POPULATION AND HABITAT VIABILITY ANALYSIS OF OCELOTS (*LEOPARDUS PARDALIS*) IN SOUTHERN TEXAS

A Dissertation

by

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ABSTRACT

Population and Habitat Viability Analysis of Ocelots (*Leopardus pardalis*) in Southern Texas

(May 2006)

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The ocelot (*Leopardus pardalis*) population in the United States (U.S.) was listed as endangered in 1982, with only 2 known isolated breeding populations occurring in southern Texas. Conservation concerns for ocelots included loss of dense thornshrub habitat, mortality from ocelot-vehicle collisions, and genetic erosion. In this study, we used a population and habitat viability analysis (PHVA) to evaluate 4 recovery strategies. These strategies were supplementation of additional ocelots from northern Mexico, reduced road mortality, habitat restoration, and linkage of two breeding populations for ocelot conservation management. The dissertation was divided into 4 chapters. Chapter 1 presents background information in regards to the purpose of this dissertation. Chapter 2 calculates ocelot survival rates to be incorporated into ocelot population modeling. Chapter 3 uses the VORTEX (Version 9.42) program to conduct a demographic population viability analysis (PVA) for an ocelot population located in Cameron County, Texas. Chapter 4 uses the RAMAS/GIS software program to conduct a habitat-based PVA or PHVA by linking landscape data with a demographic metapopulation model. The primary goal of this dissertation was to provide a template for evaluating ocelot recovery strategies in the U.S. Short-term strategies should include reducing ocelot road mortality, and the introduction of ocelots into the U.S. from northern Mexico. Long-term strategies should include the restoration of habitat around occupied ocelot habitat patches and the establishment of an ocelot dispersal corridor between ocelot breeding populations.

DEDICATION

This dissertation is entirely dedicated to my family. To my wife and best friend Eileen Haines. You have been my strength and inspiration in everything I do and accomplish. I can never thank you enough for always being there to complete me. To my beautiful daughters Fiona Haines and Maeve Haines. I hope the completion of this project provides me the opportunities to not only provide both of you a future with some financial security but also a future in which you and future generations can continue to enjoy our invaluable wildlife resource. To the two greatest role models I have ever had, Kathleen Haines and Michael Haines. You have been my biggest supporters and provided my life the foundation it needed to go out and achieve my dreams. I cannot do enough to show my thanks except provide for my children what you have provided me. To Niamh Haines and Conor Haines you have always been an important part of my life and I will continue to treasure your friendship and love. To Lucy Schaffer and John Haines for their love and support. To the newer members of my family: Marta Smith, John Smith III, Emily Smith, and Alex Smith. I thank you for all you have done and I feel fortunate to be considered part of your family. God Bless all of you. Love, Aaron.

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CHAPTER I

BACKGROUND INFORMATION

The ocelot (*Leopardus pardalis*) population in the United States (U.S.) was listed as federally endangered by the U.S. Fish and Wildlife Service in 1982, and was included in Appendix I of CITES (Convention on International Trade in Endangered Species) in 1989. Current ocelot distribution within the U.S. ranges from southern Texas to the northern border of Tamaulipas, Mexico (Tewes and Everett, 1986). There are only 2 known breeding populations within southern Texas; one in and around Laguna Atascosa National Wildlife Refuge (LANWR) in eastern Cameron County (i.e., Cameron Population) and the other on a private ranch located in Willacy County (i.e., Willacy Population) (Navarro-Lopez, 1985; Laack, 1991) (Figure 1). Individuals have been reported outside of these populations but there is no evidence of another breeding population occurring in the U.S. The most recent population estimate for ocelots in the U.S. was 80–120 individuals based on available habitat (Tewes and Everett, 1986). Conservation concerns for ocelots include genetic erosion, mortality from ocelot-vehicle collisions, and loss of dense thornshrub cover (Tewes and Everett, 1986; Tewes and Miller, 1987; Walker, 1997; Tewes and Hughes, 2001).

The goals of this dissertation were to use a population and habitat viability analysis (PHVA) to identify effective recovery strategies for ocelot conservation within the Lower Rio Grande Valley of southern Texas (Possingham et al. 2002). Population viability analysis have been used in the past to evaluate population viability (Shaeffer

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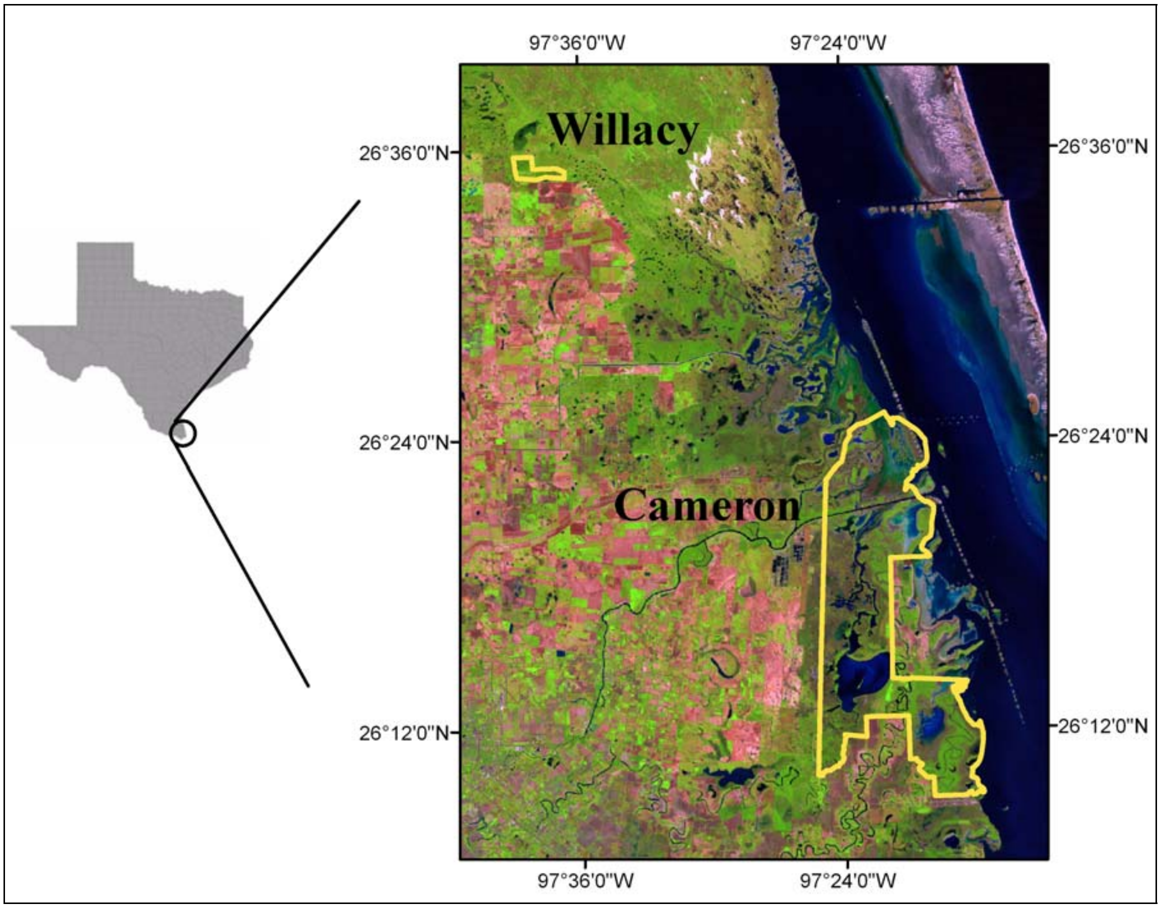

Fig. 1. Locations of the Cameron and Willacy breeding populations of ocelot in the Lower Rio Grande Valley of southern Texas, USA.

1981), and rank the vulnerability of a species (Mace and Lande, 1991). However, Possingham et al. (1993) and Noon and McKelvy (1996) doubted the ability of PVAs to estimate extinction risk, preferring to use the PVA modeling process to select between management options. The PVA modeling process has been used successfully to evaluate management strategies to help conserve free-ranging mammalian species in other studies (Forys and Humphrey, 1999; Maehr et al., 2002; Nilsson, 2003).

This dissertation is divided into 3 main chapters. Each of these chapters were written in the style of a specific scientific journal as a complete manuscript. Chapter 2 analyzes 20 years of ocelot telemetry data to calculate survival rates for the ocelot population on LANWR using Program MICROMORT (Heisey and Fuller, 1985). Chapter 3 is a PVA model of ocelot demographic data developed in VORTEX (Lacy et al., 2003). Chapter 3 incorporates data from Chapter 2 and other studies on ocelot natural history. The objective of chapter 3 was to evaluate ocelot recovery strategies for the Cameron population of ocelots based on demographic parameters. Chapter 4 also evaluates ocelot recovery strategies, but incorporates landscape parameters into the PVA model by creating a vegetative cover map (Akcakaya et al, 1995; Akcakaya, 2000) of Cameron and Willacy counties, Texas. This map established a linkage between demographic and landscape data into a metapopulation model of the Cameron and Willacy populations using RAMAS/GIS (Akcakaya, 2002), thus creating a PHVA.

The ultimate goal of this dissertation was to provide a template for federal and state agencies to manage and conserve the relict breeding ocelots within the U.S. This was done by using the PHVA process to accomplish the following objectives:

1) Create a functional ocelot cover map of Cameron and Willacy counties, Texas.

2) Develop a PHVA for the ocelot populations in Cameron and Willacy counties, Texas.

3) Estimate the threat of extinction for the ocelot metapopulation in southern Texas by using the PHVA modeling process.

4) Determine the impact of 4 conservation strategies (i.e., translocation of ocelots from northern Mexico, reduction of ocelot vehicle-collisions, ocelot habitat protection and restoration, and establishment of a corridor between the Cameron and Willacy ocelot populations) and their possible combinations on the extinction probability for the 2 ocelot populations residing in southern Texas.

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CHAPTER II

SURVIVAL AND SOURCES OF MORTALITY IN OCELOTS

INRODUCTION

The ocelot population within the United States once ranged from Arkansas to Arizona, and is now limited to 80-120 individuals in southern Texas (Hall 1981, Tewes and Everett 1986). During 1989, the ocelot was listed in Appendix I by the Convention on International Trade in Endangered Species (CITES) (Sunquist and Sunquist 2002), which prohibits international commerce of skins (i.e., pelts) and live animals. In addition, the ocelot is listed as federally endangered within the United States by the U.S. Fish and Wildlife Service (1982). Ocelot persistence in a declining population can be assisted by understanding population processes, particularly factors affecting their survival.

Estimates of survival and cause-specific mortality rates are needed to assess population viability and to develop conservation strategies (White 1983). Seasonal, age, and sex-specific survival rates represent important information for conservation biologists to plan recovery strategies. This information will allow biologists to identify major sources of ocelot mortality, and allow researchers to model ocelot populations under different management scenarios to predict population response. However, these estimates are difficult to obtain for secretive, long-lived mammals that occur at low densities, such as the ocelot (Lindzey et al. 1988).

This chapter follows the style and format of *Journal of Wildlife Management*.

Estimates of small cat survival and cause-specific mortality rates have been primarily limited to bobcat (*Lynx rufus*) studies in temperate regions of the United States (Fuller et al. 1985, 1995, Knick 1990, Chamberlain et al. 1999, Kamler and Gipson 2000, Nielsen and Woolf 2002). Bobcats are similar to ocelots in size, and co-occur with ocelots in southern Texas (Tewes 1986). However, ocelots are more specialized, requiring areas of dense cover and high rodent density (Tewes 1986, Emmons 1988). The few ecological studies on ocelots have not reported survival or mortality rates (Emmons 1987, Ludlow and Sunquist 1987, Konecny 1989, Crawshaw 1995). Results of this study represent the first assessment of these population parameters for ocelots. Our objectives were to (1) estimate seasonal and annual survival for male and female resident and transient ocelots, (2) estimate annual survival for resident and transient ocelots during drought conditions, (3) estimate seasonal and annual cause-specific mortality rates for male and female resident and transient ocelots, and (4) evaluate differences in seasonal and annual survival rates and differences in cause-specific mortality rates between male and female resident and transient ocelots.

We hypothesized that (1) survival of transient ocelots will be 50% lower than resident ocelots because transients will be more susceptible to mortality (e.g., vehicle collision, intraspecific mortality) in unfamiliar environments, (2) ocelot survival will be similar between male and female resident and transient ocelots, as is the case with unexploited bobcats (Nielson and Woolf 2002), (3) ocelot survival will be 25% lower during drought conditions because prey resources will be limited, and (4) unnatural sources of mortality (e.g., ocelot-vehicle collisions) will represent 80% of mortalities for both resident and transient ocelots, as found with unexploited bobcats (Nielsen and Woolf 2002).

STUDY AREA

We monitored ocelots in Laguna Atascosa National Wildlife Refuge located in Cameron County, within the Lower Rio Grande Valley (LRGV) of southern Texas (Figure 2). Laguna Atascosa National Wildlife Refuge is an 18,200 ha refuge that provides wintering and feeding areas for migratory waterfowl, and habitat for ocelots. The LRGV is an alluvial plain dissected by numerous arroyos and ephemeral streams that flow into the Rio Grande River or the Gulf of Mexico (Everitt and Drawe 1993). The LRGV has a wide diversity of fertile soil types (Williams et al. 1977). The subtropical, semi-arid climate is characterized by hot summers and mild winters (Thornthwaite 1948, Lonard and Judd 1985). Mean length of the frost-free period is 330 days with winters frequently occurring without freezing temperatures. Mean annual temperature and rainfall is 23 C^{o} and 68 cm, although rainfall fluctuates widely through the year (Norwine and Bingham 1985, Lonard et al. 1991).

