USE OF GIS AND REMOTE SENSING TECHNOLOGIES TO STUDY HABITAT REQUIREMENTS OF OCELOTS, LEOPARDUS PARDALIS, IN SOUTH TEXAS

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The goals of this study were to use Geographic Information Systems (GIS) and remote sensing technologies to gain a better understanding of habitat requirements of a population of ocelots in south Texas, and then apply this knowledge to form a predictive model to locate areas of suitable habitat in Willacy and Cameron counties, Texas. Satellite imagery from August 1991 and August 2000 were classified into four land cover types: closed canopy, open canopy, water, and urban/barren. These classified images were converted into digital thematic maps for use in resource utilization studies and modeling. Location estimates (762 from 1991 and 406 from 2000) were entered into a GIS in order to extract information about home range and resource selection. Each animal's home range was calculated using both Minimum Convex Polygon (MCP) and Kernel home range estimators (95% and 50%). Habitat parameters of interest were: soil, land cover, human density, road density, and distance to closest road, city and water body. Ocelots were found to prefer closed canopy and avoid open canopy land cover types. Ocelots preferred soils known to support thorn scrub, an indication of the importance of this habitat. Landscape metrics associated with habitat used by ocelots were determined through the use of Patch Analyst, an extension for ArcView 3.2. Contrary to expectations, ocelots utilized areas with greater fragmentation than random areas available for use. However, this use of highly fragmented areas was an indication of the degree of fragmentation of suitable habitat in the area. Further investigation of patch size selection indicated that ocelots used large sized patches disproportionately to availability, indicating a preference for larger patches. A model was created using the resource selection and habitat preference GIS database from 1991. This model was used to identify areas of “optimal”, ”sub-optimal”, and “unsuitable” habitat for ocelots in 2000. This resultant map was compared to known locations of ocelots in 2000. Ocelots were found to prefer optimal habitat and avoid unsuitable habitat, an indication that the model created was valid.

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CHAPTER 1

INTRODUCTION

Overview of Research

Extinction rates in species from different taxa and habitats have been estimated to be 100 to 1,000 times higher today than during pre-human times (Pimm et. al., 1995). Rare and local species are most prone to extinction. Species with restricted ranges have lower local population densities than do widespread species. When their habitat is destroyed, these species are more likely to be eliminated, and any remaining populations would be too low to be viable (Pimm et. al., 1995). Carnivores possess certain life history traits, e.g. relatively low population densities, large home range requirements, low reproductive output, etc., that increase their vulnerability to extinction (Sunquist and Sunquist, 2001).

In North America, ocelots (Leopardus pardalis) once were found as far north as Arkansas and Arizona but are currently limited to the southern tip of Texas, where population estimates are no greater than 120 individuals (Tewes and Everett, 1986). They are listed as “endangered” both federally and within the state of Texas (U. S. Fish and Wildlife Service, 1982; Texas Parks and Wildlife Department, 1977). Loss of habitat and reduction of corridors between known populations are major threats to the potential recovery and ongoing viability of populations of ocelots. Over 95% of the native chaparral and riparian forests of the Lower Rio Grande Valley, which serve as the primary habitat for ocelots in south Texas, have been modified by human use (Purdy, 1983).

Understanding where suitable habitat and corridors exist is essential to any management decisions for conservation of this endangered species. The goals of this study were to use Geographic Information Systems (GIS) and remote sensing technologies to gain a better understanding of habitat requirements of a population of ocelots in south Texas, and then apply this knowledge to form a predictive model to locate areas of suitable habitat in Willacy and Cameron counties, Texas. These areas can then be considered for inclusion into the federal refuge system.

The goals of this research were met by performing a series of tasks that included:

1. the development of a land cover theme from Landsat Thematic Mapper images;
2. an assessment of home range and resource requirements of ocelots in south Texas;
3. an assessment of landscape metrics associated with ocelot home ranges; and
4. the creation of a weighted model using resource requirements and landscape metrics for predicting suitable areas for ocelots.

Scientific Merit

As a result of loss of habitat and over-exploitation, ocelots are classified as “vulnerable” by the International Union for the Conservation of Nature (1978), “endangered” by the United States Fish and Wildlife Service (1982), and “endangered” in Texas (Texas Parks and Wildlife Department, 1977). Recovery efforts for this species are limited by the scant information available about population dynamics and habitat needs

(U.S. Fish and Wildlife Service, 1990). Loss of habitat and corridors between known populations are major threats to the potential recovery and ongoing viability of populations, and understanding where suitable habitat and corridors exist is essential to any management decisions.

Identifying potential habitat and corridors in south Texas will allow Texas Parks and Wildlife and U.S. Fish and Wildlife biologists to manage for this species more effectively. This study will increase knowledge about ocelot habitat availability in south Texas and will allow wildlife managers to make informed management decisions regarding the maintenance of current populations and reintroduction of new populations. Identification of areas of suitable habitat will also help with land acquisition decisions. Methodologies explored in this research for using GIS and remote sensing technologies can be applied to other species of concern.

Natural History of Ocelots

Four Neotropical species of felids have been reported within the United States. The ocelot, Leopardus pardalis; margay, L. wiedii; jaguarundi, Felis yagouaroundi; and jaguar, Panthera onca; have been documented as either transient or resident in Arizona, New Mexico, and/or Texas. Recently, reports of only ocelots and jaguars exist from the southwestern United States. The historic distribution of ocelots extended from Arkansas to Arizona and southward to Paraguay, Uruguay, and northern Argentina (Fig. 1.1). More recently, viable populations are known to exist only in Cameron County, Texas and southward to northern Argentina. Some ocelots, believed to be transient visitors from northern Mexico, have been sighted in Arizona (Bill Van Pelt, pers. comm.).

Figure 1.1 The historical distribution of ocelots, Leopardus pardalis.

Ocelots inhabit a variety of habitat types across their range. In Texas, they occur predominantly in dense, thorny chaparral with mesquite (Prosopis glandulosa), Acacia spp., Condalia spp., Castella spp., granjeno (Celtis pallida), cenizo (Leucophyllum spp.), and white brush (Aloysia spp.) vegetation predominating (Tewes and Schmidly, 1987). As recently as the 1950's and 1960's, ocelots living in the Edwards Plateau region of Texas utilized dense Juniperus spp. communities (Tewes and Schmidly, 1987). In a study conducted by Shindle (1995) in Cameron County, Texas, 12 of 15 ocelots preferred dense thorn scrub tracts for transportation corridors, and none of the ocelots avoided these areas. In 1986, Tewes found eight of 12 ocelots living in "resacas", old river channels with dense strips of vegetation and fertile silty loam soils. Ocelots are found in the 810-ha Santa Ana National Wildlife Refuge (Hidalgo County, TX) and the 16-ha Audubon Sabal Palm Grove Sanctuary (Cameron County, TX --Brown, 1989/1990). Cleared, cultivated lands that may keep ocelots from moving outward surround these two protected areas.

Ocelots inhabit heavy rainforests to sparse tropical deciduous forests in Mexico (Leopold, 1959; Tewes and Schmidly, 1987). In Venezuela, ocelots inhabit tropical humid evergreen forests, pre-montane humid evergreen forests, lowland tropical semi-deciduous forests, pre-montane semi-deciduous forests, and tropical dry thorny forests (Mondolfi, 1986). Although ocelots have a preference for gallery (riverine) forests, they also can be found in mangroves, pasture lands, upland savannas, and swampy savannas (Mondolfi, 1986). In Costa Rica, ocelots occupy a variety of habitats from sea level to 3800 m, including dense forests, secondary forests, swamp forests, mangroves, scrublands, pastures, subalpine areas, paramos, and occasionally coffee plantations (Tewes and Schmidly, 1987). All of these habitat types contain dense cover.

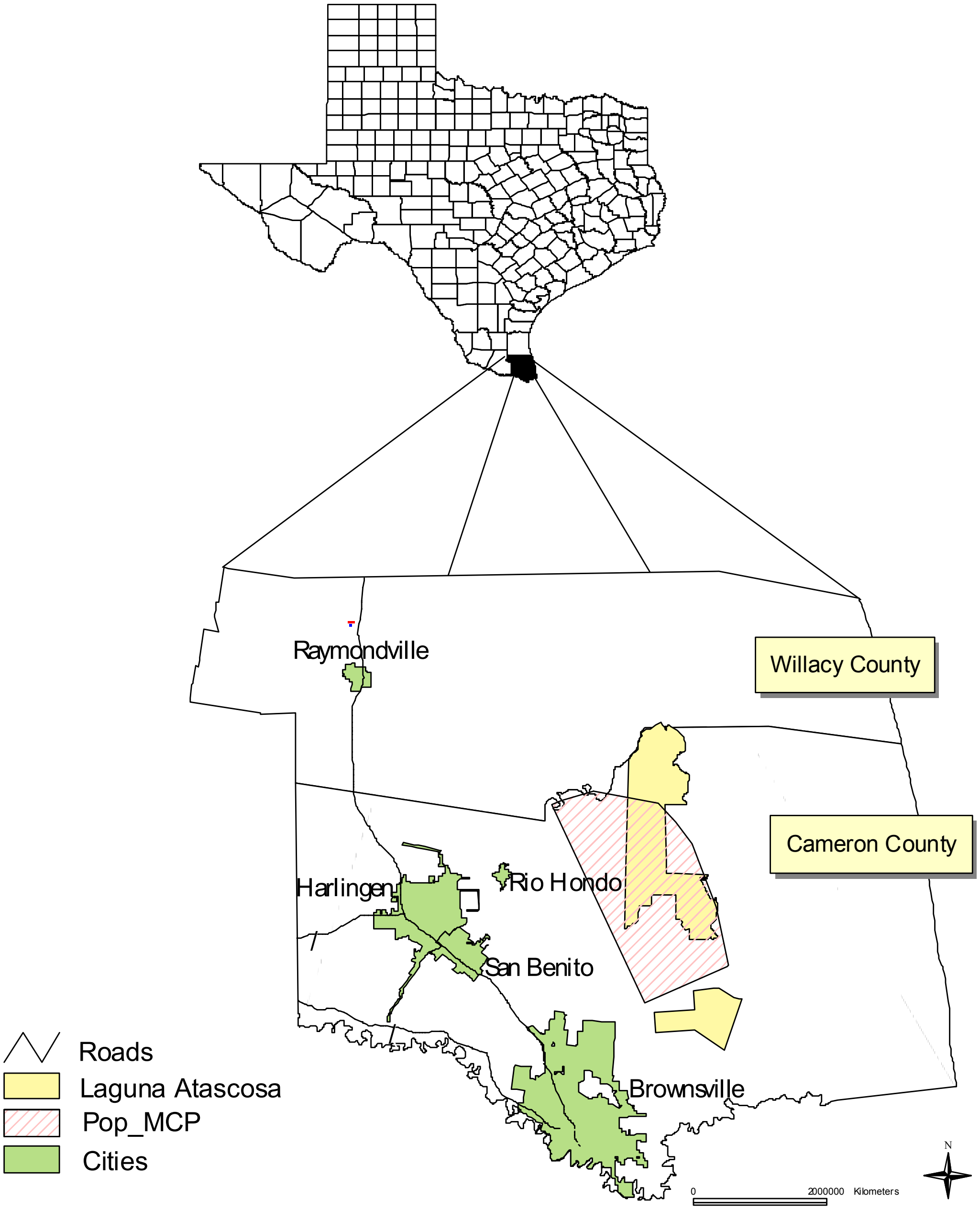
Ocelots are carnivores, eating a varied diet of prey items consisting of agouti, armadillos, sloths, common opossums, rat opossums, spiny rats, Cricetid rodents, iguanas, snakes, young land tortoises, frogs, crabs, and beetles (Mondolfi, 1986; Tewes and Schmidly, 1987). In Venezuela, the diet of ocelots is mostly mammalian (Bisbal, 1986), and prey has a body size of less than 1 kg (Emmons, 1987). Suspected predators of ocelots in south Texas include coyotes and feral dogs (Tewes et al., 1995). Emmons et al. (1989) reported the predation of ocelots by harpy eagles, pumas, jaguars, and anacondas. However, in Brazil and northern Argentina, four out of five known mortalities were directly linked to human activity; poaching killed two ocelots and two ocelots were killed by vehicles (Crawshaw, 1995). Laack (1991) reported that vehicles caused several ocelot mortalities during her study of a population in south Texas.

Study Area

The study area included Cameron and Willacy counties, Texas (Fig. 1.2). Specifically, this study concentrated on land available to a known population of approximately 40 ocelots near Laguna Atascosa National Wildlife Refuge (LANWR), located in the northeastern portion of Cameron County and extending into southern Willacy County.

LANWR is bordered to the north, south, and west by privately-owned land used primarily for agriculture and on the east by the Laguna Madre of the Gulf of Mexico. The refuge contains coastal prairies, salt flats, estuaries, and thorn forest. Small tracts of native vegetation exist in the surrounding landscape and are linked by vegetated resacas (old river channels), drainages, and fencerows (Laack, 1991).

Figure 1.2 Willacy and Cameron counties, Texas. Cities, Laguna Atascosa NWR, and the area utilized by ocelots in 1991 are highlighted.



The principal habitat used by ocelots, thorn scrub, occupies approximately 1,200 ha of LANWR. The dominant tree species in this habitat include honey mesquite (Prosopis glandulosa), Texas ebony (Pithecellobium flexicaule), spiny hackberry (Celtis pallida), brasil (Condalia obovata), and colima (Zanthoxylum fagara). Foresteria (Foresteria texana), snake-eyes (Phaulothamnus spinescens), Texas lantana (Lantana horrida), and coyotillo (Karwinskia humboldtiana) are among the most dominant understory shrubs (Laack, 1991).

This region of Texas is known for its long summers and brief, mild winters. The climate is subtropical and semi-arid. Mean annual precipitation is approximately 65 - 70 cm, with the bulk falling in thundershowers. Thus, large variations in precipitation occur (Williams et al., 1977; Turner, 1982). Topography of the region is flat with elevation ranging from sea level to the east and 21 - 27 m to the west in Cameron and Willacy counties, respectively (Williams et al., 1977; Turner, 1982).

CHAPTER 2

REMOTE SENSING

Introduction

Features on the earth's surface reflect or emit electromagnetic energy in certain patterns, or spectral signatures, which can be correlated with land cover and vegetation patterns. These electromagnetic patterns can be recorded by aerial cameras or satellites to create remotely-sensed data. Remote sensing data can be manipulated into thematic maps that can then be utilized by ecologists for landscape-level issues. Numerous examples of the applications of remote sensing to ecological studies have been presented in the literature. Following are examples that pertain specifically to this research.

Remotely-sensed data can provide information regarding land cover at the landscape scale. Congalton et al. (1998) used remotely-sensed data in conjunction with GIS to assess agricultural crops and other land cover in the lower Colorado River Basin for inclusion into the Lower Colorado River Accounting System (LCRAS) model. The U.S. Bureau of Reclamation (USBR) and the U.S. Geological Survey (USGS) developed this LCRAS model to estimate consumptive use of water in the Colorado River Basin. Landsat Thematic Mapper (TM) images were classified into groups of vegetation having similar water use characteristics. Agricultural fields were digitized within the study area, and vegetation cover was assessed four times throughout the year to cover all seasonal crops. The ground-visited fields were split randomly into two groups, 2/3 of the data were used in the supervised classification of the images and 1/3 of the data were retained for accuracy assessment. High accuracies were achieved in classification by combining detailed field observations with automated signature extraction and data exploration routines.

Remotely-sensed data can help gain knowledge about isolated and inaccessible areas. Hayes and Sader (2001) used Landsat TM data to quantify deforestation of Guatemala's Maya Biosphere Reserve (MBR). Three dates of imagery acquired two years apart were used to examine the change in land cover on MBR. The change detection maps created were used to support ecological research and socio-economic studies of land cover change in this area.

Erickson, McDonald, and Skinner (1998) presented a case study that used remotely-sensed data in conjunction with GIS to study resource selection of moose in Alaska. Relative probability of moose selecting an area was determined based on land cover. Landsat TM data were classified into 22 land cover classes to develop a base map reflecting vegetation present. Moose groups were located in 1994 and 1996, and the class at each location was recorded. Regression analysis was used to determine the land cover classes avoided or preferred by groups of moose.

Glennon and Porter (1999) used TM imagery to create thematic maps with seven categories of land cover for 1986 and 1993. These land cover maps were entered into a GIS with known locations of turkeys to study how landscape metrics affected the distribution of turkeys in a primarily forested area of southwestern New York.

Remotely-sensed data, used in conjunction with GIS, can enhance ecological research. Habitat characteristics such as land cover and land use can be assessed through satellite imagery and then imported into a GIS for further analyses. This study built upon the methods outlined in the aforementioned studies for the use of remotely sensed data in a GIS to study habitat requirements of ocelots in south Texas.

Materials and Methods

Geometric correction and subset

Imagery was obtained from the U.S. Department of the Interior, U. S. Geological Survey (USGS). A Landsat Thematic Mapper image, taken in August 1991, was purchased through the Multi-Resolution Land Characteristics (MRLC) project through a joint research initiative with LANWR. A Landsat Enhanced Thematic Mapper image, taken in August 2000, was purchased directly from USGS.

Images taken from satellites contain systematic and unsystematic geometric errors. Systematic errors are normally removed from most commercially available images, whereas unsystematic errors must be removed by the researcher (Jensen, 1996). Unsystematic errors, such as attitude (roll, pitch, and yaw) and altitude, can be corrected through the use of ground control points (GCPs) and georectification. Whenever accurate area, direction, and distance measurements are required, image to map georectification is required (Jensen, 1996). When two images taken on different dates are to be compared, image to image registration is advised. If image to image registration is used, any error in the first image will be inherent in the second image (Jensen, 1996). Therefore, a hybrid approach using both methods of georectification is preferred.

For georectification of the 1991 image, digital maps of roads were downloaded from USGS as digital line graphs, manipulated in ArcInfo (ESRI, 1995) into a vector coverage, and then converted into a shapefile (ArcVew digital map) for use in IMAGINE

(ERDAS, 1997). Forty GCPs scattered throughout the image were located on the roads shapefile to assign the image spatial reference. Due to the relatively small area of this study site, approximately 1/4 of the total Landsat TM image, a first order, six-parameter, affine transformation was thought to be sufficient (Jensen, 1996). This resulted in the following errors: x error = 0.1539, y error = 0.1745, total root-mean-square error (rms) = 0.2327. Nearest neighbor interpolation was used to resample the image in order to relocate brightness values from the raw image pixels to the proper, georectified location. A hybrid approach was used to georectify the 2000 image using 20 GCPs located on both the 1991 image and the roads shapefile. This georectification procedure yielded an x error = 0.1355, y error = 0.1733, and rms = 0.2200. A subset of the original image was created that was slightly larger than the study site, enabling more rapid analyses.

