping. Males are blue and females are red.



a)

b)

c)

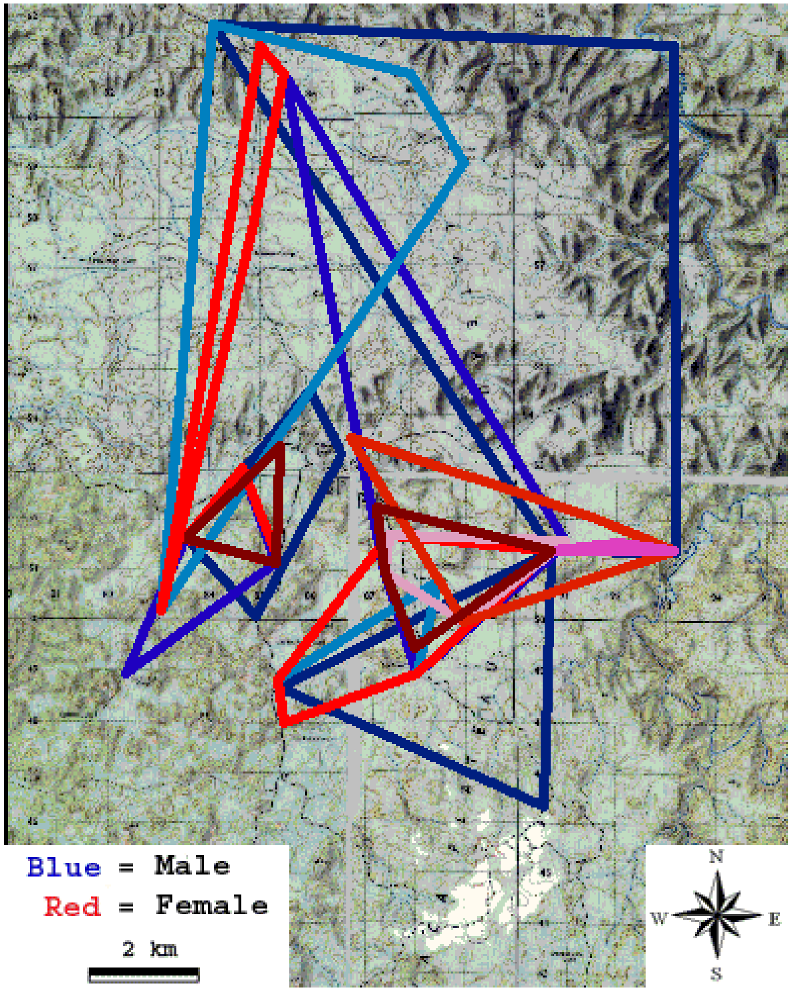


Figure 4.3 100% MCP (km^2) camera trapping (CT) home range, 95% fixed kernel (km^2) radio telemetry (RT) home range, and 100% MCP (km^2) radio telemetry (RT) home range for male ocelot O7.