This region supports a variety of plants, wildlife, and habitats as part of the Tamaulipan Biotic Province (Blair 1950, Richardson 1995). Predominant woody species in the LRGV include spiny hackberry (*Celtis pallida*), crucita (*Eupatorium odoratum*), Berlandier fiddlewood (*Citharexylum berlandieri*), honey mesquite (*Prosopis glandulosa*), desert olive (*Forestiera angustifolia*), snake-eyes (*Phaulothamnus spinescens*), colima (*Zanthoxylum fagara*), and brasil (*Condalia hookeri*) (Lonard and Judd 1993). However, >95% of the native rangeland in the LRGV has been converted for agricultural and urban land uses (Jahrsdoerfer and Leslie 1988).

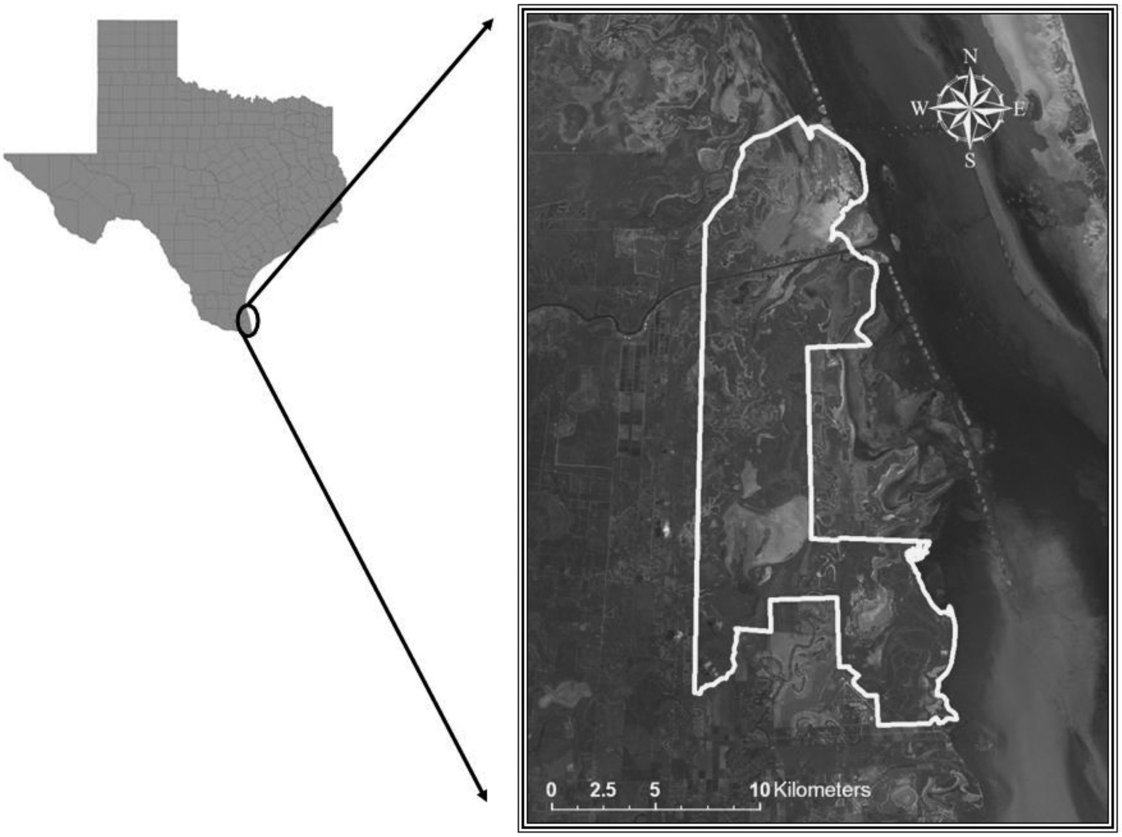

Fig. 2. Map of the Laguna Atascosa National Wildlife Refuge located in the Lower Rio Grande Valley, eastern Cameron County, Texas, USA.

MATERIALS AND METHODS

Trapping and Radiotelemetry

During 15 September 1982 to 11 November 2001, we captured 80 ocelots (36 F, 44 M) with single-door, 108 × 55 × 40 cm wire box traps (Tomahawk Trap Co., Tomahawk, WI). We attached a separate compartment containing a domestic live chicken to the trap as bait. We placed traps in shaded areas and checked each morning to reduce the risk of hyperthermia.

We immobilized ocelots with a 9:1 ratio of ketamine hydrochloride and acepromazine maleate (Beltran and Tewes 1995). We injected this mixture with a pole syringe at a dosage of 20 mg/kg body weight. We sexed, weighed, and classified ocelots as adults or subadults based on maturation of morphological development, dental wear (sharp dentition for juveniles), canine length (> 15 mm for adults), and weight (female adults > 6.5 kg, male adults > 8.5 kg). We fitted immobilized adult and subadult ocelots with collar-mounted radiotransmitters containing a mortality sensor and a frequency of 148−149 MHz (Telonics Inc., Mesa Ariz.). We used ground stations and aerial radiotelemetry to locate ocelots 2−3 times each week anytime between 1 hr before sunrise until 1 hr after sunset. We monitored radio signals with a directional H-antenna connected to a model LB12 receiver (Telonics Inc., Mesa Ariz.). We located and recovered dead ocelots to determine cause of mortality. We conducted tracking from a small aircraft if a collared ocelot could not be found during ground searches. We classified mortality into 4 categories based on field observations and necropsy information: vehicle-caused, natural cause (i.e., mammal attack, disease), unknown, or other (other anthropogenic induced mortality) (Tewes 1986, Laack 1991).

Survival and Cause-Specific Mortality

We estimated annual and seasonal survival rates and cause-specific mortality rates of resident and transient ocelots using number of transmitter-days and total number of deaths within a defined time interval (Trent and Rongstad 1974, Heisey and Fuller 1985*a*). This was done using the program MICROMORT (Heisey and Fuller 1985*b*), which is based on the Mayfield methodology (Mayfield 1961, 1975). To meet the assumptions of the Mayfield method, we assumed that constant survival occurred during the hot (16 April–15 October) and cool (16 October–15 April) seasons in the study area. Study assumptions included that newly collared ocelots had the same survival rate as previously collared ocelots, sampled ocelots were random and independent, working collars were always located, censoring was random, and trapping, handling, and radiocollaring did not impact ocelot survival (Winterstein et al. 2001). We used ocelots with transmitter failure in the data analysis for survival probabilities until signal loss occurred (Burger et al. 1995). We censored these cats from the survival analysis, but they were not considered mortalities (Pollock et al. 1989).

We pooled data across years because low annual sample sizes would have resulted in a low statistical power for the tests (Fuller et al. 1985, Cunningham et al. 2001, and Nielsen and Woolf 2002). Nielsen and Woolf (2002) stated that testing for differences in annual survival rates over years would have been biased due to differing number of radio days occurring for each year. Hence, Nielsen and Woolf (2002) believed that testing for differences in survival between years is unfounded and biologically meaningless (Yoccoz 1991, Cherry 1998). However, we did not pool years during 1989–1991 or 2000–2002 because during these years the 12-month Palmer Modified

Drought Severity Index (PMDI), which assesses the severity of dry or wet conditions, was consistently lower from January 1989–April 1991 and January 2000–December 2002, compared to January 1983–December 1988 and May 1991–December 1999 (Figure 3).

Blankenship (2000) found that on the Welder Wildlife Refuge (WWR) in San Patricio County, Texas, bobcat survival and fecundity, and prey density dropped dramatically during drought conditions in 1996. During 1996, the mean 12-month PMDI was -2.52 within the WWR area, which indicated moderate drought conditions. From January 1989–May 1991 and January 2000–December 2002, the mean 12-month PMDI was −2.42 and −2.48 within LRGV of Texas which also indicated moderate drought conditions, whereas the mean 12-month PMDI from January 1983–December 1988 and May 1991–December 1999 was 0.55 and 0.11 which indicated normal moisture conditions (National Climatic Data Center; http://www.ncdc.noaa.gov). Consequently, we analyzed survival of ocelots separately from January 1989–May 1991 and January 2000–2002 to minimize differences in survival between years so they could be pooled. We analyzed cause-specific mortality throughout the period from January 1982–December 2002.

We used chi-square tests in the program CONTRAST to test for differences in annual survival and annual cause-specific mortality between resident and transient ocelots, and pooled annual survival and cause-specific mortality rates between sexes and seasons for resident and transient ocelots (Hines and Sauer 1989, Sauer and Williams 1989). We tested for differences in annual and seasonal survival rates and annual and seasonal mortality rates between male and female resident ocelots, and between male and

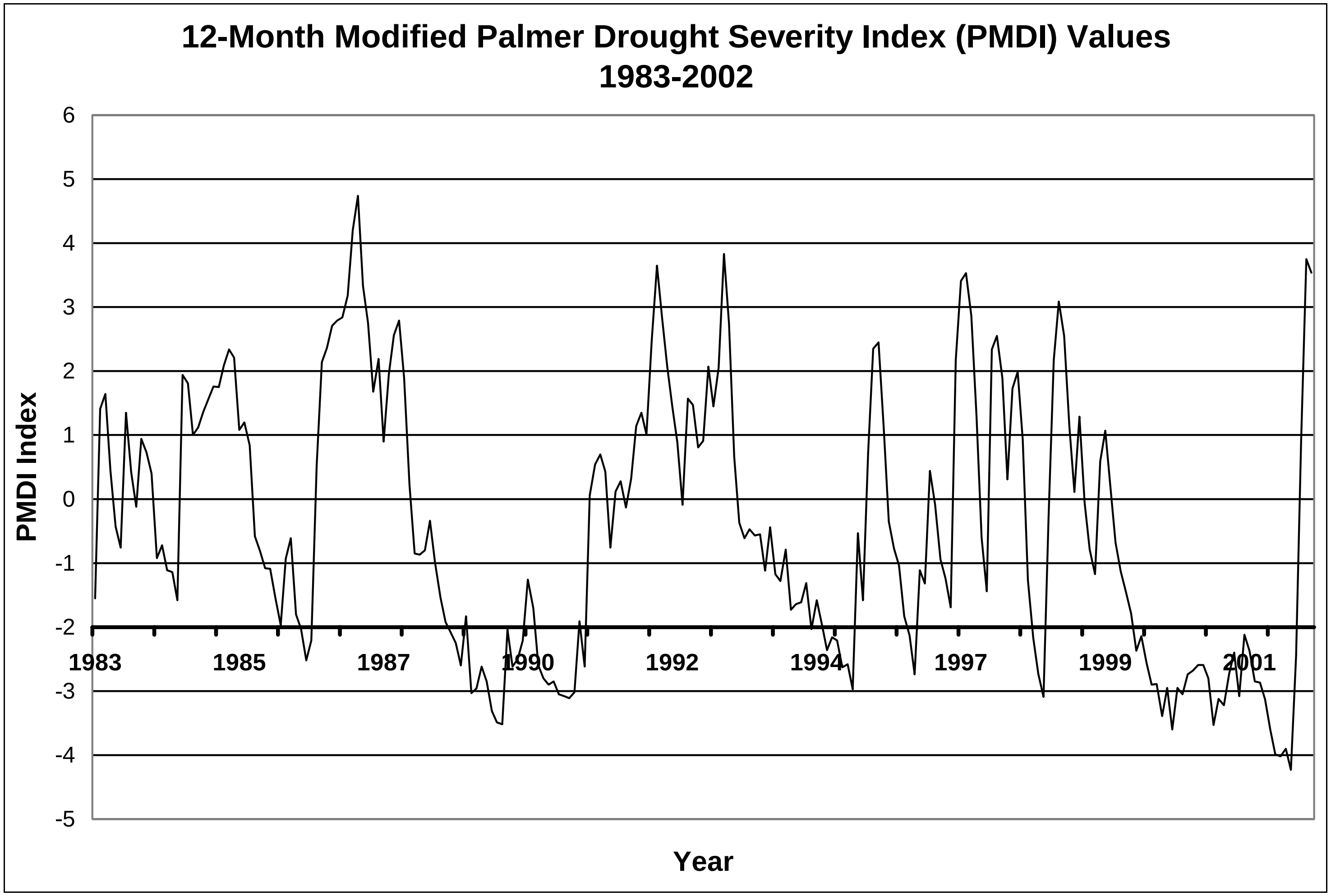

Fig. 3. The 12-month Modified Palmer Drought Severity Index within the Lower Rio Grande Valley of Texas, USA from January 1983 to December 2002.

female transient ocelots. We also tested for differences in annual survival rates during drought and normal conditions for resident and transient ocelots. Experiment wise error rate was maintained during associated multiple comparisons by adjusting α with a Bonferroni correction factor (α/no. of comparisons) (Neter and Wasserman 1974). Statistical significance was inferred at $P \leq 0.05$.

We defined resident ocelots as an individual that used a single restricted area (i.e., home range) for 3 months or more, and defined transient ocelots as an individual that moved from the natal or breeding range and traveled nomadically until a stable range was established. We applied a resident status to transient ocelots following establishment of a stable breeding range. We correctly classified most transients as subadults with ocelots usually leaving their natal range at 2-3 years of age (Sunquist and Sunquist 2002). Resident ocelots included juvenile cats still residing on their natal range and adult cats with a defined breeding range.

RESULTS

From 1 January 1983 to 31 December 2002, we used 72 resident (33 F, 39 M) and 20 transient (6 F, 14 M) ocelots for 50,901 radio days ($\bar{x}$ days/ocelot = 749, range 11−1,669 days) for survival and cause-specific mortality analyses. Individual ocelots sometimes shifted between resident and transient status. We monitored resident ocelots for 46,550 radio days ($\bar{x}$ = 647 days/ocelot, range 45−1,669 days) and transient ocelots were monitored for 4,641 radio days ($\bar{x}$ = 218 days/ocelot, range 11−645 days). We monitored resident female ocelots for more radio days (25,549) than male residents (21,001 radio days), and male transient ocelots for more radio days (3,511) than female transients (1,130 radio days).