Classification

To classify pixels into land cover types, brightness values of each pixel, determined by the reflectance of the substrate at that particular location, are assessed and assigned into a particular land cover type. Unsupervised classification techniques allow the computer to partition the image into a user-defined number of classes, known as spectral clusters, without any a priori knowledge of what types of habitats occur. Supervised classification techniques allow the user to define spectral characteristics of known areas of land cover types for the computer to compare to remaining pixels for determination of land cover. Both unsupervised and supervised routines were used to classify the images into four land cover types including open canopy (mostly range and agricultural areas), closed canopy (mostly scrub), barren/urban, and water. Several attempts were made to classify pixels into one of the four land cover types. Each attempt included an initial unsupervised classification routine where 60 classes were determined by IMAGINE (ERDAS, 1997), and each of these 60 classes were assigned to one of the four land cover types. After assessing the accuracy of this attempt, classification was further revised by recoding any classes that were confused and running supervised (with areas of known habitat) classification and unsupervised classification methods. The classification was continually refined until an acceptable accuracy was attained.

Accuracy assessment

After classifying the images, an accuracy assessment was performed using aerial photographs (September 28, 1993) archived at TNRIS (Texas Natural Resources Information System) for the 1991 image and Digital Orthophoto Quadrangles (DOQs, January 15, 1995) provided by TNRIS for the 2000 image. Personnel at Willacy and Cameron Natural Resources Conservation Service offices indicated that the 1995 aerial photos should adequately reflect land cover during 2000. A minimum of 204 reference points should be assessed when the expected accuracy is 85% at an allowable error of 5% (Jensen, 1996). Congalton (1991) suggested the collection of at least 50 reference points per land cover class when calculating an error matrix. A stratified random sampling technique was employed to locate approximately 50 reference points in each land cover class. The land cover was determined from aerial photos and/or DOQs for each of these random points and entered into the accuracy assessment function of IMAGINE 8.4. The minimum level of accuracy acceptable for land use and land cover classification is 85% (Anderson et al., 1976).

Four types of accuracy were assessed for each image. Overall accuracy is the number of correctly identified pixels divided by the number of pixels in the error matrix.

Producer's accuracy (errors of omission) is the probability that a reference pixel is correctly classified and is calculated by dividing the number of correctly classified pixels in each category by the total number of reference pixels for that category. This is a measure of how well the producer classified a particular land cover (Jensen, 1996). User's accuracy (errors of commission) is the probability that a pixel classified on the map actually represents that category on the ground and is calculated by dividing the number of correctly classified pixels in each category by the total number of pixels classified in that category. This is a measure of how accurately the map reflects land cover. Kappa analysis yields a k_{hat} statistic that measures overall accuracy by incorporating errors of omission and commission (Jensen, 1996). The k_{hat} statistic is a measure of the agreement between image data and reference data, and ranges from zero (no association) to one (full association, or perfect agreement). If a negative value is calculated, a less than chance agreement is signified (Corsi, et. al., 2000). After an acceptable level of accuracy was obtained, change in land cover was assessed between the two images.

Change Detection

The change detection wizard extension written for IMAGINE 8.4 by John Esposito was used to perform a change detection analysis. This extension created an image that had pixel values that reflect both the original land cover (1991) and the present (2000) land cover. A map reflecting important change, emergence of new closed canopy, loss of closed canopy, and emergence of new barren/urban areas was created.

Results

Accuracy Assessment

Thematic maps depicting four land cover types were created for August 1991 and August 2000 (Fig. 2.1 and Fig. 2.2). Referenced and classified totals can be found in Appendix A. The 2000 image contained pixels that were either cloud or shadow, whereas these two cover types were unknown in the 1991 image. Overall accuracy rates of 88.10% for 1991 and 86.62% for 2000 images were achieved. Users accuracy (errors of commission) ranged from 100% for water for both years, to 70% for urban/barren in 2000 (Table 2.1 and Table 2.2). Producer's accuracy (errors of omission) ranged from 97% for water in 2000 to 75% for urban/barren in 1991. Kappa statistics ranged from 1.0 (both years) to 0.65 (2000).

Table 2.1 Errors of omission (Producer's Accuracy) and commission (User's Accuracy) and Kappa statistics for classification of 1991 Landsat TM image. Overall accuracy was 88.10%.

	Producer's Accuracy	User's Accuracy	Kappa Statistics
water	96.83%	100%	1
closed canopy	86.36%	74.51%	0.6912
open canopy	90.11%	91.11%	0.8609
barren/urban	75.93%	82.00%	0.7709

Figure 2.1 Classified image of Willacy and Cameron counties from Landsat Thematic Mapper imagery taken in August, 1991.

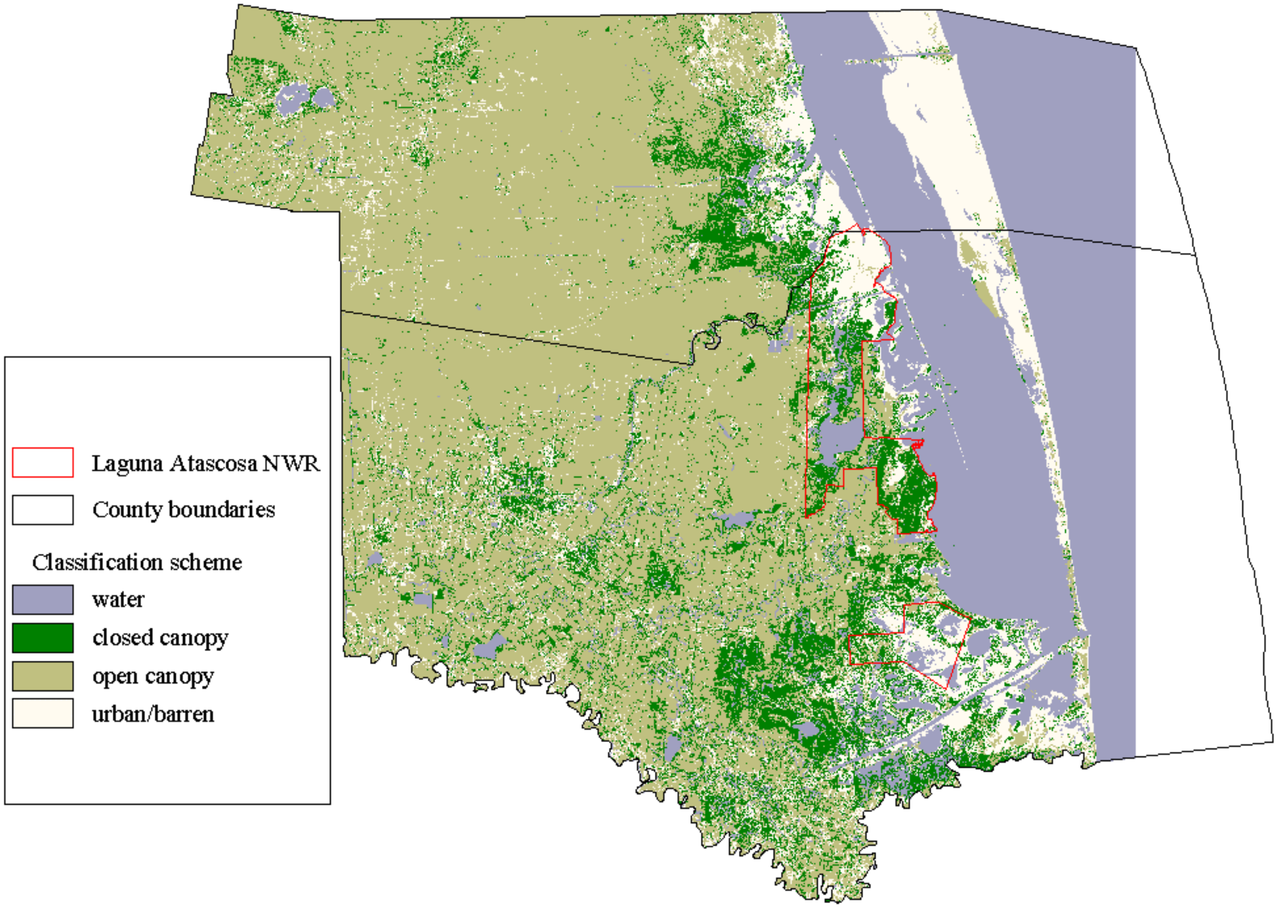


Figure 2.2 Classified image of Willacy and Cameron counties from Landsat Thematic Mapper imagery taken in August, 2000.

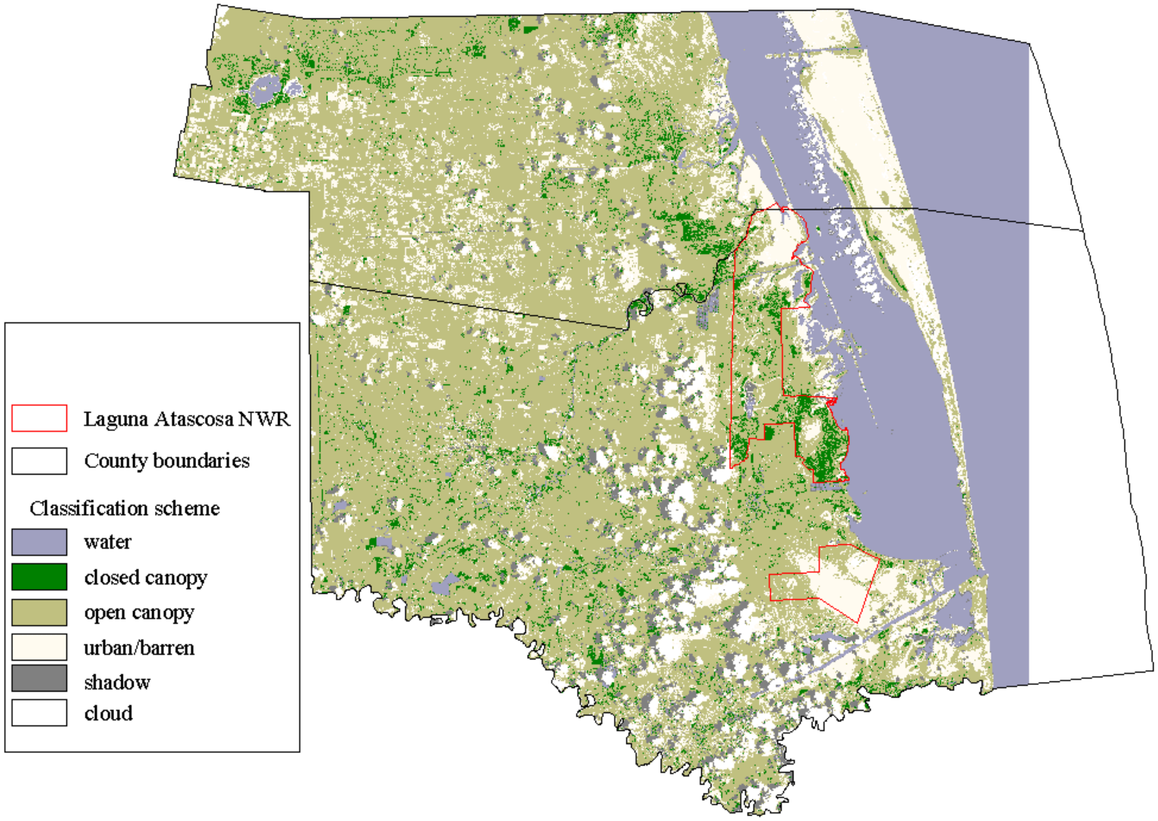


Table 2.2 Errors of omission (Producer's Accuracy) and commission (User's Accuracy) and Kappa statistics for classification of 2000 Landsat TM image. Overall accuracy for was 86.62%.

	Producer's Accuracy	User's Accuracy	Kappa Statistics
water	97.14%	100.00%	1
closed canopy	92.98%	77.94%	0.7305
open canopy	81.69%	90.63%	0.8289
barren/urban	77.78%	70.00%	0.6498

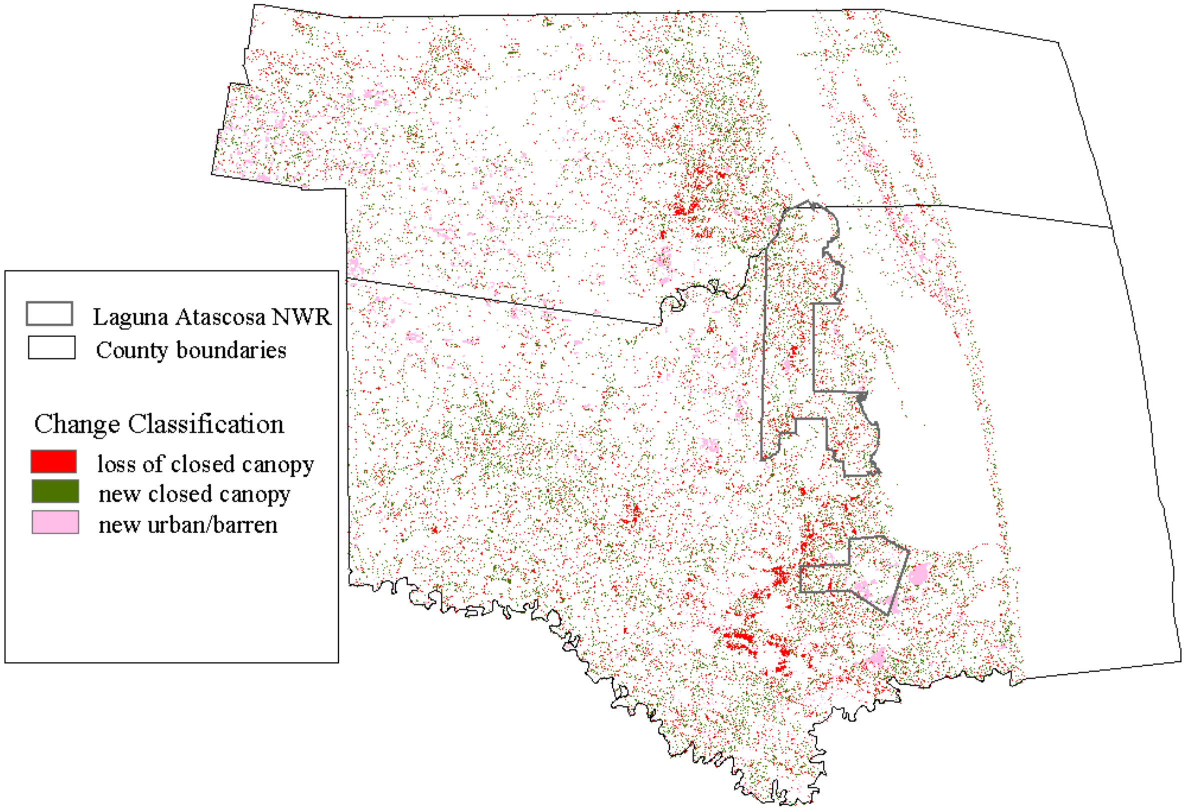
Change Detection

A change detection matrix was created for the classified images for August 1991 and August 2000 (Table 2.3). Raw numbers are available in Appendix B. A map illustrating types of land cover change was also created (Fig.2.3). Changes from open canopy to the other land cover types (including cloud and shadow) and from the other land cover types to open canopy accounted for the greatest proportion of change, 35% and 44% respectively. Seventy-seven percent of the change in closed canopy resulted in open canopy.

Table 2.3 Change detection matrix for Landsat TM Images from August 1991 and August 2000. Numbers indicate the percentage of changed pixels from one class in 1991 to another in 2000.

		2000				
		water	closed canopy	open canopy	barren/urban	cloud/shadow
1991	water	0.00%	7.06%	31.08%	27.91%	33.95%
	closed canopy	0.12%	0.00%	76.79%	8.39%	14.70%
	open canopy	0.36%	18.27%	0.00%	52.93%	28.44%
	barren/urban	1.50%	2.00%	80.64%	0.00%	15.87%
	cloud/shadow	0.00%	0.00%	0.00%	0.00%	0.00%

Figure 2.3 Addition and loss of closed canopy and addition of urban/barren land cover types between August 1991 and August 2000 for Cameron and Willacy counties, Texas.



Conclusion

The overall accuracy of classification of both satellite images was greater than the 85% minimum suggested by Anderson et. al. (1976). User's accuracy for several of the categories was affected by the change in time between reference ancillary data (the month the aerial photos were taken) and satellite orbit. Changes in water level would certainly affect the proportion of water and barren mudflats visible at any certain time. The growing vegetation and the amount of canopy cover would also change between dates.

Classification of an image is dependent upon the ability to detect the differences in reflected and emitted electromagnetic energy among different land covers. This may be difficult when land covers have similar composition and thus similar patterns of electromagnetic reflection and emittance. Mixed pixels, i.e., pixels containing a variety of land cover types, are difficult to classify accurately. Glennon and Porter (1991) used mid-June TM imagery from 1986 and 1993 to create land cover maps with seven categories of land cover. Their overall accuracy was 83.7% and 84.6% (1986 and 1993 respectively), which they attributed to the subtle differences in land cover types.

Another factor suggested by Glennon and Porter (1991) creating error in their classification was that disked fields become highly reflective and resembled developed or barren land as the soil dries. A factor that may have caused confusion between closed canopy and open canopy in this study is the difference between growth stages of crops. Some crops, i.e., milo and sorghum, grown in the area can grow in dense stands before harvest. The most important crops grown in south Texas, corn, sorghum, and cotton, are harvested in August (Enrique Perez, Cameron County Texas Cooperative Extension, pers. comm.). These crops could have classified as closed canopy if fully grown, but not harvested, or barren/urban if newly harvested and disked.

The impacts of patch size and land cover heterogeneity on classification accuracy were assessed by Smith et. al. (2002) and were determined to be detrimental. An increase in heterogeneity of land cover decreased classification accuracy. Accuracy of classification increases with increasing size of patches (Smith et. al., 2002). This study site had a large degree of patchiness (Chapter 4), especially within the closed canopy cover type. This may have contributed to a lower degree of accuracy in classifying closed canopy as opposed to water, which had relatively large, homogeneous patches.

Change between the 1991 image and the 2000 image can be explained in part by the inherent nature of coastal areas to undergo change in land cover. Changes from water to barren and vice versa can be explained by the change in water depth. Annual precipitation in 1991 was 32.31 in whereas annual precipitation in 2000 was 16.88 in. This difference in rainfall is clearly seen in the amount of exposed land in 2000 that was covered by water in 1991. Areas of land close to bodies of water may show expanses of thick vegetation during beneficial weather, but as water dries up, vegetation could die and disappear. Of greatest concern is the apparent loss of closed canopy land cover and its change to open canopy. Nearly 77% of the change in closed canopy resulted in open canopy. Further investigation is needed to understand whether this is an indication of the true amount of habitat loss or classification error.