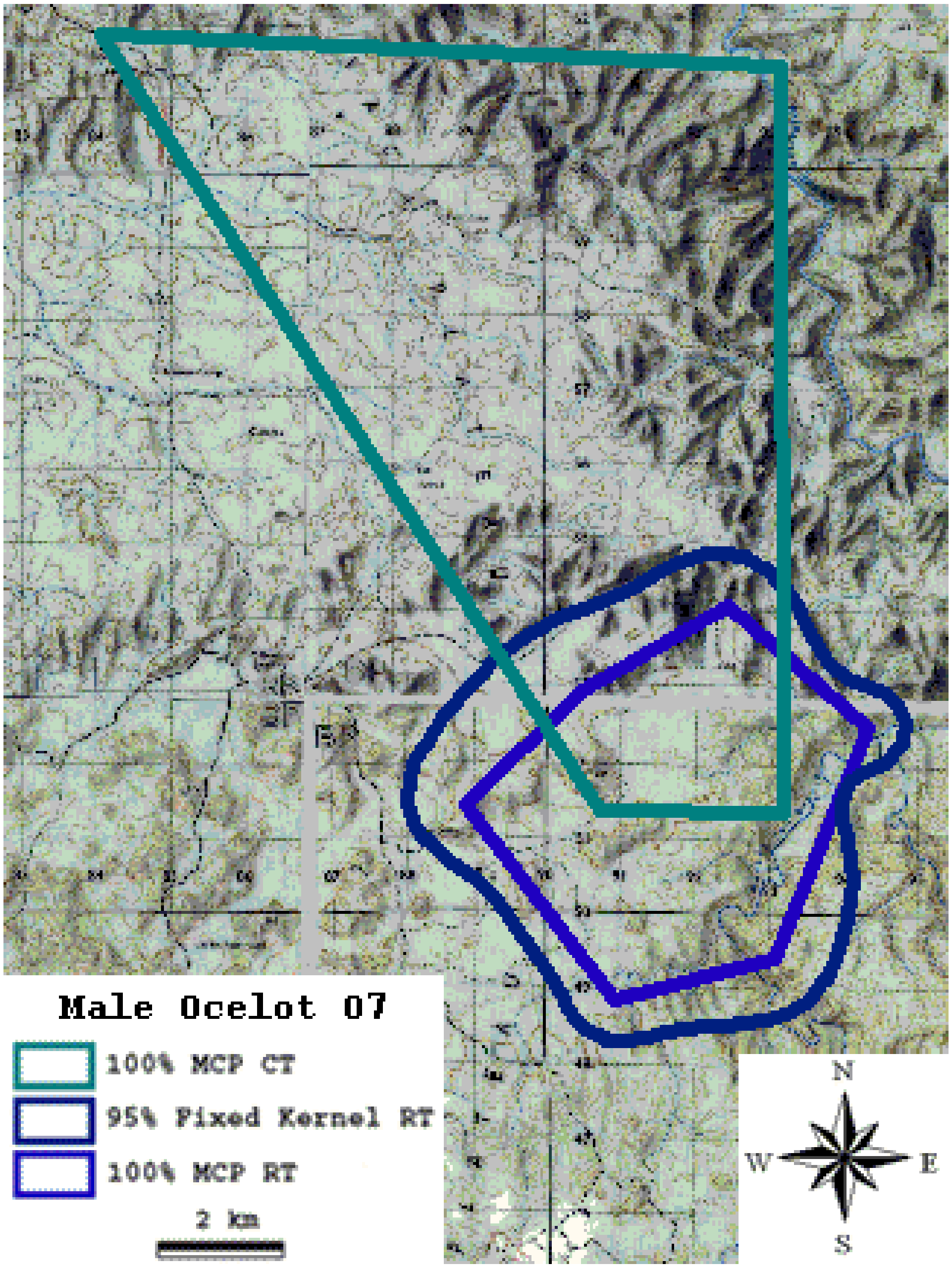
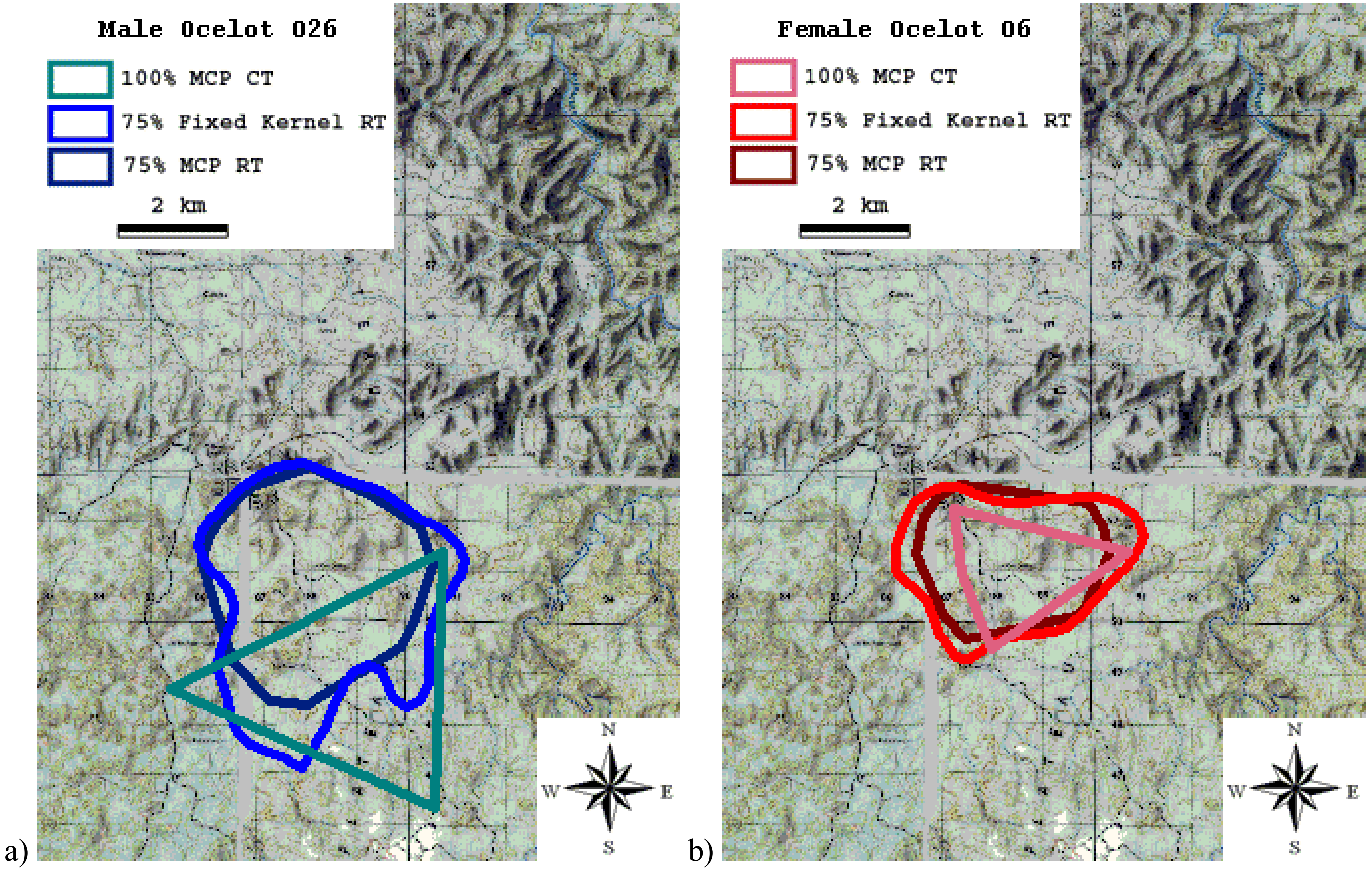