Twenty-nine mortalities occurred during the study with 21 residents (14 F, 7 M) and 8 transients (2 F, 5 M). Mortalities within resident ocelots included 7 (33%) vehicle-caused and 6 natural mortalities (29%). Natural mortalities included 2 diseased (chronic ear infection, heartworm [*Dirofilaria immitis*] infestation), 3 aggressive animal encounters (e.g., rattlesnake [*Crotalus atrox*] bite, attack from another cat, attack from another animal leading to septic peritonitis and pleuritis), and 1 predation. Five (24%) resident ocelot mortalities were unknown, and we classified 3 (14%) resident ocelot mortalities as "other" (killed by dogs [*Canis domesticus*], capture hyperthermia, and poisoned by organophosphate aldicarb [illegal predator control agent]). Mortalities within transient ocelots included 4 (50%) natural mortalities (1 mange, 1 lung abscess from plant material, 2 intraspecific mortality), 3 (37.5%) vehicle-caused, and 1 (12.5%) unknown. Overall, mortalities for ocelots did not differ dramatically between the cool (n = 14, 48%) and hot (n = 15, 52%) season. Vehicle-caused (35%) and natural (35%) mortalities were the highest sources of mortalities for ocelots in southern Texas followed by unknown (20%), and other mortalities (10%). Unnatural mortalities constituted 45% of total mortalities, which was lower than the 80% we had hypothesized.

Survival

From January 1983 to December 1999, during normal conditions, resident ocelots had a 30% higher annual survival rate than transient ocelots (Table 1). This supported our hypothesis that resident ocelot survival would be higher than transient ocelot survival, albeit not 50% higher. Annual survival rates did not differ ($\chi^2_1 = 1.98$, $P = 0.16$) between male and female resident ocelots, or between male and female transient ocelots

Table 1. Seasonal and annual survival rates (Ŝ) of male and female resident and transient ocelots in Cameron County, Texas, USA, January 1983–31 December 1988 and 2 April 1991–31 December 1999 during normal moisture conditions.

	Residents				Transients			
	Mortalities	Radio days	Ŝ	S.E	Mortalities	Radio days	Ŝ	S.E.
Male								
Cool[a]	4	8,368	0.92	0.04	2	1,318	0.74	0.15
Hot[b]	0	8,388	1.00	0.00	3	1,696	0.71	0.13
Annual	4	16,756	0.92	0.04	5	3,014	0.53	0.15
Female								
Cool	4	8,595	0.92	0.04	0	605	1.00	0.00
Hot	5	9,474	0.91	0.04	1	469	0.63	0.27
Annual	9	18,069	0.83	0.05	1	1,074	0.63	0.27
Pooled								
Cool	8	16,963	0.92	0.03	2	1,923	0.82	0.11

Table 1. Continued.

	Residents				Transients			
	Mortalities	Radio days	Ŝ	S.E	Mortalities	Radio days	Ŝ	S.E.
Pooled								
Hot	5	17,862	0.95	0.04	4	2,165	0.70	0.12
Annual	13	34,825	0.87	0.02	6	4,088	0.57	0.13

[a] 16 Oct-15 Apr.

[b] 16 Apr-15 Oct.

($\chi^2_1 = 0.10$, $P = 0.75$) (Table 1). This supported our hypothesis that survival between sexes would be similar.

Because annual survival differed ($\chi^2_1 = 5.22$, $P = 0.02$) between resident and transient ocelots, we analyzed survival and cause-specific mortality rates separately between resident and transient ocelots. For resident ocelots, survival did not differ between the cool and hot season (Table 1). For transient ocelots, survival also did not differ ($\chi^2_1 = 0.54$, $P = 0.46$) between the cool and hot season (Table 1). Survival did not differ ($\chi^2_1 = 1.25$, $P = 0.26$) between male and female resident ocelots, or between male and female transient ocelots during the cool season ($\chi^2_1 = 3.00$, $P = 0.08$) (Table 1). During the hot season male survival was higher ($\chi^2_1 = 5.01$, $P = 0.02$) than female survival for resident ocelots (Table 1), whereas survival between male and female transient ocelots did not differ ($\chi^2_1 = 0.07$, $P = 0.79$) (Table 1).

During drought conditions annual survival of resident ocelots ($\hat{S} = 0.77$, SE 0.07) was higher ($\chi^2_1 = 6.08$, $P = 0.01$) than for transient ocelots ($\hat{S} = 0.13$, SE 0.25). We monitored 27 (16 F, 11 M) resident ocelots during the drought periods (January 1989–April 1991 and January 2000–December 2002) for 11,725 radio days ($\bar{x}$ days/ocelot = 434, range 20–1,095 radio days). Annual survival of resident ocelots during drought conditions ($\hat{S} = 0.77$, SE 0.07) did not differ significantly ($\chi^2_1 = 1.89$, $P = 0.17$) from resident ocelot annual survival during normal conditions (January 1983–December 1988 and May 1991–December 1999) ($\hat{S} = 0.87$, SE 0.05). Resident ocelot survival during drought conditions decreased by 10%, thus supporting our hypothesis that ocelot survival would decrease during drought periods. However, this decrease was not significantly different and was not as severe as the 25% decline we hypothesized. We monitored 4 (2F, 2M) transient ocelots during the drought periods for 553 radio days ($\bar{x}$ days/ocelot = 136.5, range 11-175 radio days), with 1 individual suffering from an intraspecific attack, another from an unknown mortality, and 2 with lost radio signals. Annual survival of transient ocelots during drought conditions ($\hat{S}$ = 0.13, SE 0.25) did not differ significantly ($\chi^2_1 = 2.44$, $P = 0.12$) from transient ocelots ($\hat{S}$ = 0.57, SE 0.13) during normal conditions. However, we attribute this nonsignificance to the low number of radio days of transients during the drought period.

Cause-Specific Mortality

Cause-specific mortality did not differ for resident ($\chi^2_1 = 1.61$, $P = 0.20$), or transient ocelots ($\chi^2_1 \leq 1.06$, $P \geq 0.30$) during the cool and hot season (Table 2). In addition, cause-specific mortality of male and female resident ocelots did not differ during the cool season ($\chi^2_1 \leq 2.25$, $P \geq 0.13$) or the hot season ($\chi^2_1 \leq 3.11$, $P \geq 0.08$). Similarly, cause-specific mortality of male and female transients did not differ during the cool season ($\chi^2_1 \leq 1.44$, $P \geq 0.23$) or the hot season ($\chi^2_1 \leq 2.89$, $P \geq 0.09$). Cause-specific mortality differed between resident and transient ocelots ($\chi^2_1 = 4.70$, $P = 0.03$), with transient ocelots having higher natural mortality ($M = 0.26$, SE 0.10) than resident ocelots ($M = 0.04$, SE 0.02). Other forms of mortality did not significantly differ between resident and transient ocelots ($\chi^2_1 \leq 2.78$, $P \geq 0.10$) (Table 2).

If we include mortality data from collared and uncollared ocelots from 1983-2002, the summary of mortality rates include 26 (45%) road mortalities; 4 (7%) other human caused mortalities; 6 (10%) disease, parasitism, and infection; 8 (14%) predation and aggression; and 14 (24%) unknown mortalities. However, direct human-caused mortality may be overrepresented because road-kills were more likely to be found.

Table 2. Pooled seasonal and annual cause-specific mortality rates (*M*) of male and female resident and transient ocelots in Cameron County, Texas, USA, 1 January 1983–31 December 2002.

		Residents			Transients		
	Mortality cause	Mortalities	*M*	S.E	Mortalities	*M*	S.E.
Cool	Vehicle	5	0.040	0.017	1	0.080	0.078
	Natural	3	0.020	0.014	2	0.160	0.100
	Unknown	2	0.015	0.010	0	0.000	0.000
	Other	1	0.010	0.001	0	0.000	0.000
Hot	Vehicle	2	0.015	0.010	2	0.130	0.080
	Natural	3	0.020	0.014	2	0.130	0.080
	Unknown	3	0.020	0.014	1	0.065	0.063
	Other	2	0.015	0.010	0	0.000	0.000
Annual	Vehicle	7	0.050	0.020	3	0.180	0.095
	Natural	6	0.040	0.017	4	0.260	0.100

Table 2. Continued.

	Resident			Transient		
Mortality cause	Mortalities	*M*	S.E	Mortalities	*M*	S.E.
Annual						
Unknown	5	0.036	0.017	1	0.050	0.045
Other	3	0.020	0.012	0	0.000	0.000

[a] 16 Oct-15 Apr.

[b] 16 Apr-15 Oct.

DISCUSSION

Our study provided the first survival and cause-specific mortality rates for ocelots. Resident ocelots exhibited a 30% higher survival than transient ocelots. Most transients were subadults probably attempting to identify a breeding range, whereas 3 transients were adult individuals probably trying to reestablish a breeding range elsewhere. Resident adult ocelots killed 2 transient ocelots. Intraspecific mortality within felids has been previously documented (Litvaitus et al. 1982, Zezulak and Minta 1987, Logan and Sweanor 2001). Intrasexual defense of a breeding range from intruding conspecifics is suspected for male and female ocelots (Tewes 1986, Laack 1991). Both mortalities coincided with the arrival of a same-sex intruder into an established breeding range of a resident ocelot, with the transient intruders exhibiting puncture wounds, and claw marks as lacerations and scratches. Soon after 1 of the transient mortalities was found, the resident ocelot of the area was captured and had claw scratches on its body. The canine spacing of the resident cat matched the cranial fracture wounds of the dead transient found on its range. Another source of natural mortality for a transient ocelot was notoedric mange, which had been previously reported in ocelots from southern Texas (Pence et al. 1995).

In 3 different studies that monitored the dispersal of 11 ocelots, 5 ocelots survived until study termination, humans directly killed (shot) 5 individuals, and a resident ocelot killed 1 individual (Ludlow and Sunquist 1987, Emmons 1988, Crawshaw 1995). Transient ocelots may be more susceptible to mortality by traveling over large unfamiliar areas, thus increasing the possibility of road kills, encountering other anthropogenic mortalities, and increased likelihood of intraspecific mortality and other animal attacks.

Sunquist and Sunquist (2002) stated that cat movement over a large area increases encounters with highways and humans, the 2 primary sources of mortality for wild cats. Kamler and Gipson (2000) found that the survival rate of resident bobcats was twice as high as transient bobcats. They attributed this difference to resident bobcats occupying a military base that served as a refuge, and transient bobcats susceptible to hunting, trapping, and being vulnerable within unfamiliar areas.

Annual survival was similar between male and female resident and transient ocelots. Knick (1990) and Nielson and Woolf (2002) found that annual survival of male and female radiomonitored adult bobcats in unexploited populations were similar. We found a difference in sex-specific seasonal survival between male and female resident ocelots during the hot season with male resident ocelots having a higher annual survival rate than female residents. We have no explanation for this difference in survival. Chamberlain et al. (1999) found that female bobcat survival was lower during the parturition–young-rearing period (1 Jun–30 Sep) in central Mississippi. However, ocelots lacked a distinct breeding season, and may breed when environmental conditions are favorable (Tewes 1986, Laack 1991).

Favorable environmental conditions in southern Texas may be dictated by precipitation, which fluctuates widely between seasons and among years, thus we partitioned ocelot survival by normal and drought periods. During drought conditions resident ocelots still had a higher annual survival rate than transient ocelots. Survival of resident ocelots during drought periods ($\hat{S} = 0.77$) did not differ significantly from resident ocelots during normal conditions ($\hat{S} = 0.87$). In addition, there was no significant difference between the survival of transient ocelots during drought ($\hat{S} = 0.13$)

and normal ($\hat{S} = 0.57$) conditions. However, the number of individual transient ocelots radiomonitored during drought conditions was only 4. This reduction in the number of radiomonitored transient ocelots during drought conditions may be due to (1) young ocelots staying within natal ranges during drought periods, (2) adult females producing few young during drought periods, or (3) the population of transient ocelots crashing during drought periods. More research is needed to test why the number of individual transient ocelots decreased during drought conditions. Blankenship (2000) found that during a drought year when primary prey of bobcats was reduced, bobcats had lower survival, no fecundity, and increased transient behavior. More research is needed to monitor the effects of drought conditions on ocelot fecundity and behavior.

Cumulative survival rates of resident ocelots ($\hat{S} = 0.87$) was similar to survival rates of unexploited bobcats in Illinois ($\hat{S} = 0.82$) (Nielsen and Woolf 2002), but higher than unexploited bobcats in Idaho ($\hat{S} = 0.67$) (Knick 1990). However, Knick (1990) and Nielsen and Woolf (2002) did not differentiate between transient and resident bobcats. Knick (1990) found 50% bobcat mortalities in an unexploited population in Idaho were human-related. Nielsen and Woolf (2002) found 19 mortalities with 10 bobcats (52%) hit by automobiles and human activities causing 79% of the cumulative mortality. In our study both resident and transient ocelot mortalities were caused by anthropogenic (e.g., vehicle collisions) and natural mortality (predation) factors, with transient ocelots having a higher rate of natural mortalities. We documented 29 mortalities with human activity causing 45% of the cumulative mortality. However, natural mortality may be indirectly related to anthropogenic habitat fragmentation. Reduced habitat availability may cause ocelot populations to be more crowded, thus increasing intraspecific conflict, competition, and disease transmission.

When analyzing the assumptions of the Mayfield method for calculating survival in this study there was no evidence to support that any of the assumptions had been violated, with maybe 1 exception. One radiocollared ocelot was recaptured and suffered from capture hyperthermia. However, this was the only documented case in which an ocelot died from trapping and handling techniques during this 20-year study. Further, no ocelots were found dead directly after being collared. The shortest time interval from when an ocelot was originally collared until it experienced mortality was 95 days.