New classification routines that can tease apart reflectance patterns into a more detailed set of land cover classes is essential for any continuation of this research. The use of image enhancement techniques, such as Tasseled-cap or NDVI indices, may help gain more information about the particular components of the landscape. Agricultural crops and native Texas thorn scrub communities need to be identified accurately. An increase in field identification of land cover and less reliance on ancillary data is recommended.

CHAPTER 3

HOME RANGE AND RESOURCE UTILIZATION

Introduction

The scant information known about resource needs of ocelots has led to an inability for wildlife biologists to make knowledge-based decisions for conservation of this rare and endangered species. Several studies have attempted to reveal the habits of this secretive animal in south Texas (Tewes, 1986; Laack, 1991; Shindle, 1995). These studies focused on trapping techniques, home ranges, and activity patterns of ocelots on and around Laguna Atascosa National Wildlife Refuge. The aim of this research was to create a GIS database for data extraction concerning the resource requirements of a population of ocelots in south Texas. Ecological parameters of interest were developed through a review of all previous research on this population. The resource requirements were then used to form an ordinal model for prediction of suitable habitat in Cameron and Willacy counties, Texas.

Burt (1943:351) defines a mammal's home range as, "that area traversed by the individual in its normal activities of food gathering, mating, and caring for young. Occasional sallies outside the area, perhaps exploratory in nature, should not be considered part of the home range". Understanding a species' home range may provide, "significant insight into mating patterns and reproduction, social organization and interactions, foraging and food choices, limiting resources, important components of habitat, and more" (Powell, 2000:74). Many species use "cognitive maps" of their home range that integrate contour maps of food resources, escape cover, travel routes, and possible mates' home ranges (Powell, 2000). These maps change over time as resources change, disappear, or develop, and, thus, home range determination is temporally limited. Interior patches of an animal's home range are often more important ecologically, because the edges are rarely used. The variability of estimating home range size is inherent in the fact that definite boundaries rarely exist (Powell, 2000).

It is important for biologists to identify resources used by animals and document the resource availability to gain knowledge of how that animal meets its requirements for survival (Manly et al., 1993). This is especially critical in efforts to preserve endangered species and manage exploited populations (Manly et al., 1993). Use is selective if resources are used disproportionately to their availability. "Preferred" resources are selected more often than expected, and "avoided" resources are used less often than expected. Habitat can be selected for discrete variables (vegetation present, aspect, etc.) or continuous variables (shrub density, distance to roads, etc.). GIS, combined with multivariate statistics, allows researchers to consider many different types of variables when studying habitat use (Erickson et al., 1998).

Materials and Methods

LOAS to triangulate bearings

Linda Laack (Wildlife Biologist, Laguna Atascosa National Wildlife Refuge) provided ocelot tracking data from January through December of 1991 and January through December of 2000. The data format included permanent station locations and respective bearings for 12 ocelots (seven males and five females) from 1991 and 12 ocelots (seven males and five females) from 2000 whose locations could be estimated.

LOAS (Ecological Software Solutions, 1999) software was used to convert bearings to point locations using best biangulation method. All data with at least two bearings could be used to estimate ocelot locations, and whenever more than two bearings were available, the two bearings that produced the smallest error ellipse were chosen. Error ellipses for each location estimate were calculated to determine which locations should be used in home range estimation.

According to White and Garrott (1990), data censoring, or the elimination of poor-quality bearings and/or location estimates, while almost universally used, is rarely explained in the methodology. Possible criteria for eliminating bearings or location estimates include confidence ellipse size larger than some arbitrary cutoff value, or the elimination of values that seem improbable (White and Garrott, 1990). Statistical analyses were performed on all error ellipse areas, and location estimates with an error ellipse greater than the 95% confidence interval were eliminated (1991: 3800 m^2 and 2000: 2800 m^2). While these cutoffs were arbitrary, the bulk of the data were retained, while bogus location estimates were eliminated. The remaining points were imported into ArcView as point shapefiles to estimate home range and resource selection.

ArcView Animal Movement (USGS) extension to calculate home range

Home ranges were estimated for ocelots with at least 20 locations (1991: three females and seven males; 2000: five females and four males). Several methodologies exist to determine home range size. For this study, the minimum convex polygon (MCP) and the adaptive kernel estimators were used to determine the area of each ocelot's home range. MCPs are constructed by connecting the outer locations of location data. Advantages in using this method include simplicity, flexibility of shape, and ease of calculation (White and Garrott, 1990). Home range size is greatly affected by the number of locations when using this methodology, and comparisons cannot be made without taking this into consideration. A major assumption of the MCP estimator is that all locations are statistically independent and should not be time correlated (White and Garrott, 1990). The simplicity of this methodology has made it popular, and it is included for comparisons with other research.

The kernel estimator is a nonparametric method that utilizes a probability density function to calculate UD (utilization distribution), or the distribution of an animal's position on a plane (Worton, 1989). Worton (1989) describes the kernel estimator as follows:

> A scaled-down probability density function, namely the kernel, is placed over each data point and the estimator is constructed by adding the n components. Thus, where there is a concentration of points the kernel estimate has a higher density than where there are few points. Because each kernel is a density the resulting estimate is a true probability function itself.

Seamen and Powell (1998) showed the kernel estimator depicted size, shape, and internal structure of home ranges more accurately than other estimators. Anderson (1982) explains how the use of MAP (0.50), or the 50% kernel estimator, is superior to other estimators because of its disregard for the effects of outliers. An ArcView extension, Animal Movement (Hooge and Eichenlaub, 1997), was utilized to create shapefiles depicting MCP and kernel home ranges for each ocelot.

To determine the area available to all members of the population, all location estimates from 1991 were pooled and the MCP estimator was used to create a polygon (population MCP). Traditionally, Chi square or Log-likelihood tests have been used to determine whether individuals of a population utilize resources at similar proportions to availability (Otis, 1997). Proportion of land cover and soil type available to ocelots was determined by the proportion in population MCP.

Resource Utilization

Through an extensive literature review, the following habitat parameters were identified as important to ocelot ecology: proximity to human disturbance, roads, and water; and the presence of certain soil types and vegetative cover. A thematic map representing each of these parameters was assembled and added to a GIS database. This GIS database was used to estimate resource utilization of ocelots.

Proximity to human disturbance was estimated by distance to closest city (m to edge) and human population density (number of people per km^2). Data from U. S. Census Tiger files were manipulated for information regarding human population and city boundaries. GRIDs were made reflecting human population density, and vector shapefiles were created outlining city boundaries. Thematic maps depicting roads and hydrology were obtained from TNRIS and manipulated to create a GRID reflecting road density and vector shapefiles of roads and hydrology.

Soil Survey Geographic (SSURGO) data were downloaded from the Natural Resources Conservation Service (NRCS) and manipulated to create a polygon coverage indicating soil types. This polygon coverage was exported from ARCINFO to ArcView for analysis. GRIDs reflecting vegetation cover were created from Landsat TM images for both years (see Chapter 1).

To determine the soil, land cover, human density, and road density present at each ocelot location, an extension for ArcView 3.2, getGridValue21.avx (Jeremy Davies, 2000), was used to determine GRID cell values at each point. Nearest Features 3.5 (Jenness Enterprises, 2000) was used to determine the distance from each point to the nearest edge of the closest city, road, and water body. These extensions for ArcView 3.2 were made available by ESRI.

Statistics

Two types of habitat parameters were evaluated: discrete variables, including land cover and soil types; and continuous variables, including human population density, road density, distance to closest roads, distance to closest city, and distance to closest water body. Log-likelihood Goodness-of-Fit tests were used to determine if ocelots were selecting land cover types and soil types disproportionately to abundance. Where observed use of a land cover type or soil was significantly different from expected, Log-likelihood tests were subset to examine patterns of preference and avoidance. A Log-likelihood Contingency test was used to determine if land cover was contingent upon soil type.

The Shapiro-Wilks test was used to test for normality for all continuous data sets to determine whether parametric or nonparametric statistical analyses were most valid. As a result of the lack of normality and homoscedasticity in most of the datasets, and to retain some consistency in analytical procedures, nonparametric tests were used to assess whether significant differences existed among the estimated locations of ocelots (as a whole, between years, and between sexes) as well as among estimated locations of ocelots, randomly distributed locations within entire study site, and randomly distributed locations within population MCP. The Mann-Whitney U-Test was used to assess differences between estimated locations of males vs. females and estimated locations of ocelots in 1991 vs. 2000. The Kruskal-Wallis test was used to determine if significant differences occurred among samples from each treatment (locations of ocelots, randomly selected points within the population MCP, and randomly selected points within entire study site). Where significant differences existed, further analyses using Student-Newman-Keuls test (a multiple comparison test) on ranked data was used to confirm exactly which datasets were significantly different.

Regression Analysis

Logistic regression is used when the dependent variable in a multiple regression equation is binary. It is also helpful when independent variables are of categorical nature (Miles and Shelvin, 2001). The value of the slope coefficient reflects the amount of change in the dependent variable associated with a change in the independent variable. Unlike linear regression, this change in the dependent variable is a change in log odds ratio, not absolute change (Miles and Shelvin, 2001). The Wald statistic is a reflection of the degree of influence any one of the variables in the equation has on the dependent variable (Hosmer and Lemeshow, 2000). Within population MCP, 762 estimated locations of ocelots from 1991 and 762 randomly located points were used in order to calculate a model based on logistic regression. Parameters of interest were: soil type and land cover present, human population density, road density, distance to closest city edge, distance to closest road, and distance to closest water body.

Results

Home Range

No significant difference between using MCP and 95% kernel home range estimators was detected, but the 50% kernel home range estimator computed significantly smaller home range areas (Kruskal-Wallis, $p<0.001$; Student-Newman-Keuls, $\alpha=0.05$). The minimum home range for all ocelots in both years computed using the MCP estimator was 0.53 km^2. Using the 95% kernel estimator, the minimum home range was 0.48 km^2, and the 50% kernel estimator yielded a minimum home range of 0.11 km^2. The maximum home range for all ocelots in both years determined by the MCP estimator was 36.6 km^2. Using the 95% kernel estimator, the maximum home range was 43.57 km^2, and using the 50% kernel estimator resulted in 6.56 km^2 (Table 3.1).

No significant difference existed between ocelot home ranges in 1991 and 2000 when using the kernel estimator (either 95% or 50%), however, a significant difference existed between 1991 and 2000 ocelot home ranges when using the MCP estimator (Mann-Whitney U Test, $p=0.022$). Mann-Whitney U tests revealed a significant difference in the home range sizes between males and females in 1991 ($p=0.017$), but no difference between male and female home range sizes in 2000 when the MCP estimator was used. When the kernel estimator was used (both 95% and 50%), a significant difference existed between male and female home ranges in 2000 ($p=0.016$ for both 95% and 50%), but no difference was found between male and female home range sizes in 1991. When both years were combined, significant differences existed between both males and females using all three estimators ($p=0.001$).

Table 3.1 Home range size (km^2) of ocelots at Laguna Atascosa National Wildlife Refuge for 1991 and 2000 using Minimum Convex Polygon (MCP), 95% kernel, and 50% kernel estimators

CatId	Year	Sex	N	MCP	95% kernel	50% kernel
F151	1991	Female	76	5.90	1.73	0.34
F158	1991	Female	94	6.52	1.15	0.28
F172*	1991	Female	60	2.33	3.39	0.46
M100	1991	Male	84	9.96	9.21	0.83
M132	1991	Male	81	15.99	5.43	0.76
M147	1991	Male	75	26.55	6.58	1.45
M165	1991	Male	75	36.60	3.36	1.02
M170	1991	Male	75	28.66	8.98	1.20
M174	1991	Male	91	7.61	1.71	0.31
M175*	1991	Male	43	30.89	43.57	6.56
F223	2000	Female	58	3.61	2.71	0.35
F228	2000	Female	61	5.22	1.90	0.34
F230	2000	Female	49	1.41	1.95	0.27
F235	2000	Female	49	0.53	0.49	0.11
F236	2000	Female	35	1.10	0.80	0.14
M192	2000	Male	57	3.37	3.96	0.37
M217	2000	Male	18	9.60	20.84	4.52

CatId	Year	Sex	N	MCP	95% kernel	50% kernel
M224	2000	Male	41	31.89	23.81	4.14
M237	2000	Male	25	5.14	5.61	1.03

* indicates subadult status

Table 3.2 The mean home range size (SD) of ocelots at Laguna Atascosa National Wildlife Refuge for 1991 and 2000 using Minimum Convex Polygon (MCP), 95% kernel, and 50% kernel estimators

	MCP km^2	95% kernel km^2	50% kernel km^2
Both years	11.64 (12.14)	7.36 (10.78)	1.22 (1.77)
1991	17.10 (12.43)	8.51 (12.66)	1.32 (1.88)
2000	6.87 (9.78)	6.90 (8.91)	1.25 (1.77)
Male 1991	22.32 (11.14)	11.26 (14.51)	1.74 (2.15)
Female 1991	4.92 (2.26)	2.09 (1.66)	0.36 (0.09)
Male 2000	12.50 (13.19)	13.55 (10.22)	2.51 (2.12)
Female 2000	2.37 (1.97)	1.57 (0.91)	0.24 (0.11)

Fig. 3.1 Home ranges of ocelot F151 at Laguna Atascosa NWR depicting MCP, 95% kernel, and 50% kernel estimations.

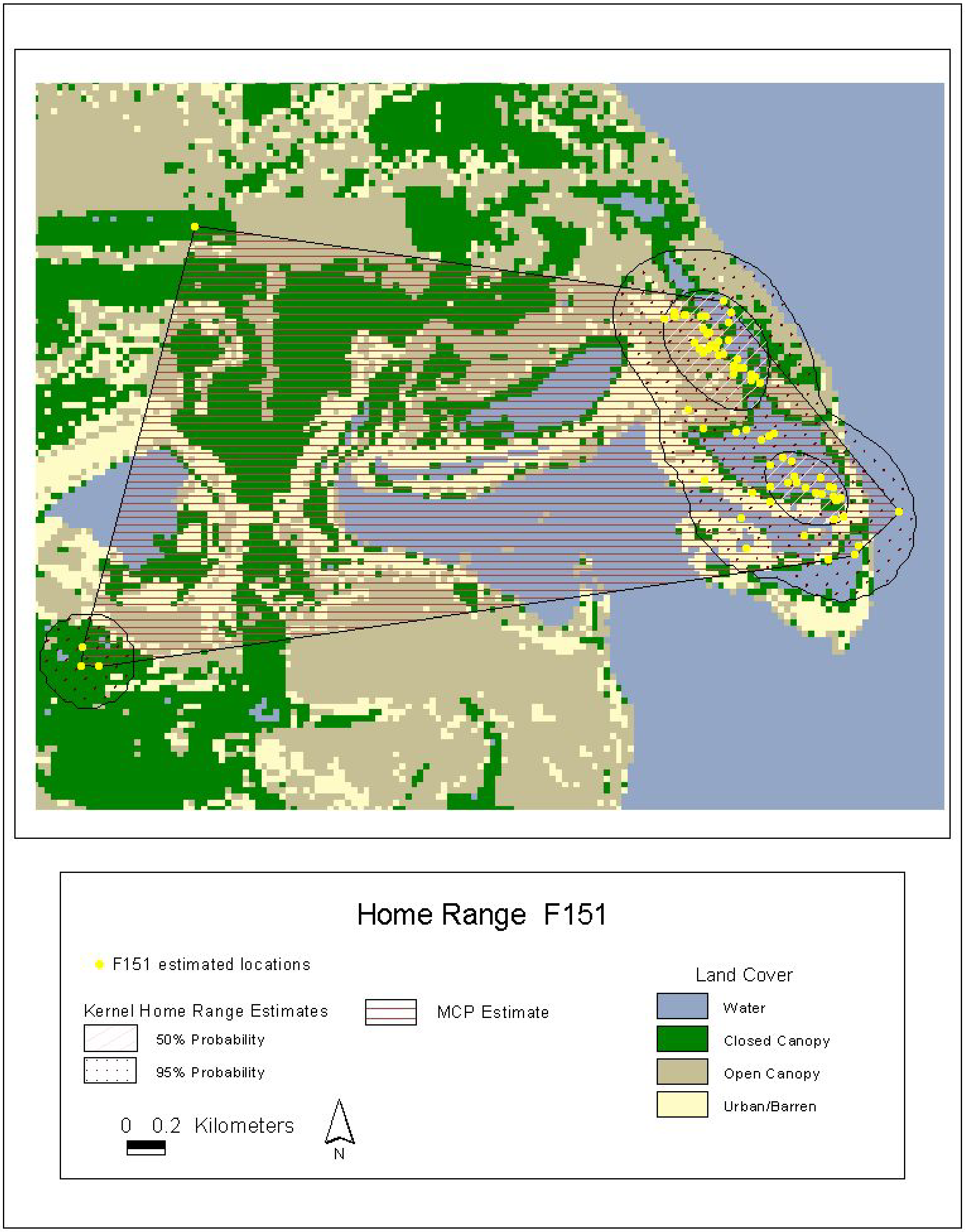


Fig. 3.2 Home ranges of ocelot F158 at Laguna Atascosa NWR depicting MCP, 95% kernel, and 50% kernel estimations.