Figure 4.4 a) 100% MCP (km^2) camera trapping (CT) home range, 75% fixed kernel (km^2) radio telemetry (RT) home range, and 75% MCP (km^2) radio telemetry (RT) home range for male ocelot O26. b) 100% MCP (km^2) camera trapping (CT) home range, 75% fixed kernel (km^2) radio telemetry (RT) home range, and 75% MCP (km^2) radio telemetry (RT) home range for female ocelot O6.



a)

b)

Figure 4.5 Camera trapping and radio telemetry buffer values (km) for each rainforest camera trapping grid (ocelot rainforest pilot (ORP), ocelot rainforest (OR), jaguar rainforest 1 (JR1), jaguar rainforest 2 (JR2), jaguar rainforest 3 (JR3)).

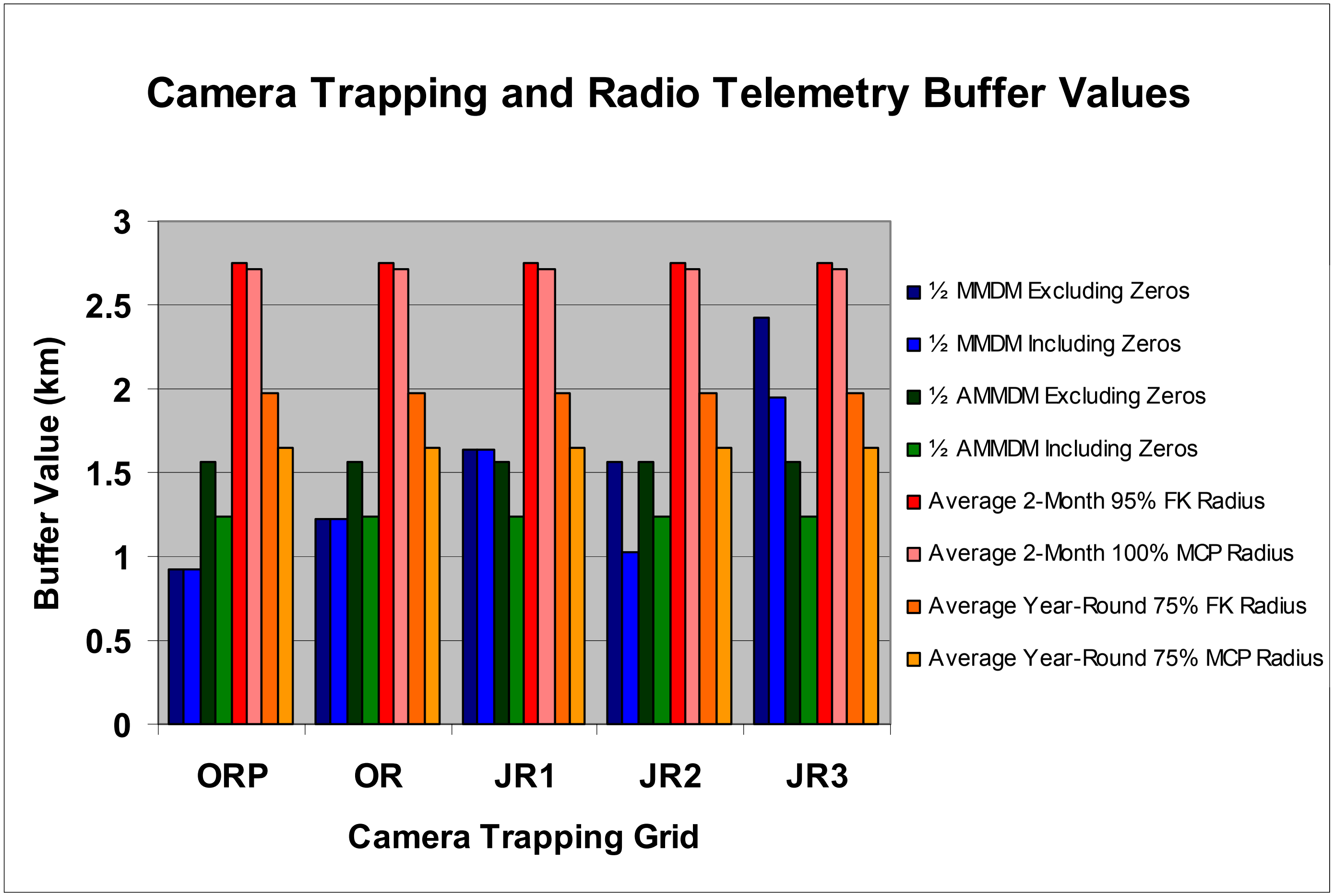
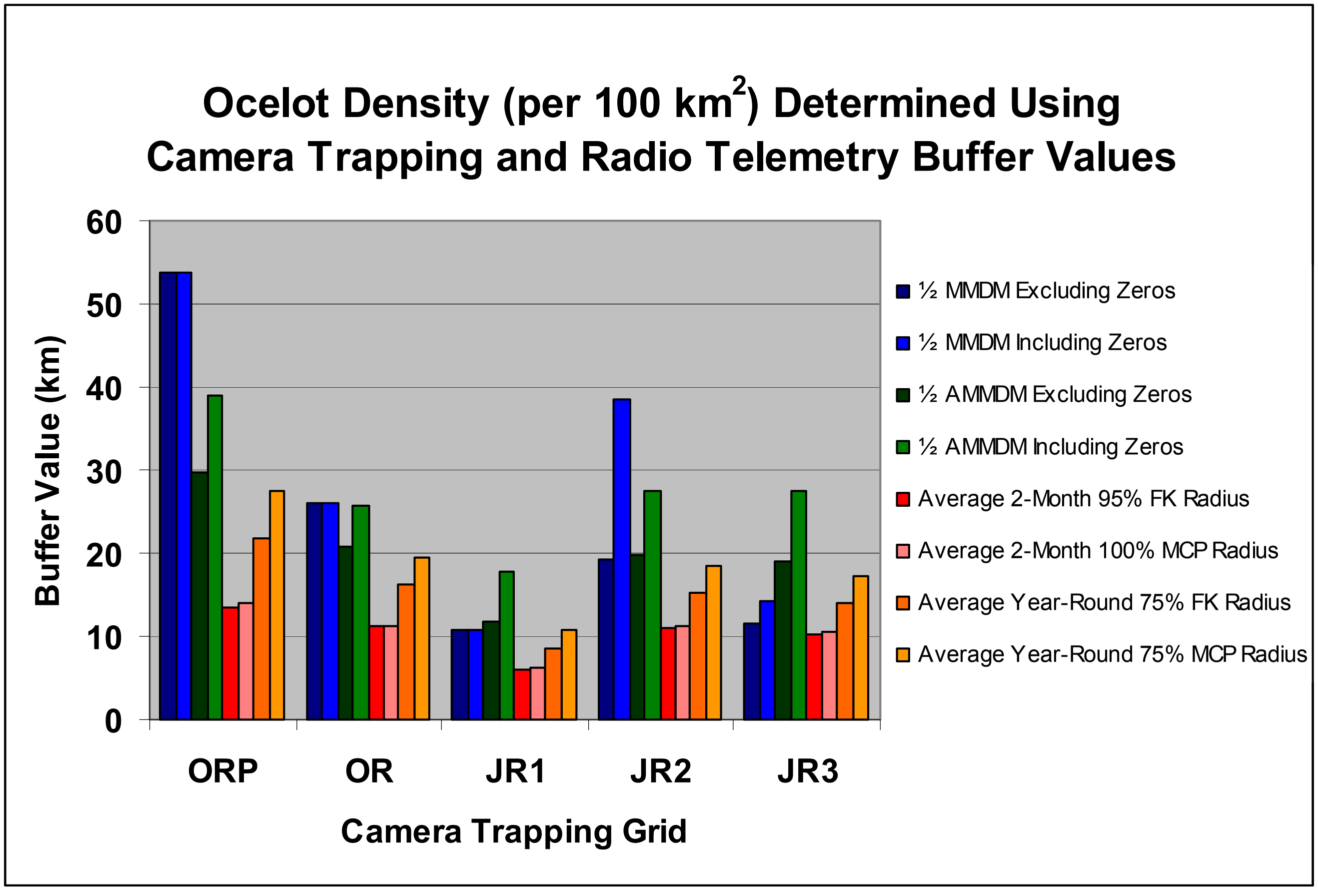