Our study found fewer female transients than male transients. There are usually fewer female transients than male transients in populations of solitary cats, because females usually settle adjacent to or within their natal range to breed (Sunquist and Sunquist 2002). This same pattern of behavior has been documented for tiger (*Panthera tigris*), leopard (*Panthera pardus*), Iberian lynx (*Lynx pardinus*), and puma (*Puma concolor*) (Smith et al. 1987, Bailey 1993, Lindzey et al. 1994, Ferreras et al. 1997).

MANAGEMENT IMPLICATIONS

Vehicle-caused mortality seems to be the primary anthropogenic factor causing ocelot deaths in the LRGV of southern Texas. Applications of remedial tactics within transportation corridors to promote safer felid movements have been proposed to minimize ocelot mortality, including cat underpasses (e.g., culverts) which have been constructed for ocelots in southern Texas (Tewes and Blanton 1998, Tewes and Hughes 2001). Proposed culverts should be placed in relation to habitat features and travel corridors, with barrier fences guiding ocelots to the culverts, and crossing structures allowing for water drainage (Tewes and Hughes 2001, Cain et al. 2003). In addition, Beier (1995) recommended that artificial lighting and unrestrained pets should be excluded from culverts. However, culvert utility and effectiveness in reducing vehicular-caused ocelot mortality still needs to be assessed, and ocelot travel corridors should be assessed prior to construction of expensive culverts, as well as other developments that are designed for ocelot passage at specific locations (Tewes and Hughes 2001). This can be done by placing remote cameras within culverts or at proposed culvert locations to monitor ocelot activity and using telemetry to monitor ocelot movements around major roadways.

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CHAPTER III

EVALUATING RECOVERY STRATEGIES FOR AN OCELOT (*LEOPARDUS PARDALIS*) POPULATION IN THE UNITED STATES

1. Introduction

The ocelot *Leopardus pardalis* population in the United States (U.S.) was listed as federally endangered by the U.S. Fish and Wildlife Service in 1982, and was included in Appendix I of CITES (Convention on International Trade in Endangered Species) in 1989. During the 1800's ocelots were found in east and central Texas, western Louisiana and southern Arkansas (Navarro-Lopez, 1985; Woodward, 1980) (Figure 4). Currently, ocelot distribution within the U.S. is limited from southern Texas to the northern border of Tamaulipas, Mexico (Tewes and Everett, 1986) (Figure 4). There are only 2 known breeding populations within southern Texas; one in and around Laguna Atascosa National Wildlife Refuge (LANWR) in eastern Cameron County (i.e., Cameron population) and the other on a private ranch located in Willacy County (i.e., Willacy population) (Navarro-Lopez, 1985; Laack, 1991). According to extensive survey efforts conducted within southern Texas, individuals have been reported outside of these populations but there is no evidence of another breeding population (Fischer, 1998; Tuovila, 1999; Shinn, 2002; Haines et al., *In Press*). The most recent population estimate for ocelots in the U.S. was 80-120 individuals based on available habitat (Tewes and Everett, 1986). Conservation concerns for ocelots include loss of dense thornshrub habitat, mortality from ocelot-vehicle collisions, and genetic erosion (Tewes and Everett,

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This chapter follows the style and format of *Biological Conservation*.

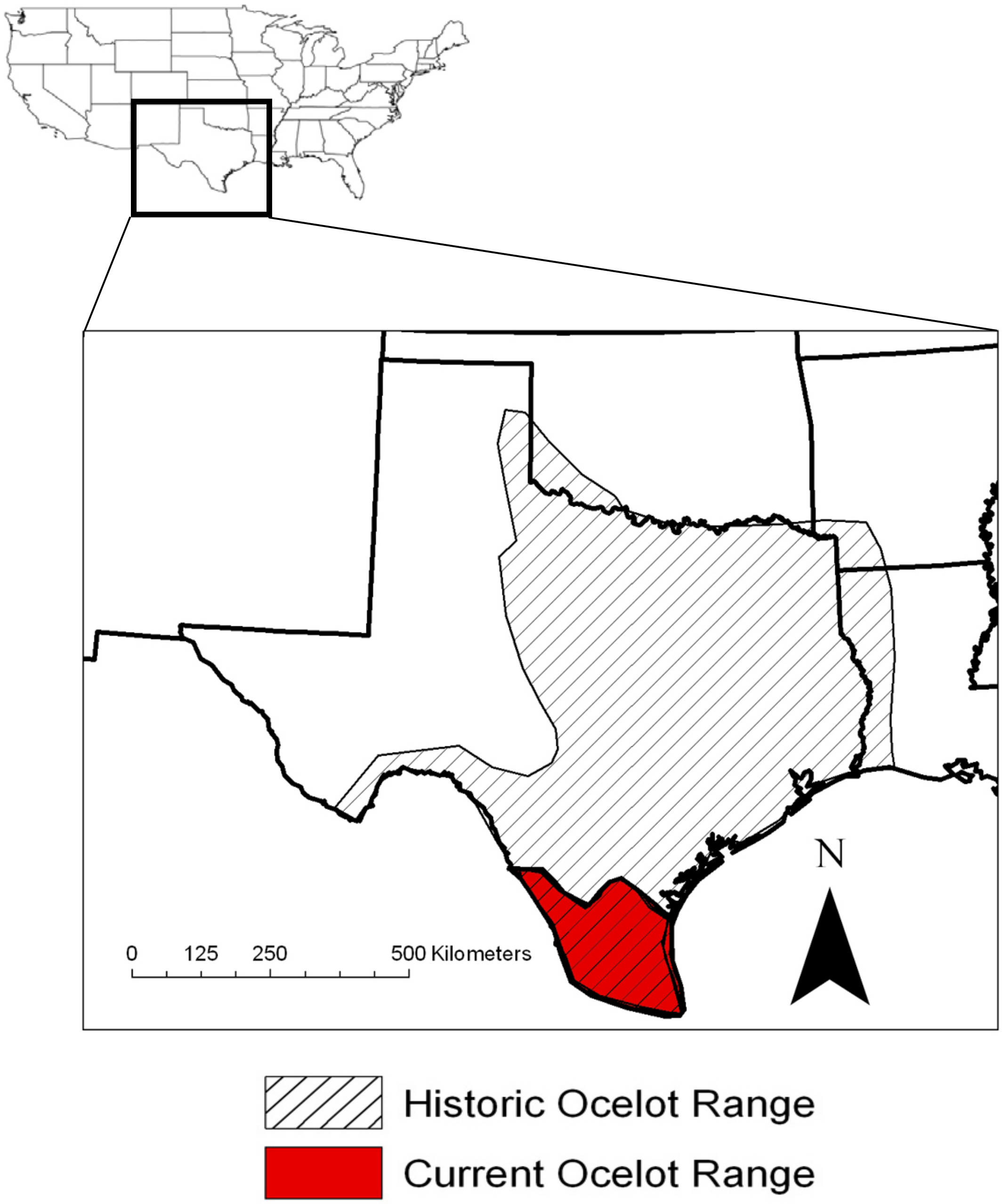

Fig. 4. Historic and current range of ocelots within the United States.

1986; Tewes and Miller, 1987; Walker, 1997; Haines et al., 2005).

In southern Texas, the ocelot has been defined as a habitat specialist, with spatial patterns strongly linked to dense thornshrub communities with ≥95% canopy cover (Navarro-Lopez, 1985; Tewes, 1986; Laack, 1991; Horne, 1998; Shindle and Tewes, 1998; Harveson et al., 2004). Tewes and Everett (1986) and Tewes and Miller (1987) reported that lack of suitable habitat was the greatest threat to ocelot conservation in the U.S. More than 95% of native rangeland within the Lower Rio Grande Valley (LRGV) of southern Texas has been altered for agriculture or development (Jahrsdoerfer and Leslie 1988).

The Lower Rio Grande Valley (LRGV) has the most impoverished and rapidly growing border population of humans in the U.S. (Fulbright and Bryant, 2002). This rapid growth not only threatens the preservation of ocelot habitat but also fosters construction of new roads in the area. A primary source of mortality for ocelots in the LRGV of southern Texas are ocelot-vehicle collisions, constituting 35% of ocelot mortalities followed by natural sources of mortality, other human-caused sources, and unknown sources (Haines et al., 2005). Further, intensively used roads can preclude an at-grade crossing by felids (Beier, 1995), possibly reducing ocelot dispersal to patches of suitable habitat, which may increase genetic isolation and mortality (Beier, 1995).

There has been no dispersal documented between the Cameron and Willacy populations (Navarro-Lopez, 1985; Tewes, 1986; Laack, 1991; Walker, 1997). Additionally, limited gene flow or dispersal occurs between the Tamaulipan ocelot population in northern Mexico and the 2 breeding populations in the U.S. (Walker, 1997).

Walker (1997) suggested that the Cameron and Willacy populations became isolated from the northern Mexico population causing a reduction in genetic variation. Reduction in genetic variation can decrease fitness in a felid population leading to inbreeding depression (O’Brien et al., 1985; O’Brien and Evermann, 1988; Roelke et al., 1993).

Because of impending threats to ocelot conservation, we used a population viability analysis (PVA) to calculate the likelihood of extinction under different management scenarios in Cameron County. In the past, PVAs have been used to evaluate population viability (Shaeffer, 1981), and rank the vulnerability of a species (Mace and Lande, 1991). However, Possingham et al. (1993) and Noon and McKelvey (1996) doubted the ability of PVAs to estimate extinction risk, preferring to use the PVA modeling process to choose between management options. In this study, we used the PVA process to rank management options and evaluate potential recovery strategies for ocelot conservation (Possingham et al., 2002). We concentrated our analysis on the Cameron ocelot population because LANWR has become an island habitat and microsatellite heterozygosity (*MH*) was lower in this population (*MH* = 0.37, *SE* 0.09) compared to the Willacy (*MH* = 0.550, *SE* 0.05) and northern Mexico (*MH* = 0.698, *SE* 0.03) ocelot populations (Walker 1997). In addition, recovery strategies cannot be implemented on private lands as readily as on public lands, and most of the research to estimate ocelot input parameters for this model came from the Cameron population.

The objectives of this study were to use the PVA process to (1) determine the impact of 4 conservation strategies and their possible combinations on the viability of the Cameron population, and (2) conduct a sensitivity analysis of input parameters within the model to identify parameters that most affect ocelot population viability. The 4 conservation strategies we evaluated were (1) translocation of ocelots into the Cameron population (translocation scenario), (2) construction of road underpasses to mitigate ocelot vehicle mortality (reduced road mortality scenario), (3) protection and restoration of habitat patches (habitat scenario), and (4) establishment of a dispersal corridor to the Willacy population of ocelots (linkage scenario).

2. Materials and methods

2.1. Study area

The Cameron population of ocelots resides in and around LANWR located in eastern Cameron County, within the LRGV of southern Texas (Figure 5). The LANWR is an 18,200 ha refuge that provides wintering and feeding areas for migratory waterfowl and habitat for ocelots. The LRGV is an alluvial plain dissected by numerous natural drainages that flow into the Rio Grande or the Gulf of Mexico (Everitt and Drawe, 1993). The LRGV has a wide diversity of fertile soil types (Williams et al., 1977). The subtropical, semiarid climate is characterized by hot summers and mild winters (Thornthwaite, 1948; Lonard and Judd, 1985). Mean length of the frost-free period is 330 days with winters frequently occurring above freezing temperatures. Mean annual temperature and rainfall is 23^{o}C and 68 cm, although rainfall fluctuates widely through the year (Norwine and Bingham, 1985; Lonard et al., 1991).

2.2. PVA software

We used the VORTEX (Version 9.42) program (Lacy et al., 2003) to conduct the PVA. The VORTEX program simulates population changes by following a series of events that describe the typical life history of a sexually reproducing, diploid organism

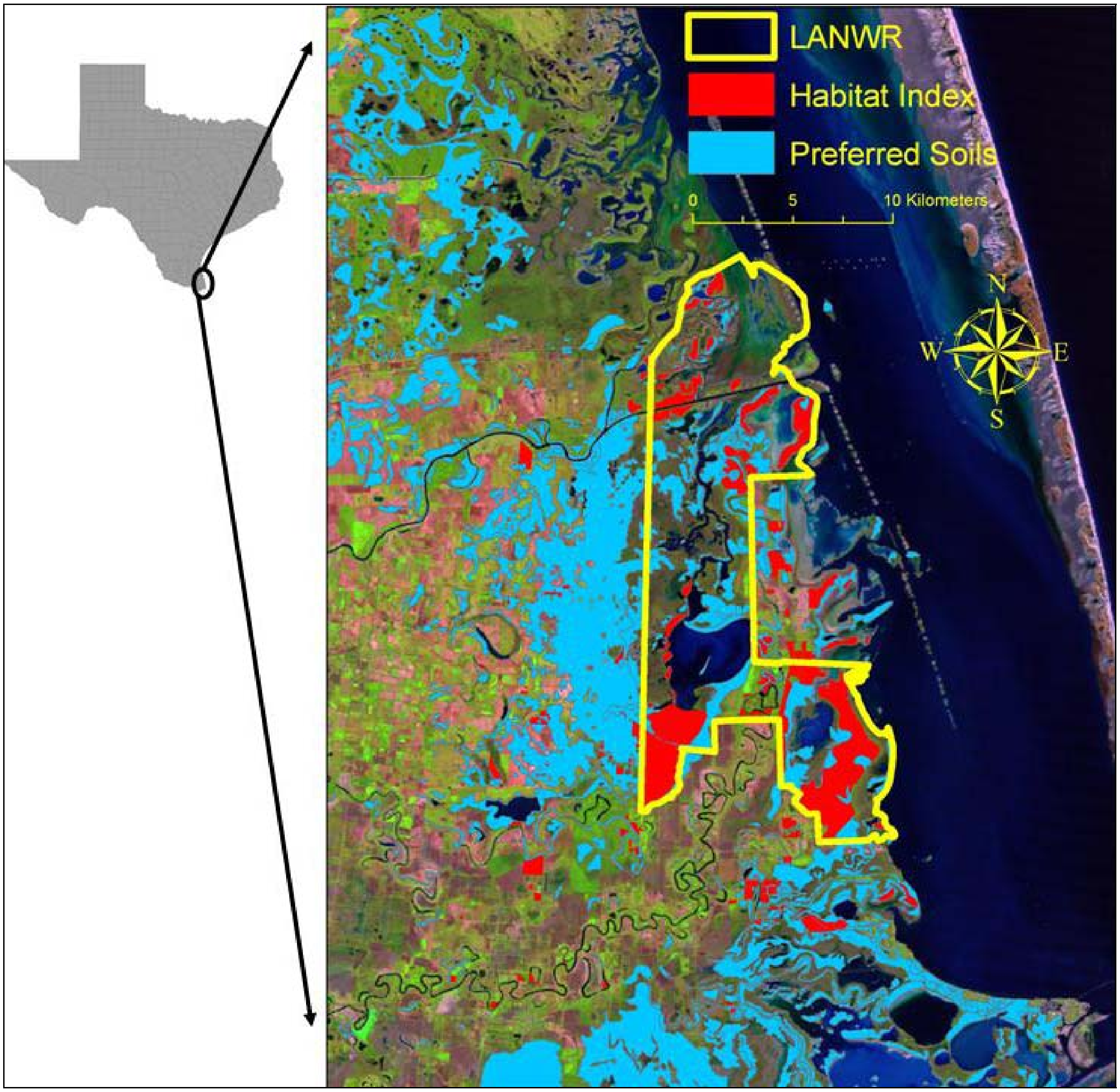

Fig. 5. Map of Laguna Atascosa National Wildlife Refuge (LANWR) and surrounding area showing an index of ocelot habitat patches (dense thornshrub) and areas of preferred soil types for ocelot habitat restoration located in the Lower Rio Grande Valley, Cameron County, Texas, USA.