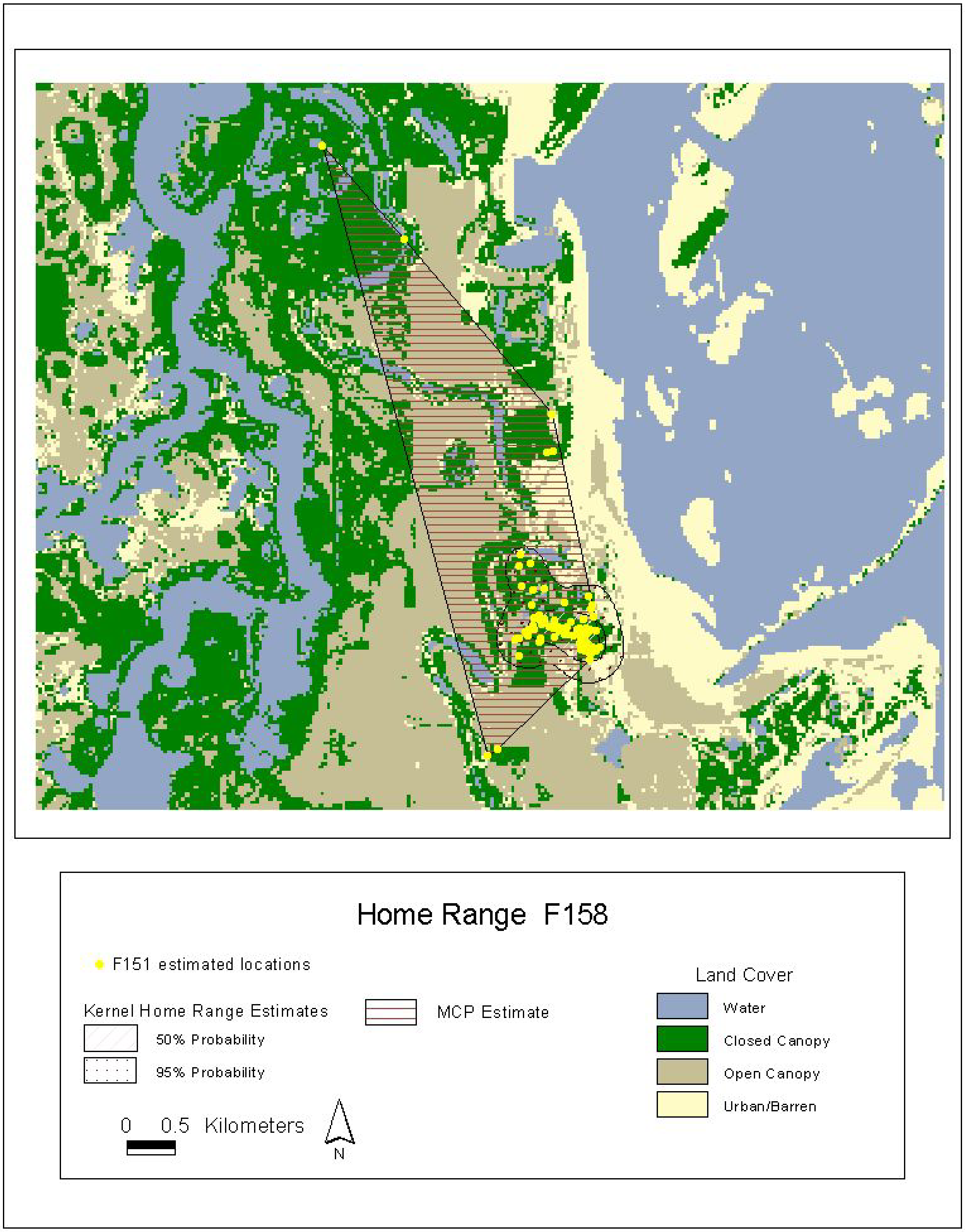


Fig. 3.3 Home ranges of ocelot F172 at Laguna Atascosa NWR depicting MCP, 95% kernel, and 50% kernel estimations.

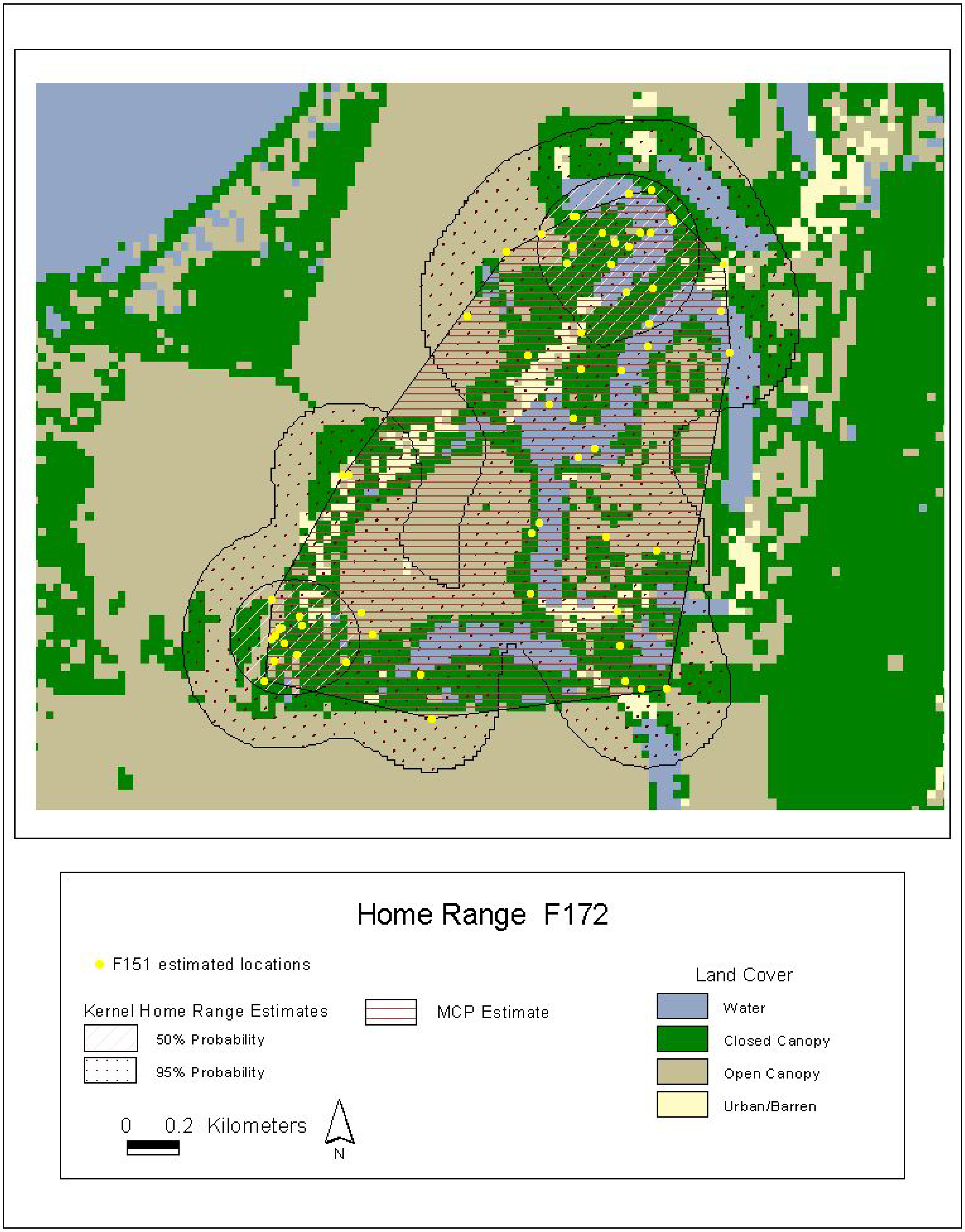


Fig. 3.4 Home ranges of ocelot M100 at Laguna Atascosa NWR depicting MCP, 95% kernel, and 50% kernel estimations.

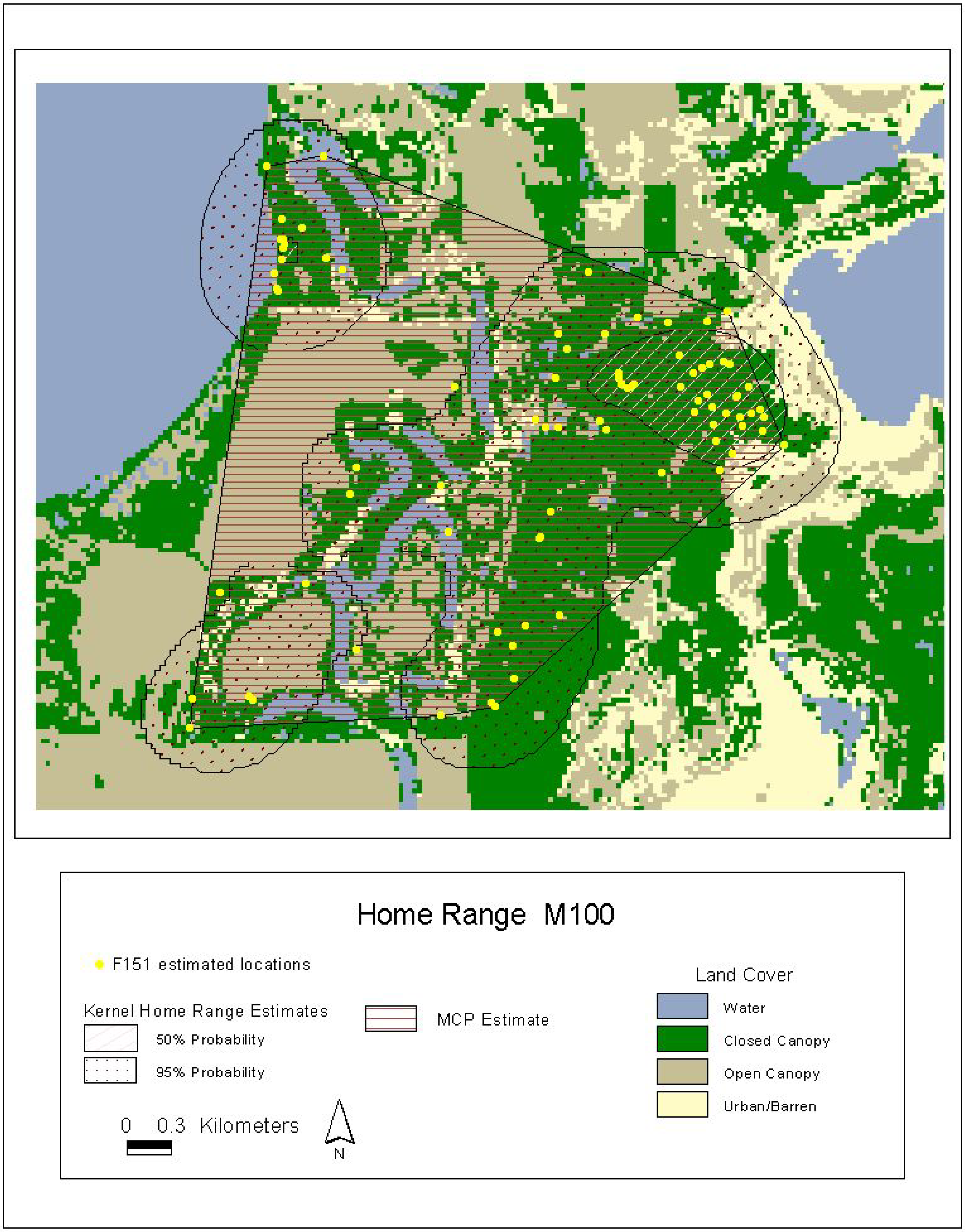


Fig. 3.5 Home ranges of ocelot M132 at Laguna Atascosa NWR depicting MCP, 95% kernel, and 50% kernel estimations.

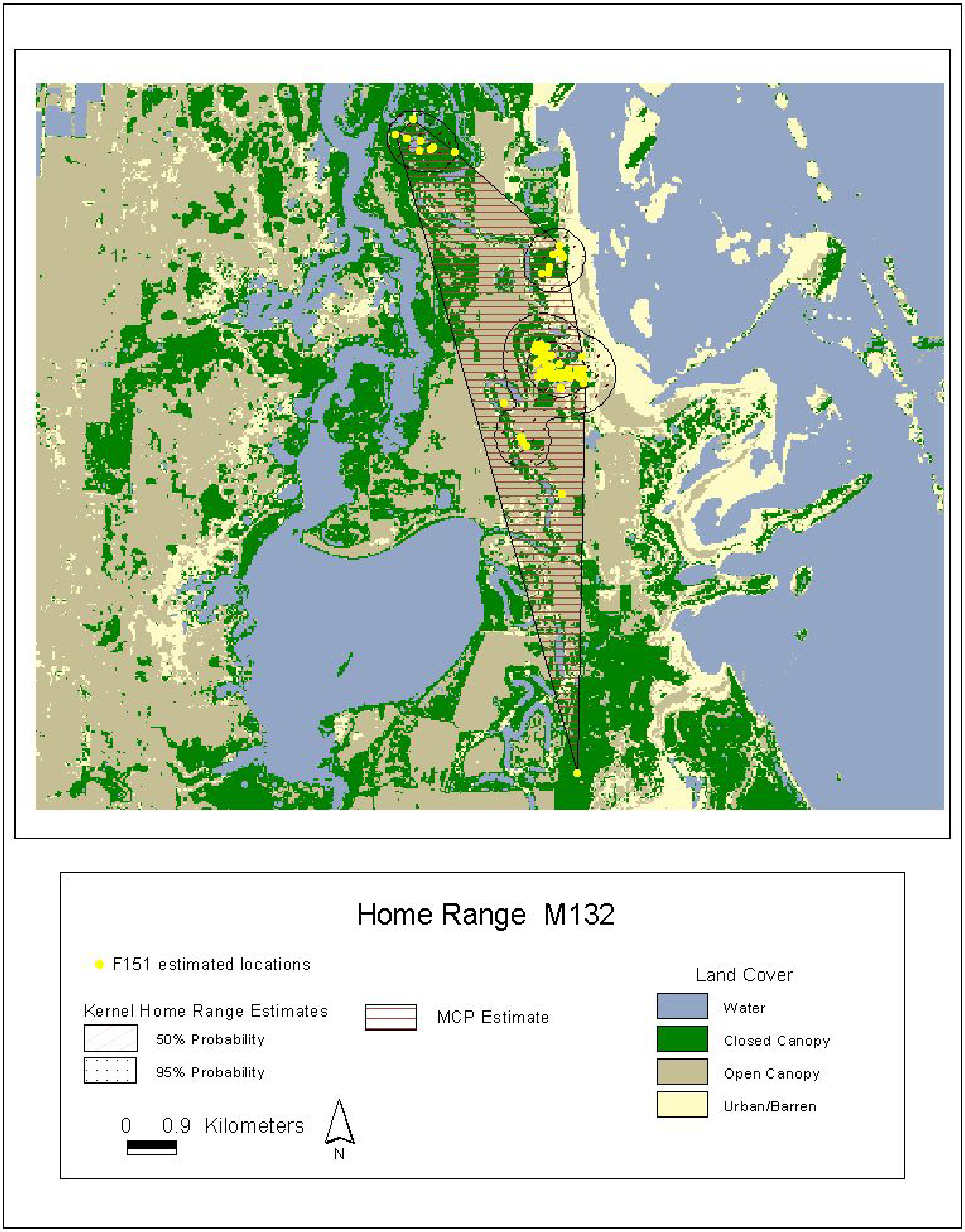


Fig. 3.6 Home ranges of ocelot M147 at Laguna Atascosa NWR depicting MCP, 95% kernel, and 50% kernel estimations.

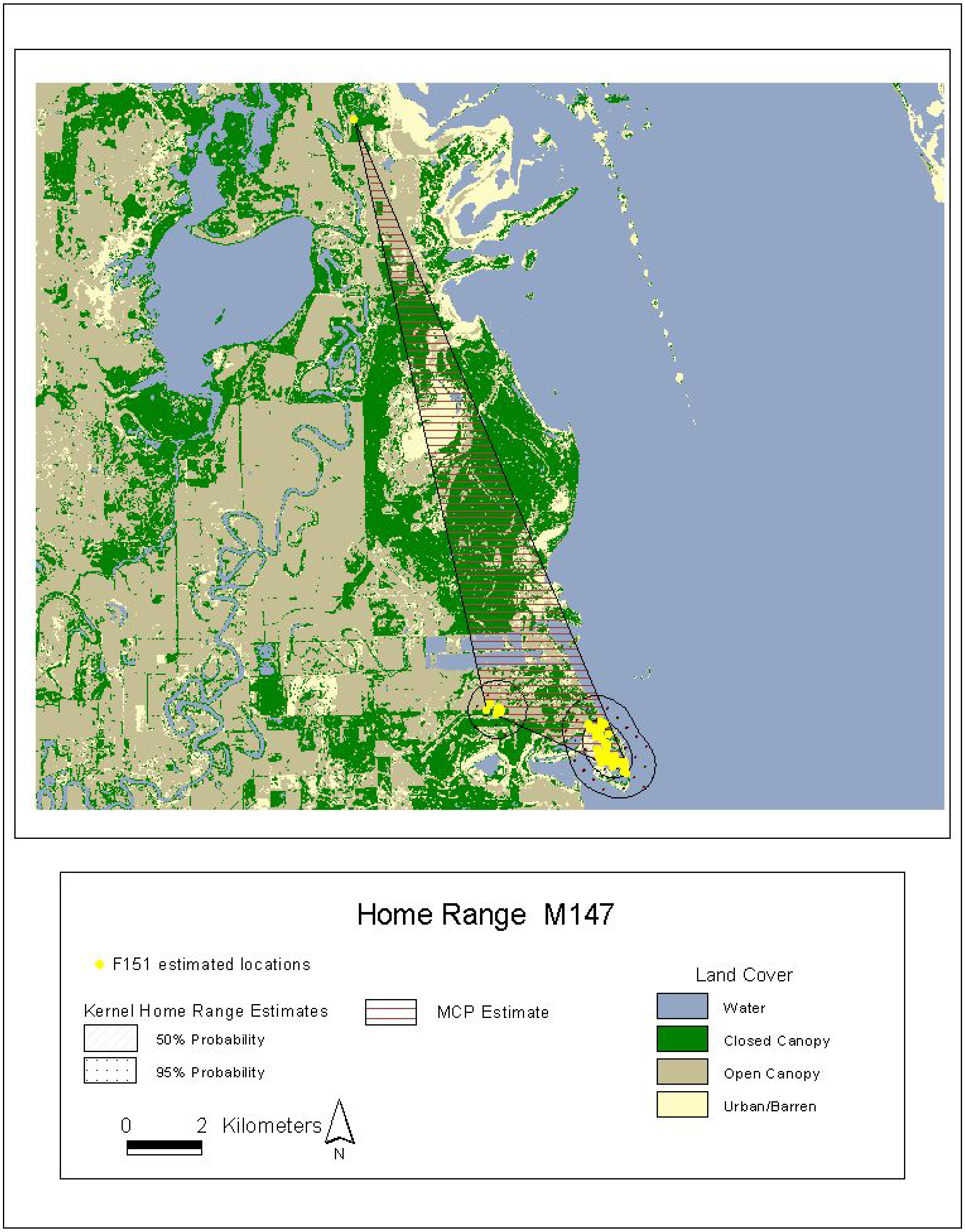


Fig. 3.7 Home ranges of ocelot M165 at Laguna Atascosa NWR depicting MCP, 95% kernel, and 50% kernel estimations.