Figure 4.6 Estimated ocelot density (per 100 km^2) determined using MMDM camera trapping buffer values and determined using average radius radio telemetry values for each rainforest camera trapping grid (ocelot rainforest pilot (ORP), ocelot rainforest (OR), jaguar rainforest 1 (JR1), jaguar rainforest 2 (JR2), jaguar rainforest 3 (JR3)).



VITA

Adam Dillon was born on May 8, 1975 to Suzanne Bertron and Greg Dillon in North Terrytown, New York. At an early age Adam and his family left the New York City area and moved to Spring, Texas, just north of Houston. Adam graduated high school in 1993 and headed to Austin to attend the University of Texas. In December of 1996 he graduated with a Bachelor of Arts in Zoology and within a year he left Texas to travel around Europe with nothing but a backpack, a few books, an open mind and an adventurous spirit.

After returning from Europe, lighter in money but richer in mind, Adam moved to where his small extended family had their roots, in Brooklyn, New York, and got a job working with the Wildlife Conservation Society at the Bronx Zoo. Although he gained a strong knowledge of animals and ecology at the Bronx Zoo, his real desire was to become involved in field work. In the summer of 2000, Adam worked with the Wildlife Conservation Society on a small mammal research project in the Hell's Canyon area of Oregon and has never looked back.

In the fall of 2000, Adam left Oregon and traveled across the United States and Canada for the next two months, visiting universities and professors, and learning as much as possible about the areas, wilderness and people he encountered. In the winter of 2001, he headed to northern Minnesota to work with the Minnesota Department of Natural Resources on a white-tailed deer/wolf research project. After gaining extensive experience and working with wonderful people in Minnesota, Adam headed to San Clemente Island, 70 Miles off the coast of San Diego, California, to work with the Institute for Wildlife Studies on an Island Fox project.

After working with foxes for a year, Adam accepted a Masters position with Dr. Marcella Kelly in the Fisheries and Wildlife Department at Virginia Tech. As part of his research on ocelot density and home range, Adam spent a year in the remote rainforest of western Belize at the Las Cuevas Research Station. In addition to collecting his own research, Adam was an instructor for a Wildlands study abroad program, based out of the University of California at Santa Barbara. Together with a colleague, he taught between 12 and 16 college students from throughout the United States about the tropical ecology and cultural geography of Belize. Adam is currently working with the Max McGraw Wildlife Foundation researching coyotes in the Chicago area.