(Miller and Lacy, 2003). We chose the VORTEX program because it was appropriate for the life history parameters of the ocelot population in southern Texas (Miller and Lacy, 2003). Additionally, VORTEX has been used to evaluate management strategies to help conserve free-ranging mammalian species in other studies (Forys and Humphrey, 1999; Lunney et al. 2002; Maehr et al., 2002; Nilsson, 2003). After each simulation, we recorded the mean stochastic growth rates (r), probabilities of extinction (PE), and mean population size (N) for each model scenario over a 100-year period. We compared the effectiveness of recovery strategies by analyzing the magnitude of extinction probabilities and final population size for each recovery scenario. Because of potential inaccuracies and assumptions within PVAs, we believed that precise estimates of extinction risk and final population size were less important than their magnitudes.

2.3. Input parameters

Key inputs of model parameters are listed in Appendix A for each separate scenario (model). These input parameters were based on an extensive literature review and analysis of ocelot ecology and life history, and on parameters for other similar species (e.g., bobcat *Lynx rufus*). Each scenario was simulated 500 times to estimate extinction risk. We reported population performance over 100 years to analyze the effectiveness of the various recovery scenarios and combinations of recovery strategies over the long-term. We defined extinction as only 1 sex remaining, and modeled only the Cameron population of ocelots in southern Texas.

2.3.1. Reproductive ecology

Ocelots are a long-term polygamous species that exhibit mate monopolization with defined breeding ranges (Tewes, 1986; Ludlow and Sunquist, 1987; Emmons, 1988;

Laack, 1991; Crawshaw, 1995). We defined the age in which females produce their first young to be at 3 years and the age at which males first sire young to be at 4 years (Laack, 1991). Laack (1991) stated that under favorable conditions in the wild, ocelot longevity could be 10 years or more. Hence, we estimated that the maximum age of reproduction for an ocelot in the wild was 11 years. We calculated a distribution of the number of progeny a female ocelot produces based on a maximum litter size of 3 kittens and mean litter size of 1.4 kittens (Eaton, 1977; Mellen, 1989). Thus, 62% of ocelot litters produced 1 young, 37% produced 2 young, and 1% of ocelot females produced 3 young. We estimated that the sex ratio at birth was 50:50 (Eaton, 1977; Mellen, 1989).

2.3.2. Mortality

Mortality rates were based on survival estimates calculated by Haines et al. (2005) for 1–2 and 3+ year old resident ocelots ($M = 0.13$) and preliminary survival estimates calculated by Laack et al. (2004) for 0–1 year old ocelots ($M = 0.29$). Transient ocelots are usually 2–3 years of age (Laack, 1991; Sunquist and Sunquist, 2002) with an annual mortality rate = 0.43 (Haines et al., 2005). Fifty percent of 2–3 year old female ocelots radiomonitored by Haines et al. (2005) were transients with a mean transient period of 6 months, whereas 100% of 2–3 year old males were transients with a mean transient period closer to 9 months. We estimated that females aged 2–3 years spent 3 months as transients (mid-point transient period between no transient period and a 6 month transient period) until they became a resident on a breeding range for the remainder of the year. A 3-month transient survival rate equals 87% ($M = 13\%$) ($0.87^4 = 0.57$), whereas resident 3-month survival equals 96.6% ($M = 3.4\%$) ($0.966^4 = 0.87$). Hence, an annual mortality rate for 2–3 year old females was 22%, and 37% for 2–3 year old males. The environmental variation in mortality corresponded to the standard errors calculated by Laack et al. (2004) and Haines et al. (2005) for survival estimates.

2.3.3. Catastrophe

We specified drought as 1 type of catastrophe. We defined drought periods when the 12-month Palmer Modified Drought Severity Index (PMDI), which assesses the severity of dry or wet conditions, had an index reading <-2.00 within southern Texas (Haines et al., 2005). Because survival for resident and transient ocelots decreased during drought conditions (Haines et al., 2005), we estimated that ocelot survival declined by 10% during drought years. In addition, we assumed that the rate of reproduction declined by 25% during drought years. We analyzed the Modified Palmer Drought Severity Index (PMDI) (National Climatic Data Center; http://www.ncdc.noaa.gov) for Cameron County (Texas region 10) during the last 100 years and found that drought conditions occurred once every 9 years on average.

2.3.4. Carrying capacity and initial population size

The Cameron population in and around LANWR is surrounded on 3 sides (north, south, and west) by intensive agriculture and on the east by the Laguna Madre. Thus, we believed estimates of ocelot carrying capacity also would represent population size. An estimate of the carrying capacity of the effective population size (i.e., number of breeding individuals) for the Cameron population was calculated by averaging ocelot breeding range size estimates. Mean range size for adult male ocelots was 10.5 km^2 (SD = 5.1 km^2), whereas adult female ocelots averaged 6.5 km^2 (SD = 2 km^2) (Navarro-Lopez, 1985; Tewes, 1986; Laack, 1991). We divided the amount of dense thornshrub habitat that was available in and around LANWR by the mean ocelot breeding range size for males and females to calculate an index of carrying capacity for the Cameron population. This was done using data from Cook (2000) within the ArcGIS 8.2 program (Environmental Systems Research Institute, Inc. Redlands, Calif.). The amount of dense thornshrub habitat available for the Cameron ocelot population was 75 km^2. This included dense thornshrub in LANWR and within a 15 km buffer surrounding the refuge (Figure 5). Fifteen kilometers is the maximum dispersal distance recorded for an ocelot in southern Texas (Laack, 1991).

The calculated index of ocelot carrying capacity (and initial population size) was 7 (range = 5–14) adult male ocelots, and 12 (range = 9−17) adult female ocelots. We estimated that the total Cameron population size was 38 ocelots with 14 males and 24 females, because breeding males and females constituted only 50% of captured ocelots (Laack, *personnel communication*; Navarro-Lopez, 1985; Tewes, 1986; Laack, 1991; Haines et al., 2005). Environmental variation in carrying capacity (4.4 individuals) was estimated by calculating the mean of the standard deviations (4.7 male and 4.1 female individuals) of the range and mean number of breeding male ($\bar{x}$ = 7; Range = 5−14; *SD* = 4.7) and female ($\bar{x}$ = 12; Range = 9−17; *SD* = 4.1) ocelots based on breeding range size. We estimated that ocelot carrying capacity would decline 0.5% every year for 40 years due to rapid human population growth in the LRGV (Fulbright and Bryant, 2002). After 40 years the only habitat available would be within the borders of LANWR (60 km^2), where carrying capacity was limited to 30 ocelots.

2.4. Recovery scenarios

2.4.1. Translocation or supplementation (translocation scenario)

In our translocation scenario, we selected the option to supplement 1 adult female ocelot into the Cameron population every year for 40 years. Blundell et al. (2002) recommended reintroductions of females when levels of dispersal are low or when extirpated populations needed to be reestablished.

2.4.2. Reducing ocelot-vehicle collisions (reduced road mortality scenario)

With ocelot-vehicle collisions being one of the leading causes of ocelot mortalities (Haines et al., 2005), we assumed that correct placement and construction of various combinations of bridges, culverts, overpasses, and fencing along roads based on the recommendations of Cain et al. (2003) and Tewes and Hughes (2001), would decrease ocelot-vehicle collisions by 50%. We selected a 50% reduction based on the assumption that some ocelot-vehicle collision mortalities were compensatory and some ocelots would still suffer vehicle-collisions even with the construction of culverts at preferred locations. We incorporated a 50% decrease in ocelot vehicle-collisions into the survival analysis conducted by Haines et al. (2005) and estimated resident and transient ocelot survival under a reduced road mortality scenario (Appendix A).

2.4.3. Habitat protection and restoration (habitat scenario)

In this scenario, we assumed that all identified dense thornshrub habitat patches within and around the LANWR will be maintained for ocelot use. We estimated that 263 km^2 of preferred soil type area (Camargo, Hidalgo, Lamolta, Laredo, Olmito, Point Isabel soil series, and Willamar) (Harveson et al., 2004; Linda Laack, *personnel communication*) was available in and 15 km around LANWR, based on soil data obtained from the Natural Resource Conservation Service (NRCS) soil survey geographic (SSURGO) database (www.ncgc.nrcs.usda.gov/branch/ssb/products/ssurgo/) and using the ArcGIS 8.2 software program (Environmental Systems Research Institute, Inc. Redlands, Calif.). We assumed that 20% of available preferred soil type area (53 km^2) would be restored for ocelot habitat. This increased carrying capacity 68% for a total of 64 ocelots, with 12 breeding males (range = 8-24) and 20 breeding females (range = 15-28). Archer et al. (1988) found that an approximate 40-year period was needed in southern Texas for discrete woody clusters scattered throughout a continuous grassland matrix to move toward a monophasic woodland. Hence, we estimated that the future change in ocelot carrying capacity would increase by 1.7% annually over 40 years (1.7% x 40 years = 68% increase in carrying capacity) because of habitat protection and restoration.

2.4.4. Corridor establishment between the Cameron and Willacy populations (linkage scenario)

As stated previously, there has been no documented dispersal between the Cameron and Willacy populations of breeding ocelots. The purpose of this scenario was to analyze the benefits of establishing a corridor to link the Willacy and Cameron breeding populations of ocelots. Both populations occur along the gulf coast of southern Texas, reside within the LRGV of Texas, and are only 32 km apart. Thus, we concluded that environmental correlation among populations was high and estimated at 0.75. In addition, we specified the same input parameters for the Willacy population as for Cameron population under the control scenario, because little to no demographic data is available on the Willacy population. However, we specified no change in carrying capacity for the Willacy population. Haines et al. (2005) found that most transient ocelots were subadults trying to establish a breeding range. Hence, we specified that dispersing ocelots would be between 2-3 years of age. In addition, Haines et al. (2005), calculated survival rates for dispersing ocelots, which were identified as transients. Thus, transient survival rates were already specified within the mortality input parameters. Furthermore, we assumed the percentage of ocelots within each population that would disperse in a year would be 5%.

2.5. Model Assumptions

For the control scenario, we incorporated inbreeding depression into the population by setting lethal equivalents at a default of 3.14 based on Ralls et al. (1988). We also set the default value of percent lethal equivalents attributed to recessive alleles as 50%, which is consistent with data on other species that have been well studied (Miller and Lacy, 2003). In addition, we assumed that the annual environmental variation in the percent of adult female ocelots that mated was 10%, and that 50% of adult male ocelots were in the breeding pool during a simulated year. We assumed that environmental variation in reproduction was correlated with variation in survival based on work conducted on bobcats in southern Texas by Blankenship (2000). We believed that female ocelots had the potential to breed every year with little seasonality (Eaton, 1977; Laack et al., 2004). In addition, we specified density dependant reproduction in the model and assumed that 85% of females would breed at low density and 65% at high density. This was based on Zezulak and Schwab (1979) that had evidence to suggest that fewer female bobcats breed at high densities. We set the Allee Parameter (A) at 0 and the Steepness Parameter (B) at 2 following the suggestion of Fowler (1981) that density dependence in reproductive success is modeled well with a quadratic function. In addition, we assumed that fecundity declined by 25% during a drought year. These model assumptions were tested in a sensitivity analysis.

3. Results

3.1. Model results

Under the control scenario, the probability of extinction for ocelots on the LANWR over 100 years was estimated at 65% (*PE*), with a negative stochastic exponential growth rate (*r*) of -0.001 (Table 3). The most effective recovery strategy that minimized the probability of extinction and increased population size for the Cameron population of ocelots was the protection and restoration of preferred habitat. This was followed by linkage between the Cameron and Willacy population and reduced road mortality being relatively similarly effective, whereas the translocation of ocelots into the Cameron population was the least effective recovery strategy (Table 3). Every scenario that included habitat protection and restoration as a recovery strategy had a lower probability of extinction and a higher final population size after 100 years (Table 3). However, when reduced road mortality was combined with linkage in a scenario, and when reduced road mortality, linkage, and translocation were combined in a scenario the probability of extinction was also very low, but the final population size was lower than the initial population size.

3.2. Sensitivity analysis

We conducted a sensitivity analysis to evaluate how changes in model assumptions affected population persistence under the various recovery scenarios. In

Table 3.