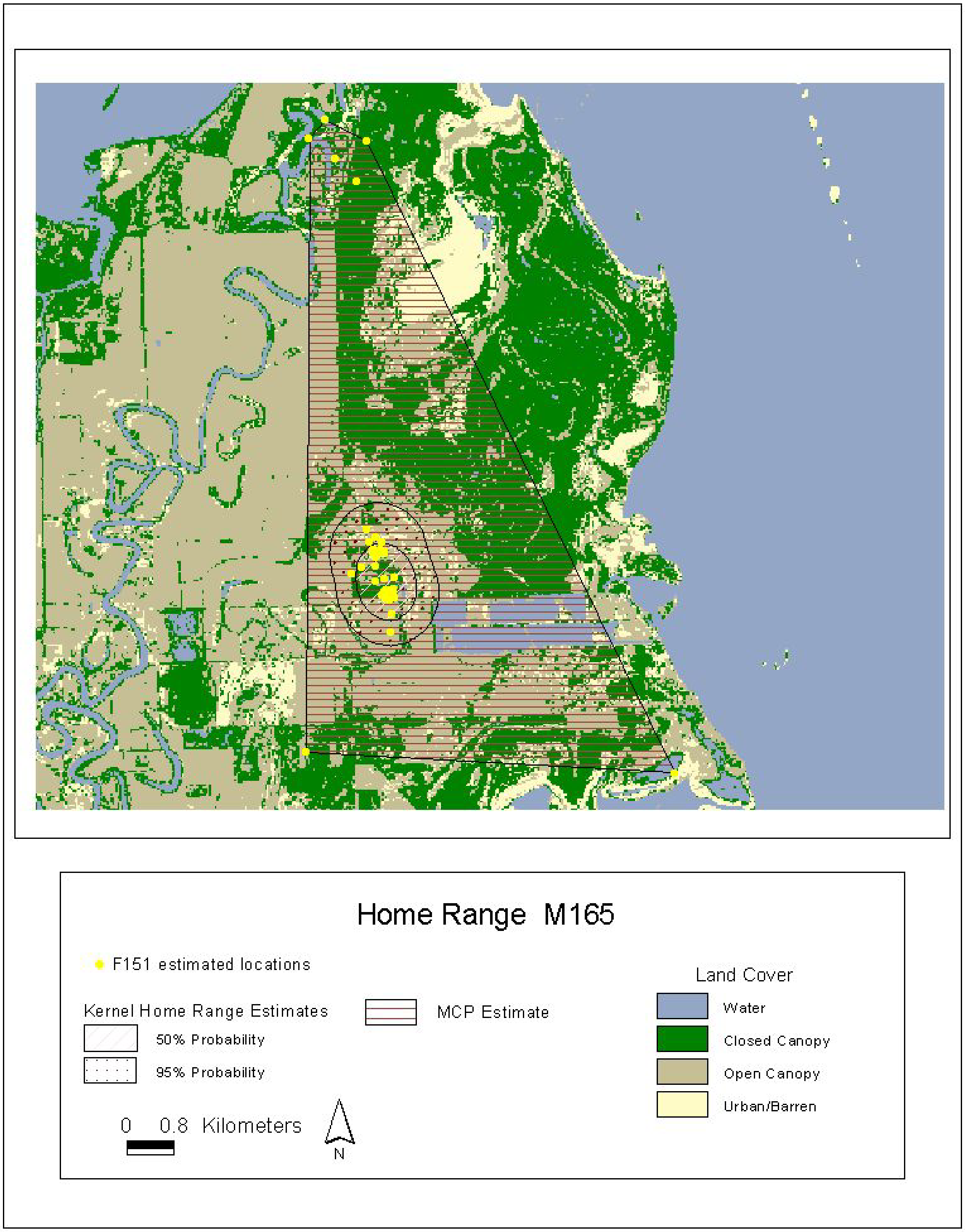


Fig. 3.8 Home ranges of ocelot M170 at Laguna Atascosa NWR depicting MCP, 95% kernel, and 50% kernel estimations.

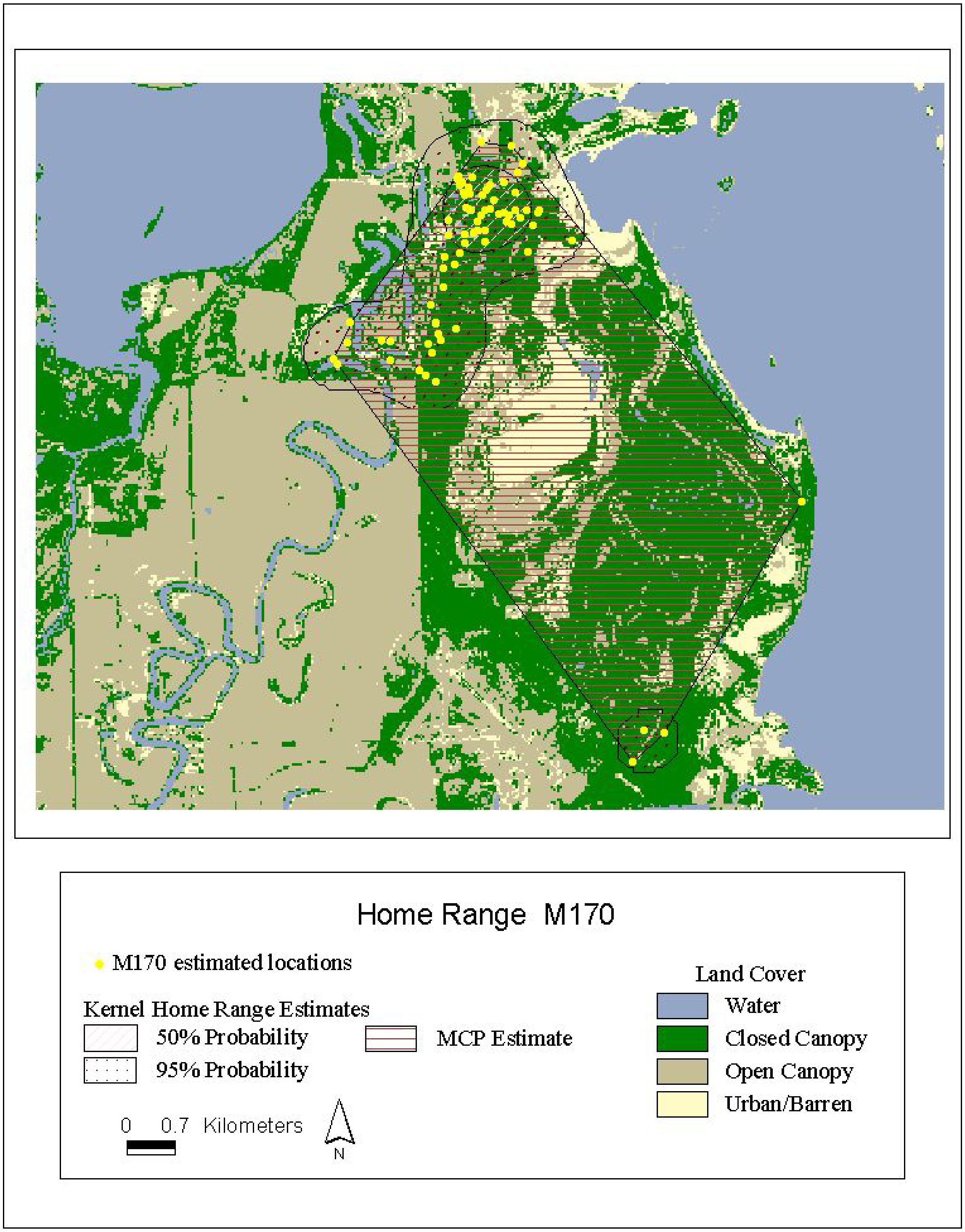


Fig. 3.9 Home ranges of ocelot M174 at Laguna Atascosa NWR depicting MCP, 95% kernel, and 50% kernel estimations.

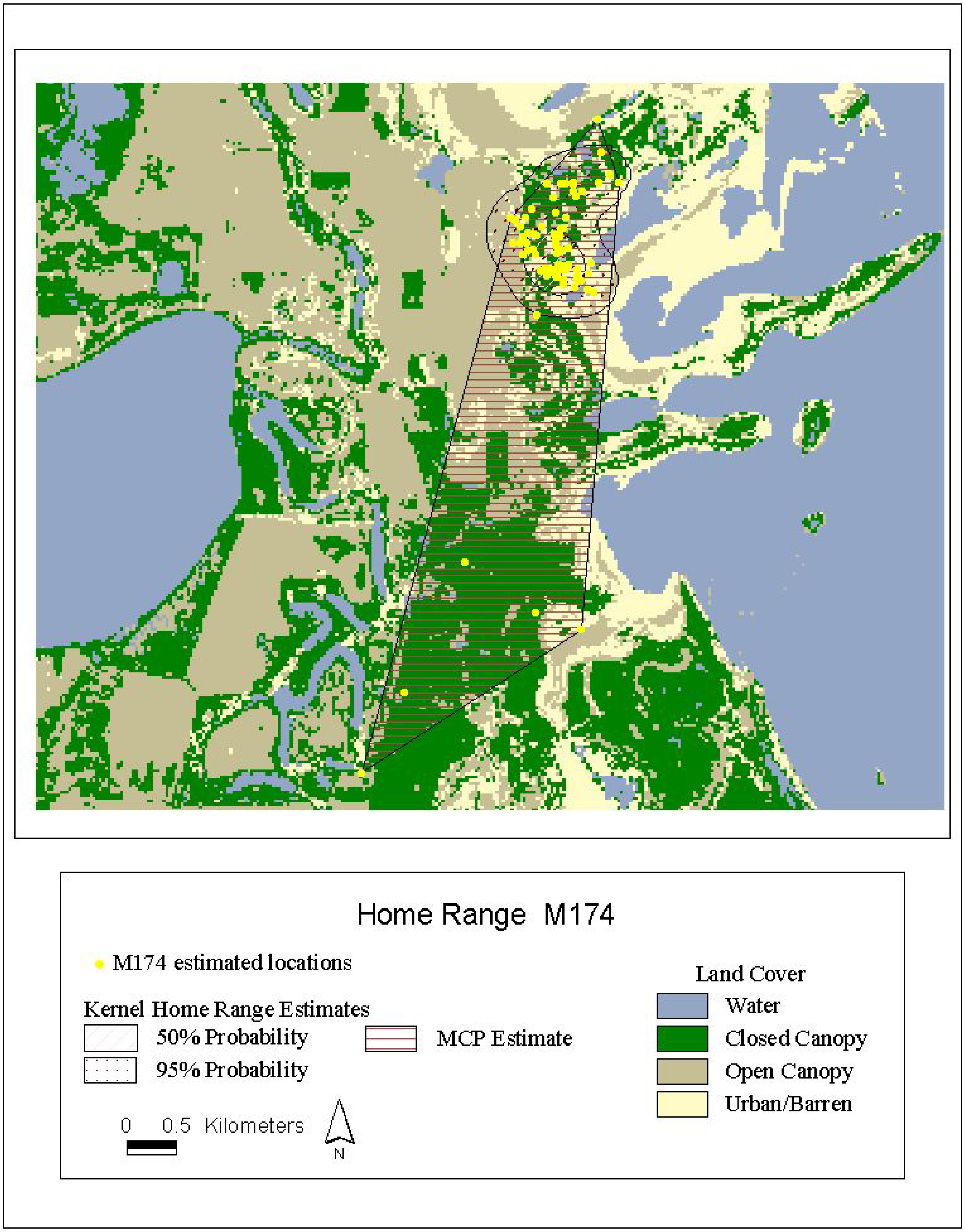
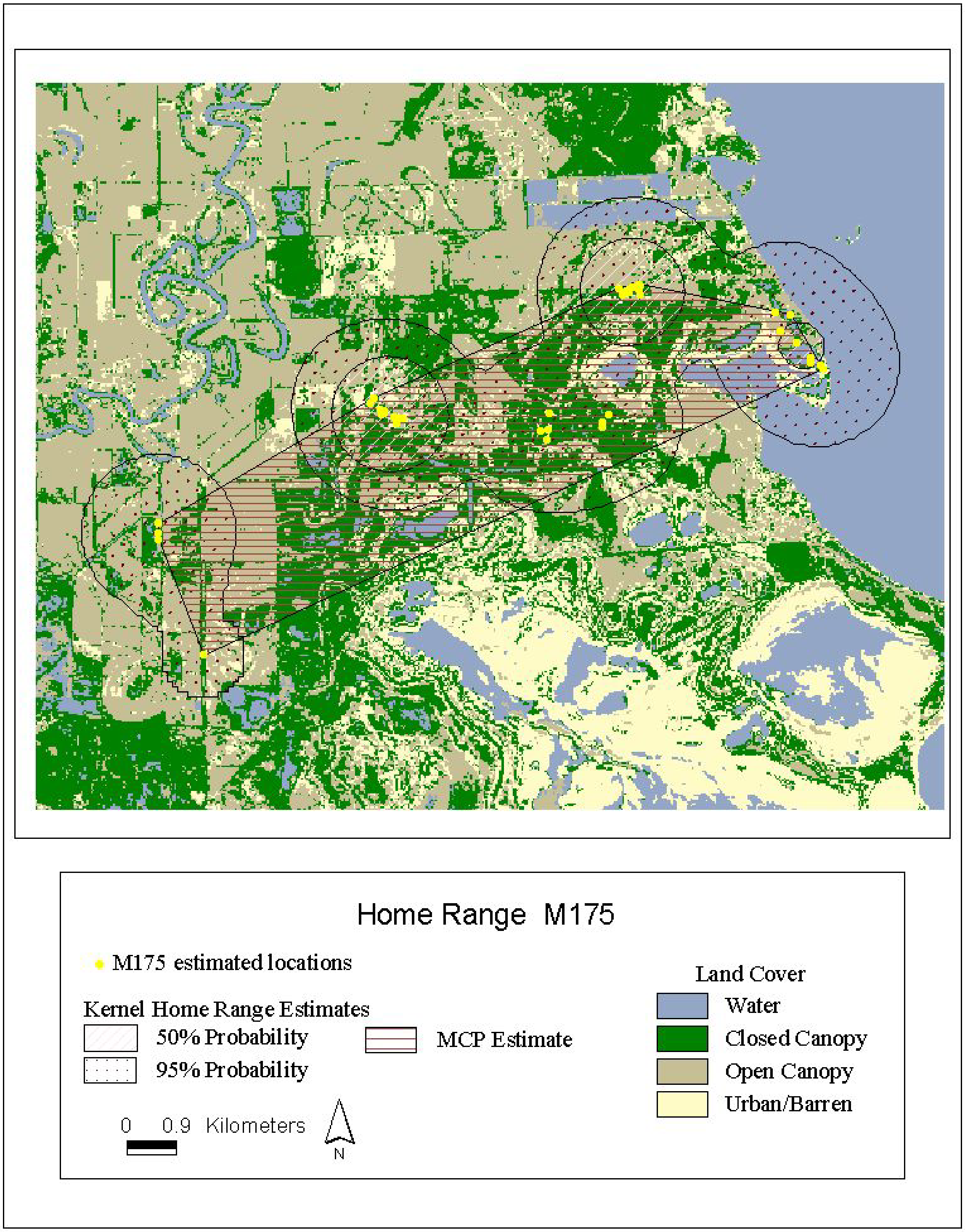


Fig. 3.10 Home ranges of ocelot M175 at Laguna Atascosa NWR depicting MCP, 95% kernel, and 50% kernel estimations.



The core areas of each ocelot's home range, represented by the 50% kernel estimation of home range, had significantly different amounts of each type of land cover (Kruskal-Wallis, Arcsine transformation, $p<0.001$). Student-Newman-Keuls tests of ranked transformed percentages of each land cover type revealed a significant difference between the amount of closed canopy present in core areas and the amount of other types of land cover ($\alpha=0.05$). The composition of each ocelot's core home range is reported in Table 3.3. The mean percentage of core area composed of closed canopy was 54%,

Table 3.3 Percentages of each land cover within the 50% kernel estimation of home

	water	closed canopy	open canopy	barren/urban
F151	40.43%	19.41%	31.91%	8.24%
F158	0.97%	82.20%	13.59%	3.24%
F172*	21.94%	61.36%	13.79%	2.91%
M100	0.00%	90.72%	4.21%	5.07%
M132	4.03%	60.29%	30.20%	5.48%
M147	37.15%	15.36%	24.52%	22.97%
M165	1.86%	37.09%	54.30%	6.74%
M170	2.54%	85.96%	11.20%	0.30%
M174	0.57%	45.85%	11.75%	41.83%
M175*	3.71%	39.08%	45.68%	11.52%
Mean	11.32%	53.73%	24.12%	10.83%

* indicates subadult status

nearly twice as much as the second largest component, open canopy. On average 24.12 % of core areas were composed of open canopy and urban/barren and water accounted for only 10.83% and 11.32% respectively.

Resource Utilization

Selection occurred for soil type (Log-likelihood Goodness-of-Fit test, $G=4103$, $p<<0.001$) and land cover (Log-likelihood Goodness-of-Fit test, $G=1309$, $p<<0.001$). Eight out of nine ocelots preferred closed canopy (Log-likelihood Goodness-of-Fit test, $p<0.005$), and all nine ocelots avoided open canopy (Log-likelihood Goodness-of-Fit test, $p<0.001$). Five ocelots neither preferred nor avoided barren/urban areas, while two ocelots preferred this habitat (Log-likelihood Goodness-of-Fit test, $p<0.025$), and one cat avoided it (Log-likelihood Goodness-of-Fit test, $p<0.01$). According to land cover thematic maps, two ocelots were found to prefer water ($p<0.001$), five ocelots avoided water ($p<0.005$), and three cats showed no preference or avoidance.

No ocelots were found on the following soil types: Benito-urban, Camargo, Cameron, Delfina, Hidalgo, Laredo-Olmito, Laredo-Reynosa, Lomalta-urban, Lozano, Lyford, Mercedes, Olmito-urban, Orelia, Raymondville, Rio, Rio Grande, Tiocano, Udipsamments, Willacy, and Zalla. At least one ocelot was found to prefer the following soil types: Barrada, Benito, Chargo, Harlingen, Laredo, Laredo-urban, Latina, Lomalta, Olmito, Point Isabel, and Wilamar. According to the soils data, all ocelots avoided water. No selection (preference or avoidance) occurred for any other soil type.

Descriptive statistics for ocelot locations and randomly located points are listed in Table 3.4. The effects of human disturbance on ocelots were measured by human density associated with ocelot locations and the distance from ocelot locations to the nearest city.

Both parameters were found to be significant among individuals of the 1991 population (Kruskal-Wallis test, $p<<0.001$). Student-Newman-Keuls ($\alpha=0.05$) tests of ranked data revealed that, for all ocelots, human population densities associated with locations were significantly different both from points randomly located throughout the study site and points randomly located within population MCP. The maximum human density associated with ocelot locations was 53 people per km^2, the maximum human density associated with randomly located points within population MCP was 62 people per km^2, and the maximum density of people associated with randomly located points throughout the study site was 2077 people per km^2. For all but one ocelot (M175), the distances to nearest city were significantly different between ocelot locations and randomly located points throughout the study site and population MCP (Student-Newman-Keuls on ranked data, $\alpha=0.05$). The median distance to closest city to ocelot locations was 9.98 km, the median distance to randomly located points in population MCP was 8.91 km, and the median distance to randomly located points throughout the study site was 7823.6 km.

Significant differences existed among individuals from the 1991 population in regards to road density (Kruskal-Wallis test, $p<<0.001$). All ocelots except one (F172) had significantly different road densities than randomly located points in either population MCP or randomly located points throughout the study site (Student-Neuman-Keuls on ranked data, $\alpha=0.05$). The median road density associated with ocelot locations was higher than the median road density associated with randomly located points in both population MCP and the entire study site. Distance to closest road and distance to closest water body were found to be significantly different among the individuals of the 1991

Table 3.4 Descriptive statistics for each continuous ecological parameter. Data are reported for 762 points associated with ocelot locations, 762 randomly located points within Willacy and Cameron counties (random site), and 762 randomly located points within population MCP (random pop).

Parameter		Mean	Median	Minimum	Maximum
Human Density people per km^2	ocelot	11.17	0.22	0.00	53.00
	random pop	5.50	0.36	0.00	62.00
	random site	55.76	0.63	0.00	2077.00
Proximity to closest City (km)	ocelot	9.06	9.98	0.39	19.51
	random	8.64	8.91	0.00	19.42
	random site	11708.70	7823.60	0.00	45409.00
Road Density m per km^2	ocelot	0.004	0.004	0.00	0.01
	random	0.0016	0.00	0.00	0.01
	random site	0.0014	0.00	0.00	0.02
Proximity to closest Road (km)	ocelot	0.10	0.08	0.00	1.06
	random	0.29	0.19	0.00	1.79
	random site	3950.10	404.80	1.26	30685.10
Proximity to closest Water (km)	ocelot	0.56	0.34	0.00	2.45
	random	0.91	0.74	0.00	3.47
	random site	2569.10	774.10	0.27	16702.10

population (Kruskal-Wallis test, $p<<0.001$). Points associated with ocelot locations were significantly different from randomly located points throughout the study site and population MCP for all but one ocelot (M175 -- Student-Newman-Keuls on ranked data, $\alpha=0.05$) in distance to closest road. All but two ocelots (M170 and M175) had significantly different distances to nearest water body than randomly located points throughout study site and population MCP. The median distance to nearest road and the median distance to nearest water were shorter for ocelot locations than randomly located points in both population MCP and the entire study site.

Regression Analysis

The eighth step of a forward stepwise model yielded an equation that accurately predicted ocelot presence 88.5% of the time. This model was significantly better than chance alone at predicting ocelot presence (Likelihood Ratio, $p<<0.001$). The equation with B coefficients and Wald statistics are summarized in Table 3.5. All habitat parameters measured except road density contributed significantly to the model. The parameters with the greatest influence on ocelot presence, as indicated by their large Wald statistics, were soil (Wald = 223.652) and land cover (Wald = 88.457). The parameter with the least influence was distance to nearest water body (Wald = 25.354). Both human density and distance to nearest city had positive relationships with ocelot presence, and proximity to nearest road and water body had negative relationships to ocelot presence.

Table 3.5 Variables in the equation for predicting presence/absence of ocelots based on logistic regression. Beta coefficients, Wald statistics, and significance of each parameter are reported.

Variables	B	Wald	Sig.
Human Density	0.050	54.479	<<0.001
Distance to nearest City	0.0001	51.557	<<0.001
Distance to nearest Road	-0.006	78.967	<<0.001
Distance to nearest Water body	-0.001	25.354	<<0.001
Soil	*	223.652	<<0.001
Land cover	*	88.457	<<0.001
Constant	-3.806	0.460	0.498

* B values for soil and land cover are not reported because these numbers reflect the odds of certain categories in respect to reference categories and are meaningless in this context.

Conclusion

Home Range

There was no significant difference between using MCP and 95% kernel home range estimators, but the 50% kernel home range estimator computed significantly smaller home range areas. Home ranges were calculated for individuals with more than 20 locations. This may have decreased the influence that sample size has on home range estimates calculated using the MCP method. The major drawback to using the MCP estimator is the effect of sample size on area estimation. Regression analysis revealed no significant association between the number of locations used and the area calculated using the MCP estimator. The conservative nature of the 50% kernel method makes it appropriate for use in estimating core attributes of home ranges.

In 1986, Tewes reported an average home range size of 12.34 km^2 for adult male ocelots and 7.00 km^2 for adult females (Table 3.6). In the same area in 1991, Laack reported smaller average home range sizes of 6.25 km^2 for male ocelots and 2.87 km^2 for females (Table 3.6). Combining both 1991 and 2000 data, the average home range of males in this study was larger, 18.75 km^2, than previously reported. The average home range of females, 3.33 km^2, was consistent with previous studies. Ocelot home ranges from two other locations are provided in Table 3.6 for comparison. The variability of home range size of ocelots throughout their distribution is great. Factors influencing home range size include density of population, availability of resources, and methodology for calculating home range. Laack attributed the difference between home

Table 3.6 Comparisons of home ranges of ocelots in south Texas (Laack, Tewes, and Jackson), northeast Mexico (Caso), and South America (Crawshaw). Home ranges estimated using the Minimum Convex Polygon method are reported in km^2 and standard deviations from the mean are reported in parentheses.

	Laack		Tewes		Caso		Crawshaw		Jackson	
	N	MCP	N	MCP	N	MCP	N	MCP	N	MCP
Males	3	6.25 (1.55)	5	12.34 (4.8)	2	8.12 (0.22)	6	38.8 (11.8)	11	18.75 (12.30)
Females	3	2.87 (2.13)	3	7.00 (2.8)	2	9.60 (0.96)	5	17.4 (16.7)	8	3.33 (2.33)

ranges calculated in 1991 and 1986 to an increase in ocelot density (Laack, 1991).

The data in this study were not divided into subadults and adults or transient individuals and those with stable home ranges. This had a large impact on the average home range for males. M175 was a subadult male without a stable home range. The area estimates were 30.89 km^2, 43.57 km^2, and 6.56 km^2 for MCP, 95% kernel, and 50% kernel home range estimators, respectively. When this individual is removed from the sample, average home range for males in 1991 decreases from 22.32 km^2 to 20.89 km^2 using the MCP estimator and from 11.26 km^2 to 5.89 km^2 using the 95% kernel estimator. A limited sample size did not provide enough data for a detailed examination for differences in home ranges and resource utilization throughout an ocelot's life. Further investigations should focus on these differences to gain a better understanding of how to meet the resource needs of ocelots throughout their life-time.

There is some evidence that, in general, male ocelots have larger home ranges than do female ocelots. However, in this data set, enough individual variation occurred to obscure this trend. This may be a reflection of not eliminating outliers that actually represent occasional forays outside of the ocelot's normal home range. Difference in home range size between males and females is supported in studies by Tewes (1986), Laack (1991), and Crawshaw (1995), but not by Caso (1994). Caso's sample size was small and may not have adequately represented the entire population of ocelots in the area.

Core areas, represented by the 50% kernel home range estimate, were composed primarily of closed canopy land cover. This dependence on closed canopy has been noted in all prior studies concerning ocelot ecology. In the few cases that a larger proportion of the core area was composed of water, a closer examination of ocelot locations revealed that the ocelots in question (F151 and M147) were utilizing patches of closed canopy that occurred on the waters edge. The 50% kernel home range estimator is a probability function that calculates the area in which one should find the ocelot at least 50% of the time. It does not take into account areas that are not accessible, such as open water.

Resource Utilization

Ocelots preferred closed canopy and avoided open canopy. This is consistent with analysis of core area requirements in this study, as well as all other prior research conducted on ocelots (Tewes, 1986, Laack, 1991, Shindle, 1995). Preference for water and urban/barren areas was probably the result of telemetry error of error in classification. Areas of closed canopy occur in close proximity to water bodies and mud flats. The estimation of ocelot locations resulting in water or urban/barren land cover use may be inaccurate, or ocelot may be using open areas to move between areas of closed canopy. Caso (1994) recorded the use of open areas by dispersing sub adults.

Ocelots did show preference/avoidance for certain soils. Harveson (1996) identified soil types and series selected indirectly by ocelots in Cameron County, Texas. She concluded that this indirect selection of particular soil types and series was a result of the ability of Laredo, Point Isabel, and Olmito soil series to sustain the optimum canopy coverage utilized by ocelots. Linda Laack (Pers. comm.) expanded this list to include Camargo, Delfina, Grulla, Hidalgo, Lomalta, Lozano, Matamoros, Rio Grande, Wilamar, Willacy, and Zalla soils. The soil types that were selected are an indication of the land cover present. The type of land cover present is contingent upon the soil on which it is located (Log-likelihood Contingency test, $p<0.001$) with a high degree of association

(Contingency coefficient = 0.6719, 78% of maximum). Knowing the soil types that are conducive to growth of vegetation used by ocelots can help with restoration projects. Currently projects are underway at LANWR for restoring the native thorn scrub on which ocelots are dependent. Knowing where restoration projects have a higher chance of success due to the presence of suitable soil can help focus efforts.

Ocelots avoid human disturbance. Ocelot locations occur in areas with low human density and are distant from cities. The significant difference between ocelot locations and randomly located points in population MCP indicates that ocelots are choosing areas of greater isolation from humans from what is available to them. Although this has not been addressed in previous research per se, it is compatible with the shy, elusive nature of ocelots reported in previous studies.

Although ocelots are found closer to roads than randomly selected points, this may be a reflection of the location of telemetry stations. Several stations on roads are used to locate individuals. When ocelots stray too far from these stations, their radio transmissions will not be picked up by the receiver. Ocelots may also be using road side ditches with thick vegetation for hunting or cover while traveling. Three out of four deaths occurring in 1986 during Tewes study were attributed to vehicular impact. Laack (1991) did not reveal the cause of most ocelot mortalities during her study, but reported at least one death attributable to vehicle impact. In South America, two of five mortalities were attributed to collisions with vehicles (Crawshaw, 1995). It is apparent that although ocelots may use roads and/or road side ditches, mortality caused by vehicles is a negative impact on ocelot survival.

Logistic Regression

All habitat parameters tested except road density contributed significantly to the model calculated through logistic regression. The differences in road density between randomly located points and locations of ocelots, while significant, were not large enough to be an accurate indicator of ocelot presence. The presence of roads was better represented by distance to closest road. The Wald statistics indicated that soil and land cover had the biggest influences on ocelot presence. Due to the nature of logistic regression, the influence of each soil type and each land cover can not be assessed through this step. However, preference/avoidance studies done in an earlier section of this chapter resulted in an indication of which soil types and land cover types were being used disproportionately to their availability. Wald statistics reported in this chapter were used to weight a model created in Chapter 5, and will be discussed further in that chapter.

CHAPTER 4

LANDSCAPE METRICS

Introduction

Spatial heterogeneity of populations and communities is a central component in many ecological theories. Landscape ecology involves the study of landscape patterns, the relationships among patterns and the populations and communities affected by these patterns, and their change over time. The key to predicting and understanding ecological processes lies in the awareness of the mechanisms responsible for observed patterns. With the advent of powerful GIS packages capable of analyzing large-scale landscape issues, research examining the relationship of landscape metrics with ecological processes is increasing.

Patches, various-sized pieces of homogenous habitat, result from both human disturbance (clear cutting, development, etc.) and natural processes (change in climate, soils, slope). Increased distance between patches and loss of connectivity results in fragmentation. The effects of fragmentation are highly dependent on the nature of the change (gradual vs. rapid change) and the type of vegetation change, e.g. from forest to barren or agricultural to old-field. Effects of fragmentation may include: an increase in patch density, inter-patch distance, boundary length, stepping stones, and corridors; and a decrease in patch size, connectivity, interior to edge ratio, maximum size of core, and total interior area (Forman, 1995).

It is necessary to conduct research exploring the quantitative relationships between landscape pattern and spatial use of habitat (Chapin et al., 1998). Fahrig and Merriam (1994) found that patch size and population persistence are positively related. In other words, small patches will have fewer individuals with higher extinction rates and less colonization. Patches that are small relative to home range requirements may receive little or no use by individual animals (Wilcove et al., 1986). Results of fragmentation may include: an increase in isolation, number of generalists, number of edge dependent species, number of invasive exotics, nest predation, and extinction rate; and a decrease in dispersal of interior specialists, species dependant on large home ranges, and species richness of interior (Forman, 1995).

Local extinctions of fragmented populations are common, and re-colonization is necessary for survival. Probability of re-colonization depends upon spatial relationships among landscape elements, dispersal characteristics of organisms, and temporal changes in landscape structure. Landscape metrics are of primary importance in management decisions for endangered animals that are typically restricted in dispersal range and in the types of habitat used for dispersal (Fahrig and Merriam, 1994).

A number of metrics associated with patches are important for ecological research. The number and quality of patches, the shape and configuration of patches, and the presence and quality of corridors that connect patches are all important to habitat use by individuals and populations. Shape of patches is important, because population dynamics may change with different amounts of edge. Although the effect of edge may seem beneficial (e.g., high number of passerine birds found close to edge), the effects of being in this habitat (increased depredation and nest parasitism) may be detrimental to survival (Fahrig and Merriam, 1994). The total number of dispersal routes, or corridors, in an area may be less important than their configuration relative to habitat patches. The quality of corridors affects both the probability of the corridor being used and whether the individual using that route will survive. Low quality corridors may produce a sink for the local population, since individuals could perish while dispersing (Fahrig and Merriam, 1994).

Chapin et al. (1998), studied effects of landscape pattern on habitat use by martens (Martes americana), small, forest dependent carnivores, which position their home ranges to minimize fragmentation. Within their study area, small patches of residual forest received little to no use by martens. Patches of residual forests chosen by martens were 18 times larger than were unused patches. Results from this study indicate that large, unfragmented patches of suitable habitat must be maintained for the ongoing viability of this marten population (Chapin et al., 1998).

Glennon and Porter (1999) used TM imagery to create thematic maps with seven categories of land cover for 1986 and 1993 to study how landscape metrics affected the distribution of turkeys (Meleagris gallopavo) in a primarily forested area of southwestern New York. Landscape metrics examined included: linear edge, edge density and contrast-weighted edge density, interspersion and juxtaposition index (measure of the spatial mixing of habitat patches), contagion (degree of aggregation or clumping of patches), patch per unit area (a measure of contagion), and disjunct core area standard deviation (a measure of the variation in size of core areas). All edge metrics indicated that edge was positively correlated to turkey abundance. Measures of contagion and interspersion indicate that they are positively correlated to turkey abundance (Glennon and Porter, 1999).

No prior studies have attempted to quantify the effects of fragmentation on ocelots. The importance of large, contiguous patches of native thorn scrub has been well documented (Tewes, 1986, Laack, 1991, Shindle, 1995); however, minimum patch size, shape of patches, and other landscape metrics associated with ocelot habitat use have not been estimated. Patch Analyst (Tewes, 1986, Laack, 1991, Shindle, 1995), an extension for ArcView 3.2 was used to assess landscape metrics in areas utilized by ocelots and randomly selected areas to study the effects of fragmentation on ocelots.

Materials and Methods

Landscape Metrics

Landscape metrics included in this research were: number of patches, mean patch size, shape, edge, and mean nearest neighbor. Nearest neighbor probabilities quantify adjacency patterns and directionality of individual land cover types, thus reflecting the degree of fragmentation (Turner, 1989). Patch Analyst, an extension for ArcView 3.2, was used to assess metrics at both the landscape and class scales. This was done using the GRID of land covers composed in Chapter One overlaid with a theme of 100-ha hexagons. Landscape metrics were assessed for each hexagon, and each hexagon was tested for use by ocelots (at least five locations) or no use (no locations). Mann-Whitney U tests were used to determine whether a significant difference existed for each metric between hexagons with known use by ocelots (N=30) and an equal number of randomly selected hexagons without use (N=30). Logistic regression was then used to assess the relationship among variables to determine which variables could accurately distinguish between hexagons with at least five ocelot sightings and those with none.

Proportional use of patches

Methodologies outlined in Otis (1997) were used to assess utilization and relationships between patch size and use within cover types. If cover types are pooled (i.e., several patches combined into one cover type patch), information is lost about relationships between patch size and use within cover types. Careful examination of results, if disproportionate use is supported, may help to define minimum patch size and habitat requirements and further explain the nature of functional relationships between patch size and use (Otis 1997). Patches of each land cover class were divided into three categories (1=first quartile of patch area, 2=second and third quartiles, 3=fourth quartile) representing small, medium, and large sized patches. Use of each of these patch sizes was calculated and Log-likelihood Goodness-of-Fit tests were used to determine whether patches of habitats were selected for disproportionately to availability. Patch selection was determined regardless of land cover type, as well as for each class of land cover.

Results

Landscape metrics assessed at both the landscape and class scale are summarized in Table 4.1. Urban/barren land cover was the most fragmented with the largest number of patches, 3847, and the smallest mean patch size, 0.71 ha. Closed canopy was the second most fragmented land cover type with 3309 patches with a mean patch size of 2.9 ha. Mean shape index was similar for all land cover types ranging from 1.28 to 1.36. Water had the largest mean nearest neighbor distance at 116.3 m, and the other three land cover types ranged from 42.52 m (open canopy) to 56.9 m (urban/barren).

Table 4.1 Landscape metrics at both the landscape and class scale

Class	Number of patches	Mean patch size (ha)	Total edge (km)	Mean shape index	Mean nearest neighbor (m)
All	10557	3.62	4194	1.32	54.9
Water	761	6.08	696	1.31	116.33
Closed canopy	3309	2.9	2904	1.36	48.32
Open canopy	2640	8.06	3104	1.31	42.52
Urban/Barren	3847	0.71	1580	1.28	56.9

Significant differences existed between hexagons with known use by ocelots and hexagons with no known use for every landscape metric tested (Mann-Whitney U test, $p<0.001$). Ocelots used hexagons with a greater number of smaller patches with more edge (Table 4.2). Mean shape index and mean nearest neighbor were both larger in hexagons with known use by ocelots (Table 4.2). These results indicate a greater degree of fragmentation associated with hexagons with use by ocelots.

The second step of a forward stepwise logistic regression model yielded an equation that accurately predicted ocelot presence 90% of the time. This model was significantly better than chance alone at predicting ocelot presence (Likelihood Ratio, $p=0.001$). The equation with B coefficients and Wald statistics are summarized in Table 4.3. These results indicate that, out of all landscape metrics tested, only mean patch size significantly contributed to the model.

Table 4.2 Descriptive statistics for landscape metrics measured in hexagons that contained no ocelot locations and hexagons that contained at least five locations. P-value reported indicates significance of Mann-Whitney U test.

Landscape Metric		Minimum	Maximum	Mean	p
Number of patches	Hexagons with ocelots	6	24	11.97	<0.001
	Hexagons without ocelots	1	19	5.63	
Mean patch size (ha)	Hexagons with ocelots	3.63	17.24	9.2	<0.001
	Hexagons without ocelots	3.9	108.68	46.87	
Total edge (km)	Hexagons with ocelots	8	25	15	<0.001
	Hexagons without ocelots	4	20	9	
Mean shape index	Hexagons with ocelots	1.08	1.52	1.19	<0.001
	Hexagons without ocelots	1.02	1.93	1.17	
Mean nearest neighbor (m)	Hexagons with ocelots	0	75.34	24.27	<0.001
	Hexagons without ocelots	0	100.94	7.99	

Table 4.3 Variables in the equation for predicting presence/absence of ocelots based on logistic regression. Beta coefficients, Wald statistics, and significance of each parameter are reported.