Results of 16 PVA scenarios for the Cameron breeding population of ocelots conducted over 100 years (*r* = mean stochastic growth rate; *PE* = probability of extinction; *N* = final population size).

			N	
Scenario	*r*	*PE*	$\bar{x}$	*SD*
Control	-0.001	0.65	4.52	7.38
Translocation	0.035	0.44	7.57	8.25
Reduced Road Mortality	0.025	0.27	12.51	9.77
Habitat	0.012	0.11	34.71	17.84
Linkage	0.017	0.20	13.15	8.93
Translocation + Reduced Road Mortality	0.060	0.13	16.48	9.01
Translocation + Habitat	0.037	0.02	44.56	14.00
Translocation + Linkage	0.046	0.10	15.80	8.23
Reduced Road Mortality + Habitat	0.036	0.01	51.99	10.59
Reduced Road Mortality + Linkage	0.040	0.04	20.30	6.81
Habitat + Linkage	0.013	0.02	38.77	14.73
Translocation + Reduced Road Mortality + Habitat	0.063	0.00	54.83	7.70
Translocation + Reduced Road Mortality + Linkage	0.068	0.02	21.01	6.72

Table 3. Continued.

			N	
Scenario	*r*	*PE*	$\bar{x}$	*SD*
Translocation + Habitat + Linkage	0.031	0.01	42.11	13.19
Reduced Road Mortality + Habitat + Linkage	0.032	0.00	50.93	9.70
Translocation + Reduced Road Mortality + Habitat + Linkage	0.053	0.00	52.69	8.78

addition, we conducted a sensitivity analysis for ocelot 0-1 year old mortality rates because current estimates were based on preliminary data. We used a manual perturbation approach to sensitivity analysis by manually altering input parameters at varying levels (Mills and Lindberg, 2002). Variations in input parameters to evaluate model assumptions are specified in Table 4. We evaluated the effects of our sensitivity analysis by analyzing the probability of extinction.

Habitat protection and restoration was still the most effective recovery strategy in minimizing ocelot probability of extinction after changing input parameters for model assumptions for the sensitivity analysis (Table 4). This was followed by both linkage between the Cameron and Willacy populations and reduced road mortality being similarly effective, whereas the translocation of ocelots into the Cameron population was the least effective recovery strategy (Table 4). However, when there was only a 50% average of adult females breeding in year, the most effective recovery strategy was linkage between the Cameron and Willacy populations. However, all recovery strategies under this scenario gave a relatively high probability of extinction.

Within the sensitivity analysis, 4 input parameters showed the greatest variation in extinction probabilities. These included the number of lethal equivalents attributed to lethal alleles, the percentage of recessive alleles, the percentage of females that breed in a year, and ocelot 0-1 year old mortality rates.

Table 4.

Results of the sensitivity analysis conducted over 100 years for the Cameron breeding population of ocelots by reporting the probability of extinction under the various recovery scenarios. The "Road" recovery scenario refers to reduced road mortality.

	Recovery scenarios for the vortex simulation				
Model Inputs	Control	Translocation	Road	Habitat	Linkage
Lethal Equivalents With 50% Attributed To Lethal Alleles					
0	0.11	0.07	0.03	0.00	0.00
3.14	0.65	0.44	0.27	0.11	0.20
6.00	0.97	0.86	0.80	0.68	0.74
Lethal Equivalent of 3.14 Attributed to A Set Percentage Of Recessive Alleles					
25%	0.85	0.57	0.40	0.21	0.37
50%	0.65	0.44	0.27	0.11	0.20
75%	0.48	0.32	0.17	0.07	0.11
Variation in Adult Females Breeding					
0%	0.64	0.42	0.24	0.09	0.21
10%	0.65	0.44	0.27	0.11	0.20
20%	0.70	0.48	0.28	0.14	0.20
% of Adult Males Breeding					
25%	0.70	0.47	0.30	0.16	0.21

Table 4. Continued.

	Recovery scenarios for the vortex simulation				
Model Inputs	Control	Translocation	Road	Habitat	Linkage
50%	0.65	0.44	0.27	0.11	0.20
75%	0.62	0.41	0.21	0.11	0.21
% Females With Litter/Year					
75%@ Low Density 25%@ High Density	0.97	0.85	0.77	0.76	0.51
85% @ Low Density 65% @ High Density	0.65	0.44	0.27	0.11	0.20
100%@ Low Density 75% @ High Density	0.24	0.14	0.04	0.00	0.04
Reproduction Not Correlated With Survival	0.63	0.35	0.24	0.09	0.17
Reproduction Correlated With Survival	0.65	0.44	0.27	0.11	0.20
% Reduction in Survival & Reproduction Rate During a Catastrophe					
5% & 15%	0.63	0.45	0.26	0.08	0.18
10% & 25%	0.65	0.44	0.27	0.11	0.20
15% & 35%	0.66	0.45	0.31	0.13	0.17

Table 4. Continued.

	Recovery scenarios for the vortex simulation				
Model Inputs	Control	Translocation	Road	Habitat	Linkage
Ocelot 0-1 Year Old Mortality Rate					
35	0.81	0.58	0.45	0.31	0.42
29	0.65	0.44	0.27	0.11	0.20
25	0.56	0.34	0.19	0.05	0.13

4. Discussion

The PVA model for the Cameron population of breeding ocelots identified protection and restoration of thornshrub habitat as being essential to the viability of the Cameron population of ocelots. In PVA simulations conducted for the Florida panther in 1989 and 1992, a ≥25% decline in preferred habitat indicated that the population had no probability of persisting for 100 years (Maehr et al., 2002).

4.1. Private landowners

Protection and restoration of sufficient ocelot habitat requires the participation of private landowners. Important tracts of potential ocelot habitat are owned by private landowners. Economic incentives for landowners to maintain and restore ocelot habitat on their land could promote ocelot recovery. Protection and restoration of ocelot habitat on private lands would probably increase ocelot carrying capacity and could potentially link the Cameron and Willacy ocelot breeding populations. Safe harbor agreements (U.S. Fish and Wildlife Service, 1997) may provide the security umbrella and incentives sought by landowners. Incentives provided by the Farm Bill (Potts, 2003), and tax-related tactics such as conservation easements that encourage landowners to retain and maintain ocelot habitat (Fulbright and Bryant, 2002) can benefit ocelot habitat recovery. In addition, communication between public land managers and private landowners may aid in the implementation of ocelot recovery strategies, landowner participation, and resolution of any perceived fears of government constraints of private land use.

4.1.2 Potential for habitat corridors

If private and public lands beyond the boundaries of LANWR were managed for ocelot habitat protection and restoration, this may not only increase ocelot carrying capacity but also enhance dispersal potential between the Cameron ocelot population and the Willacy and northern Mexico populations. In conducting a PVA for cougars in the Santa Ana Mountains of southern California, Beier (1996) found that the preservation of corridors was essential for the persistence of the cougar population, with only a few dispersers a decade needed to benefit an isolated population (Beier, 1993). In addition to ocelot habitat protection and restoration, the effectiveness of a developed ocelot habitat corridor can be increased by the placement of an appropriately designed culvert under roads that may cross a habitat corridor (Foster and Humphrey, 1992; Beier, 1996).

Increased dispersal of ocelots can potentially increase the overall genetic diversity of ocelots in the Cameron population. However, a low level of genetic heterozygosity is not always directly correlated with extinction probability. In some species population persistence does not seem to be impaired under low levels of genetic heterozygosity (Hoelzel et al., 1993; Sherwin et al., 1991). Lande (1988) stated that stochastic, demographic, and behavioral considerations should be of greater importance when formulating recovery plans for endangered species rather than genetic heterozygosity. However, O’Brien and Evermann (1988) found evidence that monitoring genetic heterozygosity was important for monitoring species population health. Furthermore, the effects of inbreeding may have been underestimated by the VORTEX model. The VORTEX program models inbreeding depression as the reduction of 1st year survival, whereas other potential impacts of inbreeding include reduced adult survival, fecundity, disease resistance, and success in competition for mates (Miller and Lacy, 2003). Hence, the potential benefits of ocelot supplementation as a recovery strategy for the Cameron population may have been underestimated in our PVA analysis.

4.2.1. Future research

Estimated extinction risk was sensitive to the number of lethal equivalents, a variable that may be impossible to estimate in wild ocelot populations, and the percentage of recessive alleles. Because of the sensitivity of these input parameters, more research on the genetics of ocelots is needed even if it is for captive populations. In addition, given the relatively high sensitivity of estimated extinction risk to percent of females breeding a year and ocelot 0-1 year old mortality rates, research priorities should include better estimates of these input parameters. The sensitivity of these input parameters further justifies our caution for interpreting all estimates of extinction risk produced by our PVA, and instead use the magnitude of extinction estimates to rank recovery strategies (Beissinger and Westphal, 1998; Ludwig and Walters, 2002).

Translocation has a success rate of only 54% for free-ranging species (Wolf et al., 1996), and the benefits of road culverts to ocelot survival have not been documented. Furthermore, the estimates of the amount of potential habitat that can be protected and restored may be optimistic and value of habitat patches to ocelots may be dependant on area, shape, and distance to other patches. However, the potential benefits provided by recovery strategies as specified in our scenarios do represent a viable inference of potential benefits to the Cameron ocelot population. We believe that the results of this model represent recovery strategies or combinations of strategies most effective in limiting the probability of extinction for the Cameron ocelot population.

Using an adaptive management approach by monitoring ocelot populations and habitats, and continuing research can answer questions about the effectiveness of recovery strategies (Beissinger and Westphal, 1998; Ludwig and Walters, 2002). In addition, a more accurate and current habitat map of southern Texas can be developed to provide a better determination of available ocelot habitat. An accurate habitat map of the south Texas landscape would assist recovery efforts and allow breeding populations of ocelots to be modeled within a metapopulation paradigm by incorporating the Cameron, Willacy, and northern Mexico populations. We also believe a cost-benefit analysis of recovery strategies is needed to evaluate the financial costs of management actions.

4.3. Conclusion

Currently, action must be taken to reduce the high probability of extinction predicted in our PVA analysis for the Cameron ocelot population. These actions include construction of effective ocelot culverts to reduce road mortality, assessing the possibility of ocelot translocation, identifying potential ocelot travel corridors, and most importantly protecting existing ocelot habitat and restoring ocelot habitat on suitable sites with appropriate soil conditions. Combinations of these recovery strategies are needed to most effectively reduce the ocelot probability of extinction over 100 years. These recovery actions will require interaction of private landowners and state and federal agencies to help conserve the relict breeding ocelots within the United States.

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CHAPTER IV

HABITAT-BASED POPULATION VIABILITY ANALYSIS FOR OCELOTS (*LEOPARDUS PARDALIS*) IN THE UNITED STATES

1. Introduction

In 1982, the ocelot *Leopardus pardalis* population within the United States (U.S.) was listed as endangered by the U.S. Fish and Wildlife Service, and in 1989 the ocelot was included in Appendix I of CITES (Convention on International Trade in Endangered Species) (Sunquist and Sunquist, 2002). Currently, there are only 2 known breeding populations of ocelots in the U.S.; 1 in Cameron County, Texas, and the other in Willacy County, Texas (Navarro-Lopez, 1985; Tewes and Everett, 1986; Laack, 1991; Haines et al., 2006) (Figure 6). However, no ocelot dispersal has been documented between the Cameron and Willacy populations (Navarro-Lopez, 1985; Tewes, 1986; Laack, 1991; Walker, 1997). Major threats faced by these populations include loss of habitat, road-mortalities, and genetic isolation (Tewes and Everett, 1986; Tewes and Miller, 1987; Walker, 1997; Haines et al., 2005 *[a]*). Recovery strategies are needed to maintain and expand current ocelot populations in the U.S. prior to delisting (U.S. Congress, 1988).

Recently, Haines et al. (2005 *[b]*) developed a population viability analysis (PVA) to evaluate recovery strategies for the ocelot population in Cameron County. They concluded that the most effective recovery scenario for ocelots was the protection and restoration of ocelot habitat. However, combinations of different recovery strategies

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This chapter follows the style and format of *Biological Conservation*.