Variables	B	Wald	Sig.
Mean patch size	-0.249	4.398	0.036
Total edge	0.0001	0.494	0.482
Constant	4.826	2.261	0.133

As a result of the presence of 13,584 patches of shadow and 6,213 patches of cloud in the 2000 image, landscape metrics were not calculated.

Evidence was presented in Chapter 3 of selection occurring for land cover type, regardless of patch size. Selection is also occurring for particular sized patches (Log-likelihood Goodness of Fit tests, $p<0.001$). A summary of selection for patch size is presented in Table 4.4. When all habitat types are pooled, ocelots prefer small patches and avoid medium- and large-sized patches. Ocelots prefer small and avoid medium and large patches of water. Ocelots prefer medium-sized patches of closed canopy and avoid small patches. No patches in the “large” category were found associated with 1000 random points for closed canopy, however, one ocelot location occurred in this category of patch size for closed canopy. This indicates that ocelots will use large patches if available, but large patches of closed canopy are rare. Ocelots avoid large patches of open

Table 4.4 Selection of patch size for all habitat types combined, water, closed canopy, open canopy, and barren/urban land cover. Small patches ranged from 0 ha to 28 ha, medium patches ranged from 29 ha to 2,461 ha, and large patches ranged from 4,930-10,614 ha.

	size category	selection	p-value
All habitats	small	P	<0.001
	medium	A	
	large	A	
Water	small	P	<0.001
	medium	A	
	large	0	
Closed canopy	small	A	<0.001
	medium	P	
	large	*	
Open canopy	small	P	<0.001
	medium	P	
	large	A	
Urban/barren	small	A	<0.001
	medium	P	
	large	0	

A = avoidance, P = preference, NS = no selection (p>0.05), and 0 = no locations within this patch size. * No randomly located points were found in large patches of closed canopy, however, one ocelot location was within a large patch of closed canopy.

canopy, but do utilize small and medium-sized patches. Ocelots prefer medium-sized patches of urban/barren and avoid small and large patches.

Conclusion

There was less fragmentation calculated for water and open canopy land cover types than for the landscape as a whole, or for closed canopy and urban/barren areas. This area is located west of the Laguna Madre of the Gulf of Mexico and contains the Laguna Atascosa, both large bodies of water. Open canopy areas include agricultural crops and open rangeland and, by definition, are large tracts of continuous vegetation. The coastal nature of this area also affects the fragmentation of closed canopy and urban/barren land cover types. Mudflats, inundated areas, and vegetation growing in these areas will form a complex pattern depending on tide depth and season.

Hexagons with ocelot use show a greater degree of fragmentation than hexagons with no known use. These results indicate that ocelots chose areas of greater fragmentation that were smaller, less contiguous patches with greater amounts of edge. However, these relationships may be misleading without understanding the species' preference for closed canopy (Chapter 3). Ocelots seem to be utilizing the largest patches of closed canopy available to them, but the mean patch size of this land cover is only 2.9 ha. The fact that no large patches of closed canopy were found associated with 1000 random points, but that one ocelot location occurred on a large patch, is further evidence of the rarity of large patches of this preferred land cover type.

Logistic regression indicated that the most important landscape metric for predicting ocelot use is mean patch size. However, since this is severely restricted due to the absence of large patches of preferred habitat (closed canopy), these results may also be misleading. If large tracts of closed canopy were available to ocelots, the mean patch size would increase accordingly.

Further research is needed to understand how patch size effects distribution of ocelots when larger patches of optimal habitat are available. Research conducted on populations of ocelots in South America may corroborate the assumption that ocelots are choosing the largest patches available to them. However, ocelots may still utilize edge for hunting and travel. Shindle (1995) speculated that the lower temperature within dense cover and the increased ability for concealment amongst the dark shadows increase ocelots' use of interior areas. A study linking edge use to time of day may indicate that ocelots use these area during the coolest, darkest nights.

CHAPTER 5

GIS AND MODEL CREATION

Introduction

Geographic Information Systems (GIS) are “an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of referenced information” (ESRI, 1995). GIS and remote sensing techniques have been used in a variety of projects, e.g., to identify habitat potential for the Florida scrub jay (Breininger et al., 1991), habitat alteration by beaver (Johnston and Naiman, 1990), undeveloped areas in Florida for habitat preservation (Kautz, 1992), and potential habitat for four key species in the Dangs district of India (Worah et al., 1989). Abiotic and biotic factors influencing a particular species distribution (e.g., land use, roadways, and vegetation) can be mapped and ranked individually to represent the extent of influence. These coverages can then be overlaid to create a new coverage that contains the sum of all the individual rankings. This procedure is used when creating ordinal models (Johnson, 1993). Ordinal models have been used in conjunction with GIS to pinpoint the optimal location for landfills, prioritize land acquisition for natural resource protection, quantify the amount of available habitat, and rank watersheds regarding non-point source pollution potential (Johnson, 1993).

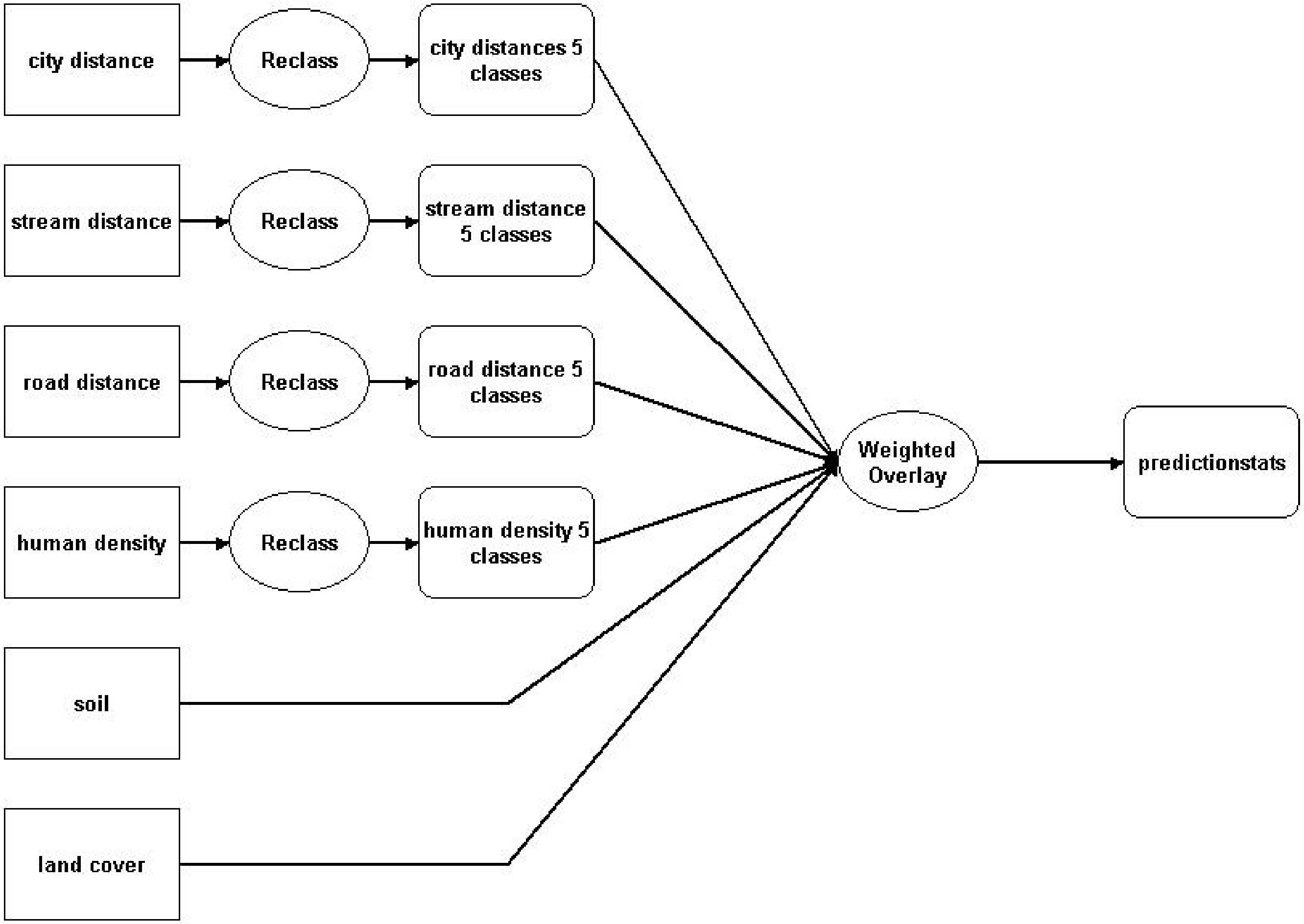
A model is not necessarily an “accurate representation of reality”, but rather a “purposeful representation”, a hypothesis or experiment used as a problem-solving tool (Starfield, 1997:262). If used solely for making decisions rather than representing the "truth", the measure of model accuracy is whether the decision-making process is better with or without it. A model represents one's current best understanding of how a system works. The key is to be thoroughly aware of the assumptions of the model (Starfield, 1997).

A standardized process for modeling wildlife habitat has been established through the use of Habitat Evaluation Procedures (HEP). Habitat Suitability Indices (HSI) for areas is assigned through combining life requisite values from the HEP. Donovan et. al. (1987), used variables concerned with habitat composition, spatial arrangement of habitats, and human use for the development of HSI models for eastern wild turkey in Michigan. They determined that the HSI model derived from these GIS variables was useful in evaluating turkey habitat. They consider the general habitat requirements of turkeys make them good candidates for this type of study.

Materials and Methods

The ModelBuilder extension for ArcView 3.2 was used to create a weighted model to predict areas of optimal, sub-optimal, and unsuitable habitat (Fig. 5.1). All coverages used were converted to GRIDs and overlaid. Two resulting GRIDs were calculated using different weighting schemes, one developed solely from logistic regression analysis of resource utilization research (see Chapter 3) and a second based on ecological factors (literature search). These GRIDs had cell values of optimal, sub-optimal, and unsuitable with respect to habitat for ocelots. The two GRIDs were assessed visually, and the more conservative GRID was chosen for accuracy assessment. Estimated locations of ocelots from January through December, 2000, were overlaid upon this predicted GRID, and GRID cell values were determined for each location.

Figure 5.1 Flow Chart representing the models created using ModelBuilder extension for ArcView 3.2 for prediction of habitat suitability for ocelots in south Texas.



Log-likelihood Goodness-of-Fit tests were used to assess whether any of the three categories (unsuitable, sub-optimal, and optimal) were being used disproportionately to availability, and therefore whether selection was occurring. A change detection analysis of predicted suitability between 1991 and 2000 was used to determine if substantial loss or gain of suitable habitat was taking place. Areas of suitable habitat without ocelot presence are of special interest to wildlife biologists in order to assess the possibility of inclusion of new areas into the refuge system.

Results

A map illustrating predicted areas of unsuitable, sub-optimal, and optimal habitat for ocelots was created for both the model based solely on statistical evidence (Fig. 5.2) and one based on an a priori knowledge of ocelot autecology (Fig. 5.3). The model created solely on statistical evidence predicted more areas of optimal habitat than the model influenced on knowledge about the ecology of ocelots (Table 5.1). The largest difference between the two models occurred in the amount of area predicted to be unsuitable and sub-optimal. Nearly 90% of the difference between the two models was the result of the change from unsuitable to sub-optimal classification.

The model that used previous knowledge of ecological factors influencing ocelot distribution was more conservative and was used for accuracy assessment. Selection did occur among the three suitability categories (Log-Likelihood Goodness-of-Fit, $G=1371$, $p<<0.001$). Eleven ocelot locations occurred in unsuitable habitat, 210 ocelot locations occurred in sub-optimal habitat, and 163 ocelot locations occurred in optimal habitat.

Figure 5.2 Predicted habitat suitability for ocelots in Willacy and Cameron counties, Texas for August 2000 using a model based solely on statistical evidence.

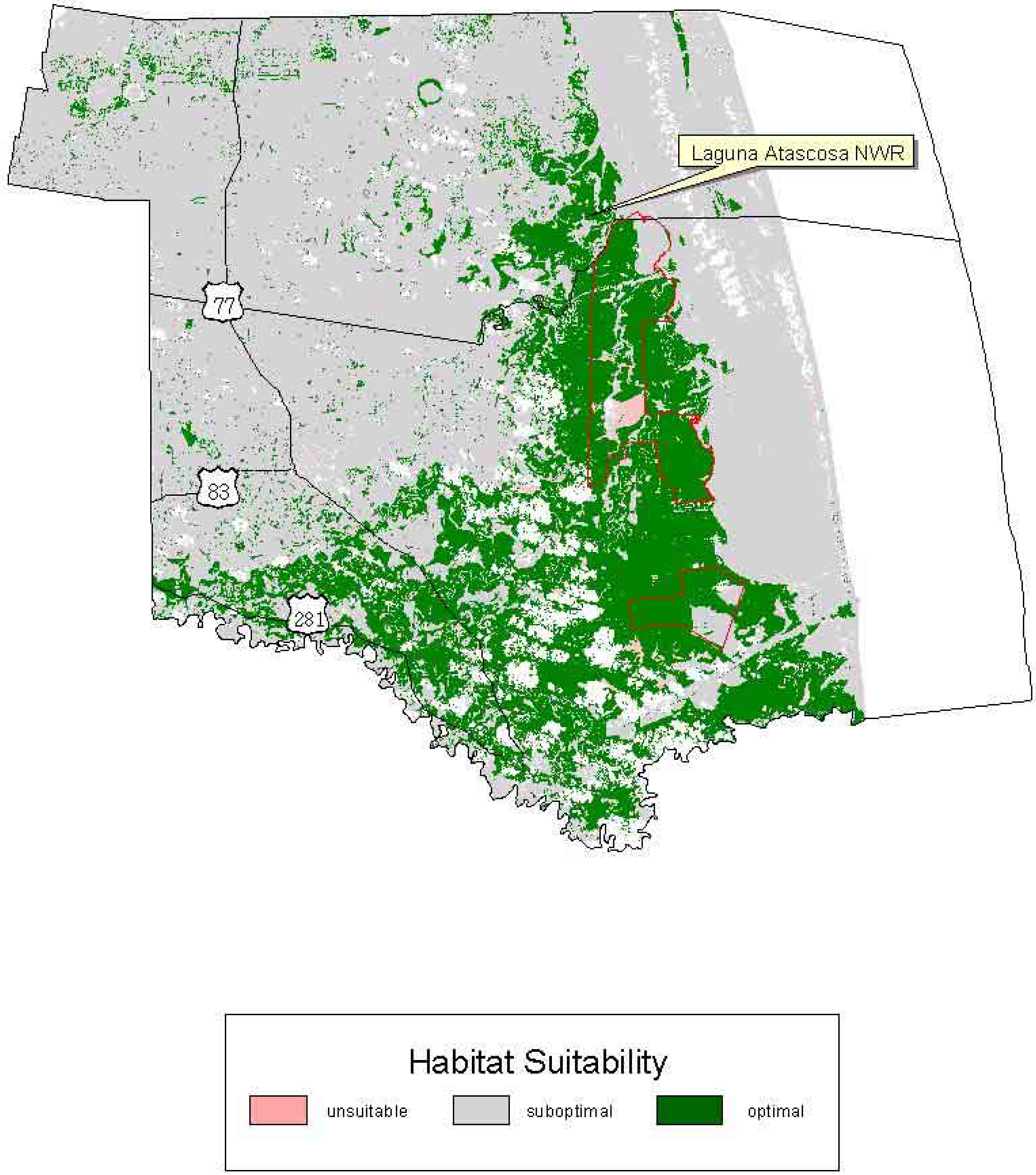


Figure 5.3 Predicted habitat suitability for ocelots in Willacy and Cameron counties, Texas for August 2000 using a model based on ecological factors.

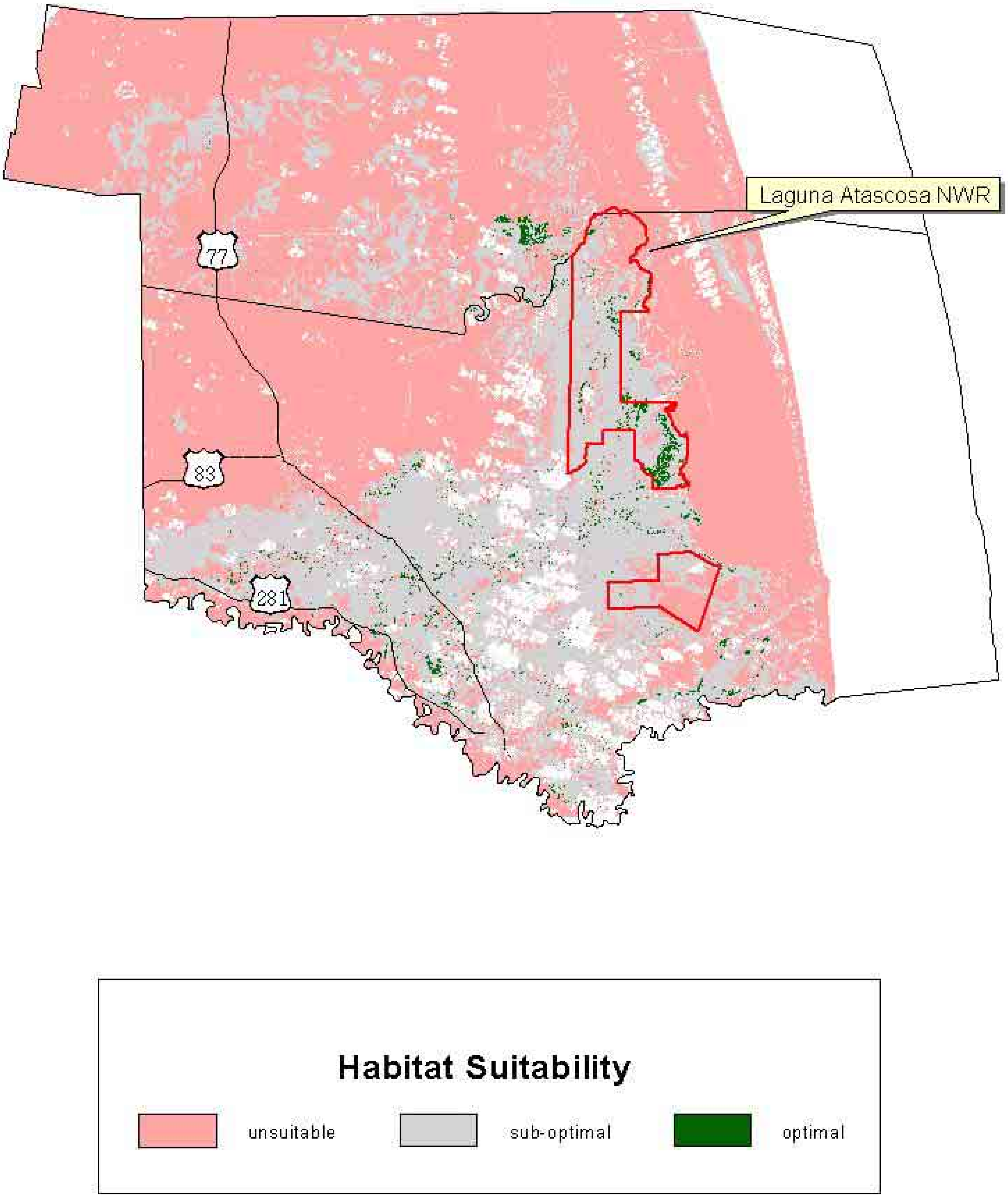


Table 5.1 Percentage of change among three levels of suitability between a model based solely on logistic regression and one influenced by ecological issues. Restricted values reflect cells with missing data or cells associated with shadow or cloud.

		Statistics Model				
		restricted	unsuitable	sub-optimal	optimal	total
Ecology Model	restricted	0.00%	0.47%	1.47%	0.11%	2.05%
	unsuitable	1.54%	0.00%	89.74%	0.06%	91.34%
	sub-optimal	0.69%	2.94%	0.00%	2.48%	6.12%
	optimal	0.04%	0.04%	0.42%	0.00%	0.50%
	total	2.27%	3.45%	91.63%	2.65%	

Ocelots preferred optimal (Log-likelihood Goodness-of-Fit test, G = 949, p<<0.001) and sub-optimal habitats (Log-likelihood Goodness-of-Fit test, G = 101, p<<0.001) and avoided unsuitable habitats (Log-likelihood Goodness-of-Fit test, G = 780, p<<0.001).

Change detection analyses (based on suitability predicted by ecology based model) revealed moderate change between 1991 and 2000 (Table 5.2). The largest change from 1991 to 2000 (ignoring restricted data) was from unsuitable to sub-optimal habitats (28.41% of all change). The total amount of change from optimal habitat to some other category was 9.40% and from some other category to optimal was 2.55%.

Table 5.2 Percentage of change among three levels of suitability between 1991 and 2000. Restricted values reflect cells with missing data or cells associated with shadow or cloud.

		2000				
		restricted	unsuitable	sub-optimal	optimal	total
1991	restricted	0.00%	0.00%	0.00%	0.00%	0.00%
	unsuitable	27.59%	0.00%	28.41%	0.55%	56.55%
	sub-optimal	17.96%	14.09%	0.00%	1.99%	34.05%
	optimal	1.66%	0.00%	7.74%	0.00%	9.40%
	total	47.21%	14.09%	36.15%	2.55%	

Conclusion

Within the refuge boundaries, the model appeared to be accurate in predicting areas of unsuitable, sub-optimal, and optimal habitat. Areas predicted to be optimal habitat for ocelots were chosen more often than expected relative to the proportion available. Off refuge boundaries, these predictions may be overly optimistic. Linda Laack (pers. comm.), Wildlife Biologist at Laguna Atascosa NWR, believes dense agricultural fields may be inaccurately represented as optimal habitat (i.e., closed canopy) off refuge in this model. This error may be corrected through a refinement of the classification procedure (Chapter 2), whereby more land cover classes are accurately defined including native Texas thorn scrub and common agricultural crops.

Obvious corridors between the population of ocelots at Laguna Atascosa NWR and populations known to occur at the Sabal Palm Audubon Sanctuary and Santa Ana NWR are non existent (Fig. 5.4). This is due to the lack of closed canopy vegetation. However, potential corridors become apparent if the land cover theme is removed from the model and the weights are adjusted accordingly (Fig. 5.5). This map indicates areas that may, through thorn scrub restoration, provide optimal habitat for ocelots. Research by Hillis (1992) has shown that reestablishment of thorn scrub in south Texas is possible.

Donovan et. al. (1987) believe that only species with generalized habitat needs make good candidates for using GIS models to predict suitable habitat. However, this study suggests the ability of GIS models to accurately predict suitable habitat for species with narrow habitat requirements. To use GIS to form models for predicting habitat suitability, variables that can be mapped digitally must be used. Some manipulation of HSI is needed to apply them to a GIS database. This can be done for small areas, but may prove difficult if the area of concern is large.

Figure 5.4 Predicted suitability of habitat between known populations of ocelots at Laguna Atascosa NWR, Santa Ana NWR, and Audubon Sabal Palm Sanctuary.

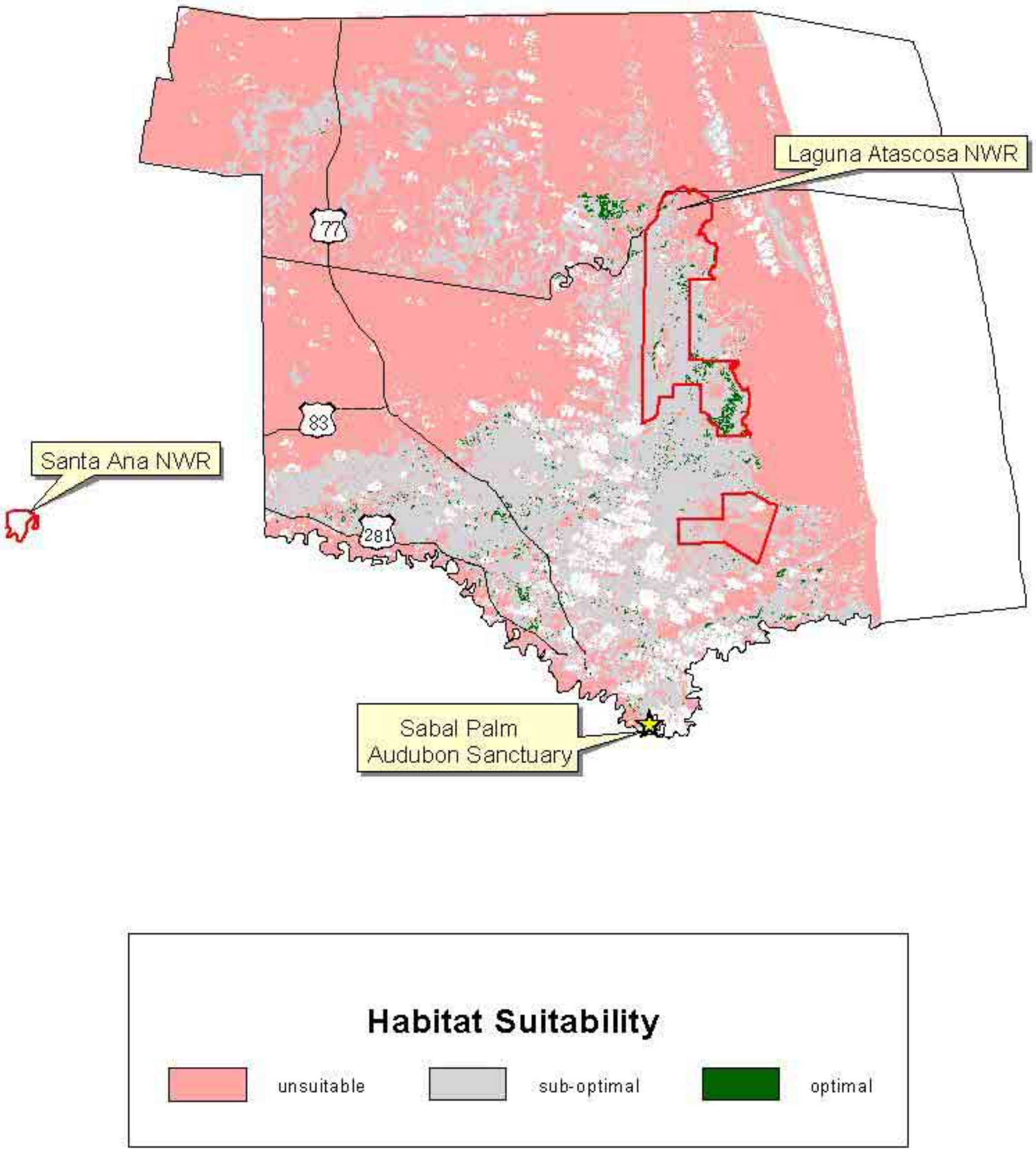
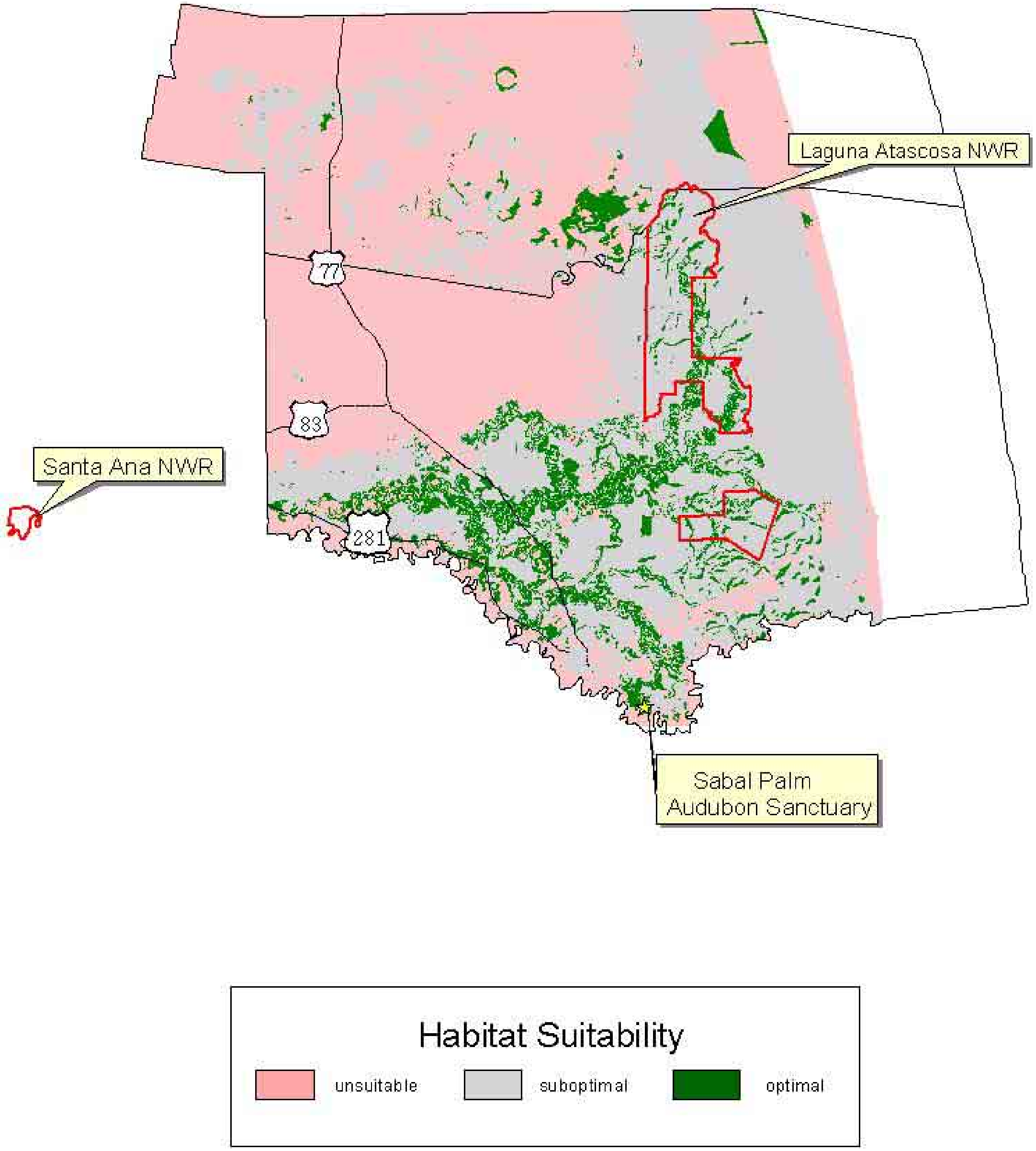


Figure 5.5 Predicted suitability of habitat between known populations of ocelots at Laguna Atascosa NWR, Santa Ana NWR, and Audubon Sabal Palm Sanctuary if vegetation can be restored.



CHAPTER 6

SUMMARY AND FUTURE RESEARCH

Land cover thematic maps were made by classifying Landsat Thematic Mapper images from August 1991 and August 2000 into land cover types including water, closed canopy, open canopy, and urban/barren. These themes were included into a GIS database for assessment of resource needs for a population of ocelots living in and around Laguna Atascosa National Wildlife Refuge. Themes depicting human disturbance (human population density and city location), roads (density and location), hydrology (location), and soils were also manipulated and entered into the database. Locations of ocelots from 1991 were used to assess the home range and resource utilization of this population. Based on this research, ocelots preferred closed canopy and avoided open canopy land cover. Selection for soils suitable for supporting thorn scrub vegetation is an indication of the importance of this habitat type. Ocelots were located in areas with low human disturbance that were close to roads and water bodies.

Landscape metrics associated with areas utilized by ocelots were also assessed. Contrary to expectations, ocelots utilized areas with greater fragmentation than random areas available for use. However, this use of highly fragmented areas was an indication of the degree of fragmentation of suitable habitat in the area. Further investigation of patch size selection indicated that ocelots used large sized patches disproportionately to availability, indicating a preference for larger patches.

A model was created to predict areas of unsuitable, sub-optimal, and optimal habitat for ocelots. This model was applied to data from 2000 and locations of ocelots from this year were used to assess the validity of the model. Ocelots preferred optimal habitat and avoided unsuitable habitat, an indication of the validity of this model.

Further research should include a refinement in the classification procedure to enhance the potential for an accurate portrayal of the amount of native Texas thorn scrub present as well as common crops for the area. The use of vegetation indices such as tasseled cap or NDVI should help separate these ambiguous classes. Increased fieldwork is needed to gain a better appreciation for the subtle differences in reflectance among different vegetation.

A better image without the confusion of clouds and shadow needs to be procured to assess the ability of landscape metrics to predict areas of suitable habitat. Using these metrics, the model may be more conservative, thus reflecting more accurately the amount of optimal habitat available. Although this research has indicated that ocelots chose medium-sized patches of closed canopy, research done in areas with larger patches of closed canopy may reveal a preference for larger patches.

Home range size and resource utilization will change throughout the lifetime of an individual. Transient sub adults need larger areas for free movement from their natal home range to their stable adult home range. Females undergoing parturition need areas rich in resources, but not necessarily as large as their normal home range. An understanding of how home range size and resource utilization changes throughout the life time of an ocelot can help understand the needs and increase the ability to manage for this species.

Ritchie (1997) identified a need for research linking landscape pattern with population dynamics, competition, predation, disease, dispersal, colonization, and extinction. Locating other populations of ocelots in south Texas and identifying potential travel corridors between populations would provide a greater understanding of potential impacts on this population on and around LANWR. Expanding the landscape metric portion of this research to encompass the distribution of ocelots from Texas to northern Mexico would help elucidate how populations of this species are distributed across the northern boundary of its range. This could help in understanding possible sources of gene flow into the south Texas population.

Applying more intensive radio-tracking data to habitat use may elucidate how ocelots use the mosaic of patches available for meeting different needs, e.g., interior thorn scrub for raising young, edge for hunting, etc. S. T. A. Pickett and K. H. Rogers (1997) propose that a mixture of patches provides the total resource needs for wildlife and biodiversity. Understanding exactly how ocelots use the mosaic of patches can help provide wildlife managers with concrete examples to use in education of landowners for conservation of useable patches of habitat.

Although this research has shown the efficacy of creating models to predict areas of suitable habitat, it does not associate any degree of fitness associated with these areas. This research focuses on how available habitat is utilized, not how it affects fitness. Further studies focusing on mortality and natality in relationship to habitat parameters need to be addressed.

Although assuring viability of some populations may be impossible, (e.g., populations that exist on public lands that do not contribute much to the population as a whole), these populations in and among themselves may be important for ecological and/or socioeconomic reasons (Soule, 1987). Habitat loss is the primary cause of recent extinctions (Shaffer, 1987). Public lands may serve as reservoirs for biological diversity (Shaffer, 1987). Maintaining current populations of ocelots in around LANWR by understanding ecological needs and effects of landscape change is a primary concern to wildlife biologists in the area.

The majority of suitable habitat and adequate corridors linking present populations occurs on privately-owned land. These tracts of land are vulnerable to continued destruction as landowners attempt to manage their land for cattle and agriculture. In order to increase protection of this endangered species, it is important to educate landowners about the laws protecting them, and to establish some monetary compensation for landowners willing to bare some of the burden for protecting ocelot habitat.

However, ocelots are most secure on lands protected by the government. Establishing areas of importance for inclusion in the state and federal refuge system is the first step in implementing a conservation strategy that may save this species from extirpation. Prioritizing land with current ocelot populations, optimal habitat, corridors between populations, and areas with the capacity for habitat restoration will help focus conservation efforts.

APPENDIX A

CLASSIFIED AND REFERENCED DATA FOR THE AUGUST 1991 AND THE AUGUST 2000 LANDSAT TM IMAGE

1991

	Reference Data				
Classified data	water	closed canopy	open canopy	barren/urban	Classified Totals
water	61	0	0	0	61
closed canopy	0	38	5	8	51
open canopy	0	3	82	5	90
barren/urban	2	3	4	41	50
Reference Totals	63	44	91	54	252

2000

	Reference Data				
Classified data	water	closed canopy	open canopy	barren/urban	Classified Totals
water	68	0	0	0	68
closed canopy	0	53	12	3	68
open canopy	1	4	116	7	128
barren/urban	1	0	14	35	50
Reference Totals	70	57	142	45	314

APPENDIX B

CHANGE DETECTION MATRIX SHOWING THE NUMBER OF 30M X 30M PIXELS THAT CHANGED LAND COVER TYPES BETWEEN 1991 AND 2000.

		2000						
		water	closed canopy	open canopy	barren/urban	cloud/shadow	Total Change	No Change
1991	water	0	21955	96618	86774	105553	310900	
	closed canopy	822	0	509260	55613	97493	663188	
	open canopy	2702	139012	0	402707	216397	760818	
	barren/urban	6141	8193	331031	0	65165	410530	
	cloud/shadow	0	0	0	0	0	0	
	Total	9665	169160	936909	545094	484608	2145436	6633659

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