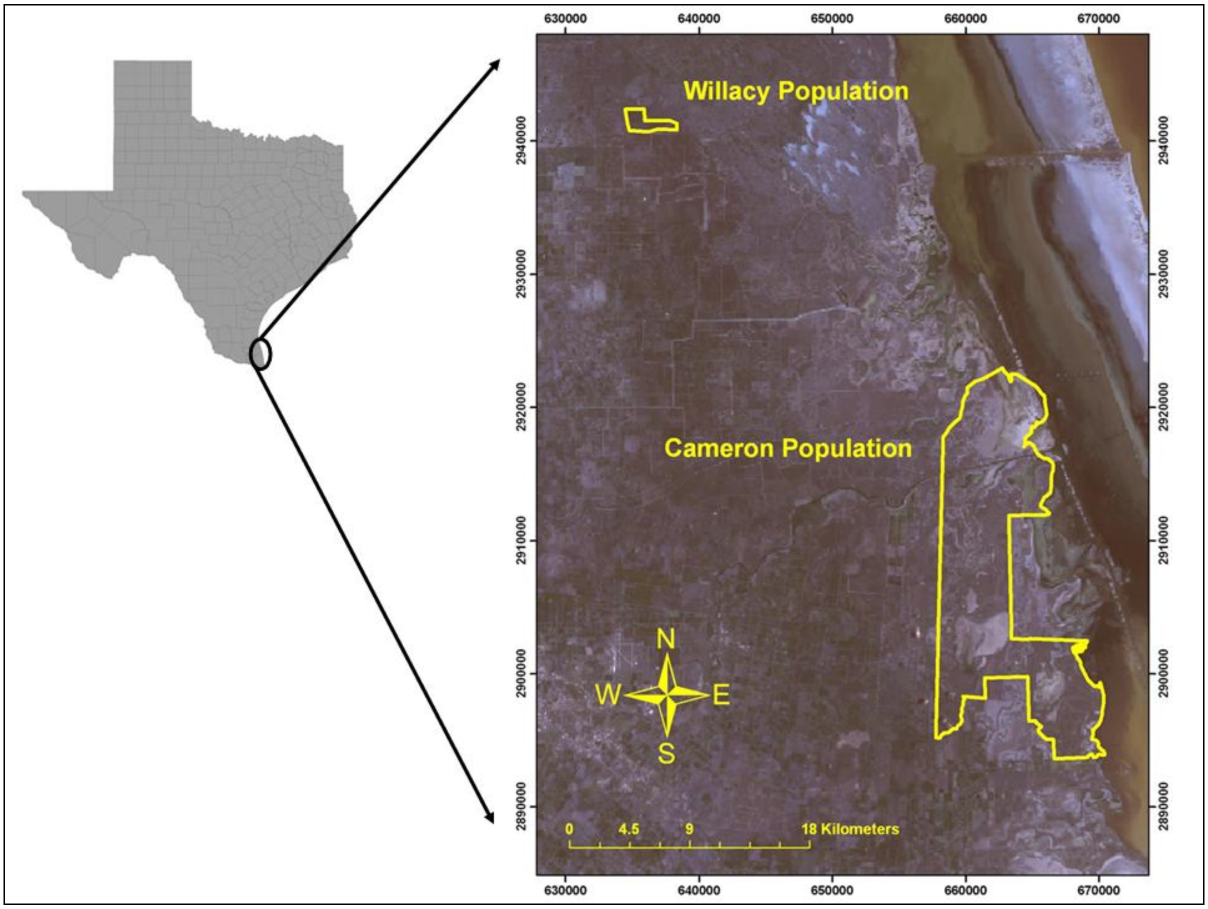


Fig. 6.

Map of Laguna Atascosa National Wildlife Refuge (LANWR) (Cameron Population) and 2 connected conservation easements (Willacy Population) in the Lower Rio Grande Valley, Cameron and Willacy counties, Texas, USA (UTM Coordinates in Zone 14R).

was most effective at reducing ocelot probability of extinction in Cameron County over 100 years (Haines et al., 2005 *[b]*).

Noon and McKelvey (1996), Beissinger and Westphal (1998), Possingham et al. (2002), and Reed et al. (2002) believed that the optimal use of PVA was to compare the outcomes for different model scenarios resulting from management decisions, and that comparisons should focus on the relative effectiveness of the different management actions, particularly compared to baseline or current conditions. The 4 conservation strategies we evaluated were the same as those evaluated by Haines et al. (2005 *[b]*): (1) translocation of ocelots into the U.S. from northern Mexico (translocation scenario), (2) construction of road underpasses to mitigate ocelot-vehicle mortality (reduced road mortality scenario), (3) restoration of ocelot habitat (habitat scenario), and (4) establishment of a dispersal corridor between the Cameron and Willacy populations of ocelots (linkage scenario).

Boyce (1993), Maehr et al. (2002), and Ralls et al. (2002) believed the PVA process was useful as a long-term, iterative process coupled with an adaptive management approach to species recovery. In addition, Haines et al. (2005 *[b]*) recommended using an adaptive management approach by monitoring ocelot populations and habitats, and continuing research to evaluate the effectiveness of recovery strategies. Furthermore, Haines et al. (2005 *[b]*) stated that the value of habitat patches to ocelots may be dependant on patch area, shape, and distance to other habitat patches. Thus, Haines et al. (2005 *[b]*) recommended the development of a habitat-based PVA for the 2 ocelot populations in southern Texas.

The habitat-based PVA model described herein updates the first PVA by incorporating more than 1 population into the analysis, incorporates spatial data, and includes updated input parameters. Akcakaya (2000) stated that unlike a single population model, the dynamics of a spatial metapopulation model includes spatial variation and interaction among populations, geographic configuration of habitat patches, dispersal, and spatial correlation.

Haines et al. (2005 *[b]*) used the VORTEX (Version 9.42) program (Lacy et al., 2003) to conduct the PVA analysis. We used RAMAS/GIS (Akcakaya, 2002) software to conduct the habitat-based PVA by linking landscape data from geographical information system analysis with a demographic metapopulation model based on input parameters from Haines et al. (2005 *[b]*) and Laack et al. (2005) (Akcakaya, 2000). Brook et al. (2000) found that PVAs were moderately accurate in predicting risk of population decline when using the RAMAS and VORTEX programs. In addition, the RAMAS/GIS program (Akcakaya, 2002) has been used in other studies to combine landscape data with demographic data for helmeted honeyeaters *Lichenostomus melanops cassidix*, California gnatcatchers *Polioptila californica californica*, and spotted owls *Strix occidentalis caurina* (Akcakaya et al., 1995; Akcakaya and Atwood, 1997; Akcakaya and Raphael, 1998).

The objectives of this study were to (1) develop a current landscape map of southern Texas that identifies areas important for ocelot conservation, (2) develop a habitat suitability model for ocelots in southern Texas, (3) link this model to an ocelot metapopulation model for viability analysis, (4) determine the impact of 4 conservation strategies and their possible combinations on the viability of the ocelot metapopulation in the U.S., and (5) conduct a sensitivity analysis of model input parameters to identify parameters that significantly affect ocelot population viability. In addition, a goal of this study was to provide the ocelot recovery team a model for evaluating recovery strategies for ocelots in the U.S.

2. Materials and methods

2.1. Study area

The ocelot population in Cameron County (i.e., Cameron population) resides in and around Laguna Atascosa National Wildlife Refuge (LANWR) located in eastern Cameron County, and the ocelot population in Willacy County (i.e., Willacy population) resides in and around the Yturria Ranch located in north-central Willacy County (Figure 6). Both populations reside in extreme southern Texas within the Lower Rio Grande Valley (LRGV). The LRGV is an alluvial plain dissected by numerous natural drainages that flow into the Rio Grande or the Gulf of Mexico (Everitt and Drawe, 1993) and has a wide diversity of fertile soil types (Williams et al., 1977). The subtropical, semiarid climate is characterized by hot summers and mild winters (Thornthwaite, 1948; Lonard and Judd, 1985). Mean length of the frost-free period is 330 days with winters frequently occurring above freezing temperatures. Mean annual temperature and rainfall is 23^{o}C and 68 cm, respectively, although rainfall fluctuates widely through the year and among years (Norwine and Bingham, 1985; Lonard et al., 1991).

2.2. PVA software

The RAMAS/GIS Spatial Data program determined the spatial structure of the ocelot metapopulation in southern Texas with a user-defined habitat suitability function based on regression coefficients used to evaluate ocelot cover importance (Akcakaya, 2000; Akcakaya, 2002). Spatial data (i.e., ocelot cover map) were linked to ocelot demographic data using the RAMAS/GIS Metapopulation program (Akcakaya, 2002) to produce a spatial metapopulation model of the Cameron and Willacy ocelot populations. Results of these model simulations were used to compare management options (Akcakaya, 2002).

Each scenario was simulated 1,000 times to estimate extinction risk. Akcakaya (2002) and Beissinger and Westphal (1998) suggested that short to medium time horizons may be more appropriate in models that are comparing alternative management options (e.g., 10, 25, or 50 years). Thus, we reported population performance over 50 years to analyze the effectiveness of the various recovery scenarios and combinations of recovery strategies. We defined extinction as only 1 individual remaining, and conducted a metapopulation model for the Cameron and Willacy ocelot populations.

2.3. Input parameters

Key inputs for the metapopulation model are listed in Appendix B for each separate model scenario (i.e., control, reduced road-mortality, translocation, linkage, and habitat). Most input parameters were based on those listed by Haines et al. (2005 *[b]*) with original information sources from Eaton (1977), Navarro-Lopez (1985), Tewes (1986), Ludlow and Sunquist (1987), Emmons (1988), Mellen, (1989), Laack (1991), Crawshaw (1995), Sunquist and Sunquist (2002), and Haines et al. (2005 *[a]*). In addition, we updated 2 reproductive life history parameters recently estimated by Laack et al. (2005). These parameters included new estimates for ocelot first year survival (68%) and mean litter size (1.2 kittens) (Appendix B). In addition, we developed an ocelot stage-matrix based on input parameters specified in Appendix B to be incorporated into the metapopulation model and combined with spatial data (Table 5).

To obtain an index of ocelot carrying capacity we reanalyzed home range data from Tewes (1986) and Laack (1991). We recalculated home range size for 8 female and 10 male ocelots with stable breeding ranges and >30 estimated locations using the 95% adaptive kernel home range estimator with least square cross validation in the program BIOTIS® (Ecological Software Solutions, 2004). The kernel home range estimator outperformed other estimators evaluated by Kernohan et al. (2001), and is recommended for most applications. We found that the mean home range size for breeding male ocelots in southern Texas was 3.71 km^2 (SD = 2.5 km^2) and the mean home range size for breeding female ocelots in southern Texas was 2.1 km^2 (SD = 1.2 km^2). Thus, carrying capacity and initial population size were based on these home range estimates.

We specified that all vital rates (survival and reproduction) were affected by density dependence in our model. This specification was based on ocelots being territorial with documented intraspecific mortality (Haines et al., 2005 *[a]*). We specified density dependence as a ceiling model, where the population grows exponentially until reaching a ceiling population size (i.e., carrying capacity) and remains at that level (Akcakaya, 2002). This type of density dependence may occur with ocelots when all territories are occupied.

We defined environmental variation as the standard deviation in carrying capacity, which Haines et al. (2005 *[b]*) calculated as 12% for the Cameron population. In addition, environmental variation was incorporated into the model as the standard deviation within the ocelot stage-matrix (Table 5).

Table 5.

Stage-matrices for ocelots in southern Texas specifying reproductive and survival input parameters under the control scenario to link spatial data with demographic data in the RAMAS/GIS Metapopulation program (standard deviations in parenthesis). ([a] Proportion of females born each year for each adult female; [b] Proportion of males born each year for each adult female).

	Age 0-1	Age 1-2	Age 2-3	Adult Age 3+
Female				
Fecundity	0.00	0.00	0.00	0.45[a] (0.17)
Survival	0.68 (0.05)	0.00	0.00	0.00
Survival	0.00	0.87 (0.02)	0.00	0.00
Survival	0.00	0.00	0.78 (0.05)	0.87 (0.02)
Male				
Fecundity	0.00	0.00	0.00	0.45[b] (0.17)
Survival	0.68 (0.05)	0.00	0.00	0.00
Survival	0.00	0.87 (0.02)	0.00	0.00
Survival	0.00	0.00	0.63 (0.10)	0.87 (0.02)

2.4. Ocelot cover map

The ocelot has been defined as a habitat specialist, with spatial patterns strongly linked to ≥95% canopy cover of the shrub layer (Navarro-Lopez, 1985; Tewes, 1986; Laack, 1991; Horne, 1998; Harveson et al., 2004). In addition, Harveson et al. (2004) and Horne (1998) found that ocelots did not avoid areas with 75-95% canopy cover, but stated that ocelots avoided areas with <75% canopy cover. Jackson et al. (2005) identified areas of open and closed canopy within Willacy and Cameron counties. However, Jackson et al. (2005) did not define percentage of canopy cover and therefore did not identify areas with >75% canopy cover. Thus, we developed an ocelot cover map for Willacy and Cameron counties that identified habitat with >75% canopy cover. This analysis was conducted by delineating spatial data from a LANDSAT ETM 7 satellite image of southern Texas (March 2003) downloaded from the Texas Synergy website (www.synergyx.tacc.utexas.edu) based on methods applied by Haines et al. (*In Press*). The LANDSAT imagery was used to identify, digitize, and create shapefiles for different cover layers (i.e., >75% woody cover [closed], 26-75% woody cover [mixed], 1-25% woody cover [open], <1% cover [bare], and water) in the ArcGIS 9.0 software program (ESRI®, Inc. Redlands, Calif.).

Shapefiles of cover layers served as training sites to develop spectra-reflective signatures that were used in a supervised classification using the ERDAS IMAGINE 8.7 software program (ERDAS®, Inc. Atlanta, Georgia). We used the supervised classification (i.e., cover map) to identify ocelot cover in those areas where field verification of cover (i.e., accuracy assessment) could be achieved in Cameron and

Willacy counties. Based on this analysis, we identified potential ocelot habitat within the Cameron and Willacy populations.

2.4.1. Accuracy assessment

An accuracy assessment of the supervised classification was conducted using the accuracy assessment tool in ERDAS IMAGINE 8.7, which created random points within a specified cover layer. We used $\geq$50 accessible random reference points for each cover layer as suggested by Congalton (1991). We downloaded these random points into a GARMIN global positioning system unit (GARMIN® International Inc., Olathe, Kansas), and conducted a ground survey in Cameron and Willacy counties, to find and ground truth the cover layer of each accessible random point. An accuracy assessment was also conducted using 1996 mosaics of Cameron and Willacy counties (based on 1996 geo-referenced aerial photos) obtained from the Wildlife Research Technologies Lab located at the Caesar Kleberg Wildlife Research Institute at Texas A&M University-Kingsville. This analysis verified that canopy cover in 1996 was similar to 2003. The minimum level of accuracy acceptable for land use and land cover classification was 85% (Anderson et al., 1976).

2.5. Ocelot telemetry

Ocelots were captured using single-door, 108 × 55 × 40 cm wire box traps (Tomahawk Trap® Co., Tomahawk, WI) with a separate compartment that contained a domestic live chicken as bait from November 1996 through January 2005. We immobilized ocelots with a 9:1 ratio of ketamine hydrochloride and acepromazine maleate (Beltran and Tewes, 1995) and injected this mixture with a pole syringe at a dosage of 20 mg/kg body weight. Ocelots were sexed, weighed, and classified as adults or subadults based on maturation of morphological development, dental wear, canine length (>15 mm for adults), and weight (female adults >6.5 kg, male adults >8.5 kg) (Laack 1991).

Each immobilized ocelot was fitted with a 120 g VHF collar containing a mortality sensor and a frequency of 148−149 MHz (Telonics® Inc., Mesa Ariz.). We used ground stations and radiotelemetry to locate ocelots approximately 4-6 times each week (i.e., approximately 2-3 diurnal locations and 2-3 nocturnal locations). We monitored radio signals with a directional H-antenna connected to a model TR-2 receiver (Telonics® Inc., Mesa Ariz.) from December 1996 through March 2005. Ocelot locations were determined by triangulating on the direction of the radio signal from 2 or 3 known points on the ground and using the LOAS® program to obtain location estimations used to calculate a habitat suitability function (Ecological Software Solutions^{TM}).

2.6. Habitat suitability function

We defined the study area boundary as the minimum convex polygon of all estimated ocelot locations. The spatial analyst tool in ArcGIS 9.0 calculated distances of each estimated ocelot location to each cover type within the study area. In addition, we generated random points within the study area using the Hawth's analysis tools (Hawth's Analysis Tools 2002-2005 © Version 3.11) in ArcGIS 9.0. These random points were buffered 100-m from estimated ocelot locations and distances of random points to each cover type was calculated using the spatial analyst tool in ArcGIS 9.0.

We used logistic regression (SAS Institute, 2000) to calculate a habitat suitability function for ocelots in the study area, which was used to calculate an index of habitat suitability for each pixel cell in the cover map. The response variable for the logistic regression was indicated where the response variable is binary (e.g., 0 = random locations, 1 = ocelot locations). We used a stepwise regression with a significance level of $p = 0.01$ for adding and removing variables. After individual variables were tested, we tested interaction terms to calculate significance (Akcakaya, 2002).

2.7. Recovery scenarios

We followed recommendations similar to Haines et al. (2005 *[b]*) in specifying potential benefits provided by various recovery strategies. For the scenario, 1 female ocelot of age class 2-3 was translocated from northern Mexico into the Cameron population every other year for 40 years. For the reduced road mortality scenario, we assumed that correct placement and construction of culverts would reduce ocelot-vehicle collisions by 50%, a value incorporated into the survival analysis conducted by Haines et al. (2005 *[a]*). For the habitat scenario, we assumed that an increase in habitat on preferred soil types (Harveson et al. 2004), as defined by Haines et al. (2005 *[b]*), would increase ocelot carrying capacity by 50%. For the linkage scenario, we assumed that ocelots in large habitat patches within the Willacy and Cameron populations would have an annual dispersal rate of 0.10. In addition, we developed a least-cost path model to identify an optimum ocelot dispersal corridor between the Cameron and Willacy populations for the linkage scenario. This assessment used the spatial analyst tool in ArcGIS 9.0.

2.8. Data analysis

After each model simulation, we recorded the probability of extinction (*PE*), and mean population size (*N*) for each model scenario over a 50-year period using the

RAMAS/GIS Metapopulation program. We compared the effectiveness of recovery strategies using the RAMAS/GIS Comparison of Results program. The Comparison of Results program used the Kolmogorov-Smirnov test statistic D, which measured the maximum vertical distance between risk curves of 2 or more different model scenarios (Akcakaya, 2002). We compared terminal extinction risk curves between model scenarios and defined statistical significance at $p < 0.001$.

Based on these test results we ranked the effectiveness of recovery strategies. Because of the potential inaccuracies and assumptions within PVAs, we believed that the Kolmogorov-Smirnov test statistic was appropriate for analyzing the magnitude of the model results instead of measuring precise estimates of extinction probability and final population size (Beissinger and Westphal, 1998; Ludwig and Walters, 2002; Haines et al., 2005 *[b]*).

2.9. Sensitivity analysis

Model assumptions were tested in a sensitivity analysis. We assumed that environmental variation in reproduction was correlated with variation in survival based on research conducted on bobcats *Lynx rufus* in southern Texas (Blankenship, 2000) and information presented by Zezulak and Schwab (1979) that suggested that fewer female bobcats breed at high densities. Furthermore, we assumed that the distribution of environmental stochasticity was lognormal. Other assumptions included that initial population size was only 1 less than the carrying capacity, that ocelot fecundity dropped by 25% during a drought year, and ocelot dispersal was density dependent.

A model scenario assuming that subpopulations 1 and 2 contained no ocelots (refer to results section 3.3), because ocelot habitat was not verified within these subpopulations, was compared to the control scenario, and a model scenario in which all vital rates were correlated was compared to a scenario in which vital rates were not correlated. Environmental variation was compared using a normal distribution and a lognormal distribution, and we assessed the effects of having all ocelot stages incorporated with density dependence compared to ocelots of age class 0-1 not incorporated with density dependence. In addition, we ran the model over 100 years, as conducted by Haines et al., (2005 *[b]*), to evaluate the effectiveness of recovery strategies.

Other assumptions were tested using the RAMAS/GIS Sensitivity Analysis program. We varied rates of initial population size, density dependant dispersal, dispersal, and correlation by ± 10% and analyzed the differences. However, we did not conduct a sensitivity analysis for the effects of drought on model results because Haines et al (2005 *[b]*) found it had no significant effect on model results.

Sensitivity analyses were conducted for the control, habitat, linkage, road, and translocation scenarios. Results of the sensitivity analyses were compared using the RAMAS/GIS Comparison of Results program that used the Kolmogorov-Smirnov test (Akcakaya, 2002). We compared terminal extinction risk curves between model scenarios and based statistical significance when $p < 0.001$ to identify which assumptions significantly changed model results.

3. Results

3.1. Ocelot cover map

The cover map identified areas of closed cover, mixed cover, open cover, bare ground, and water with 88% accuracy in Willacy and Cameron counties during 2005. In addition, the cover map identified cover types with 87% accuracy in Willacy and Cameron counties during 1996. Because the results of our accuracy assessments were >85% for the cover map, we used the cover map as an index for land use classification in southern Texas (Anderson et al., 1976).

3.2. Ocelot telemetry & habitat suitability function

We captured 30 ocelots (14 females, 16 males), from which we obtained 810 estimated locations from June 1996 through March 2005. The chi-square goodness-of-fit for the logistic regression model was highly significant ($\chi^2_5 = 688.49$, $p < 0.01$) with closed, mixed, open, and bare cover statistically significant ($p \leq 0.001$). Water and interaction terms were not significant. Based on the value of the regression coefficients calculated in the regression model for each cover variable, closed cover had the highest value and was closest to ocelot locations followed by mixed and open cover, with bare ground having a negative slope value and being the farthest cover type from ocelot locations. We calculated the following habitat suitability function for ocelots in the cover map based on these regression coefficients of the slope and an estimated y-intercept constant = 1.5786:

(0.0122*[Closed]+0.00168*[Mixed]+0.000712*[Open]-0.00288*[Bare]+1.5786).

We specified a habitat suitability threshold and a neighborhood distance to link the habitat map to the metapopulation model. Laack et al. (2005) analyzed 10 ocelot den sites, and found that they were located within close proximity to, or directly underneath, dense thornshrub cover, with the exception of 1 den site that had no vertical cover but was found along a thornshrub corridor with dense canopy cover nearby. Thus, we defined the habitat suitability threshold as 1.598, which defined all areas with >75% canopy cover and represented the minimal pixel value below which habitat would not be suitable for ocelot reproduction. Navarro-Lopez (1985) monitored 5 ocelots in Willacy County and found that the mean daily movement was approximately 800 m. Thus, we defined the neighborhood distance as 1.5, which corresponds to a buffer of 1 km around habitat patches being included as part of the same patch.

3.3 Spatial data

Based on the results of the RAMAS/GIS Spatial Data program, we identified 11 habitat patches (i.e., subpopulations) that had an area >3.71 km^2, and were deemed large enough to provide resources for at least 1 breeding male ocelot (Table 6). Based on distances between habitat patches we concluded that habitat patches 1-3 belonged to the Willacy population and habitat patches 4-11 belonged to the Cameron population. We calculated an index of carrying capacity for each patch by dividing the patch area by mean ocelot stable breeding range sizes defined in section 2.3. Thus, a patch size of 4 km^2 could be used by 1 breeding male and 2 breeding females. In addition, since breeding adults constitute only half of the captured ocelot population (Laack, *personnel communication*; Navarro-Lopez, 1985; Tewes, 1986; Laack, 1991; Haines et al., 2005 *[a]*) the full carrying capacity for a 4 km^2 habitat patch would be 6 ocelots (Table 6).

Table 6.

Identification of 11 habitat patches (i.e., subpopulations) within 2 ocelot breeding populations in southern Texas identified by the RAMAS/GIS Spatial Data program (*K* = carrying capacity; *Nt* = initial population size).

Patch ID	Patch Size (km^2)	*K*	*Nt*	Population (Willacy/Cameron)
1	4.00	6	5	Willacy
2	6.00	10	9	Willacy
3	4.00	6	5	Willacy
4	4.00	6	5	Cameron
5	5.00	6	5	Cameron
6	7.00	10	9	Cameron
7	4.00	6	5	Cameron
8	5.00	6	5	Cameron
9	7.00	10	9	Cameron
10	6.00	10	9	Cameron
11	4.00	6	5	Cameron
Total:	56.00	82	71	

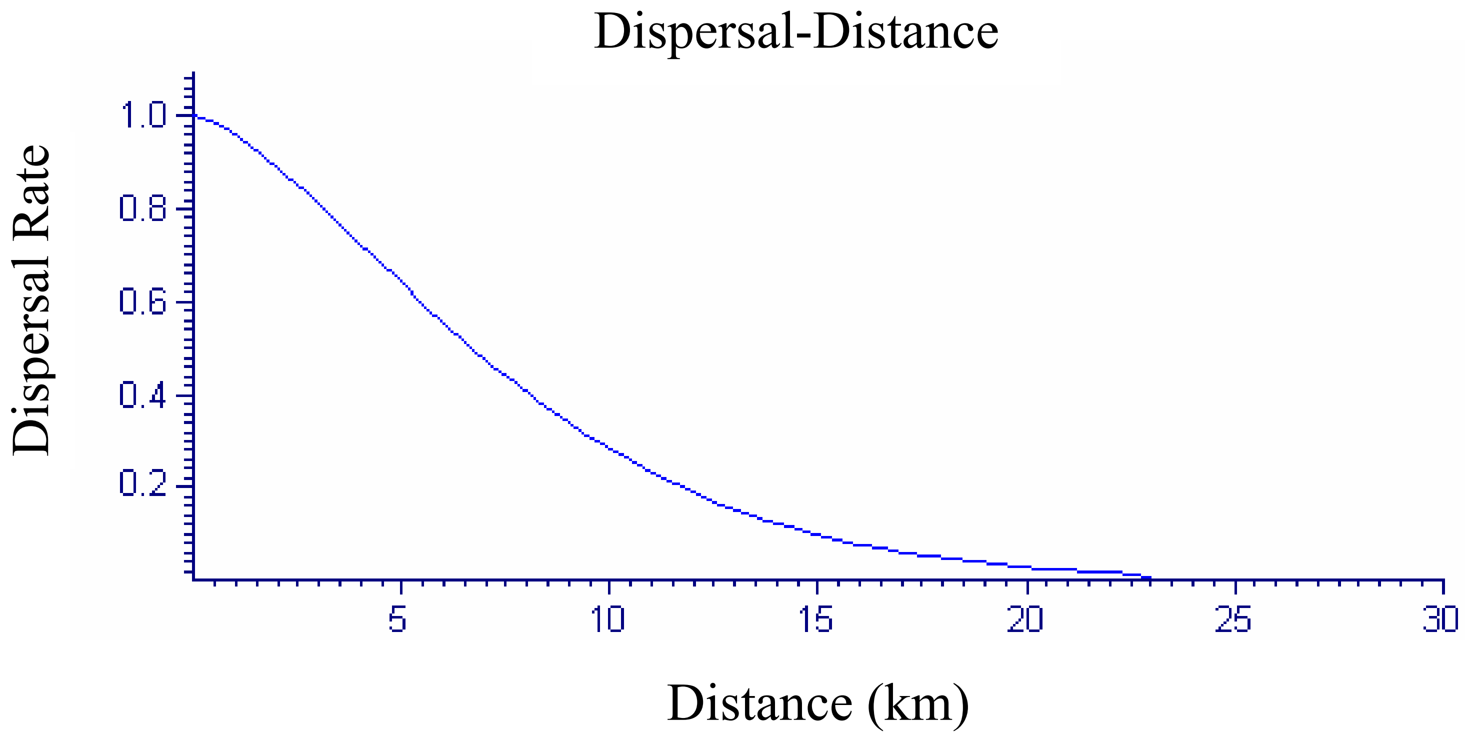
We calculated a total carrying capacity of 82 ocelots based on patch sizes for the combined breeding populations of ocelots in southern Texas (Table 6). Furthermore, we assumed initial population size for each habitat patch to be 1 less than carrying capacity (Table 6).

The RAMAS/GIS Spatial Data program calculated distances between habitat patches, which we specified to be the shortest distance from boundary to boundary. We used the RAMAS/GIS Metapopulation program to calculate a dispersal function based on 15 recorded ocelot dispersal events (Navarro-Lopez, 1985; Tewes, 1986; Laack, 1991). Based on the dispersal function we produced a dispersal-matrix and defined dispersal rate based on distance between subpopulations (Figure 7). However, no dispersal event has been recorded between the Willacy and Cameron populations. Thus, we defined no dispersal between these populations. We specified that 100% of males would disperse at age class 2-3, whereas 50% of females of age class 2-3 would disperse (Haines et al., 2005 *[a]*; Haines et al., 2005 *[b]*). In addition, we defined dispersal as a function of carrying capacity. When the habitat patch reaches its carrying capacity, the dispersal rate was determined by the dispersal-matrix. If the habitat patch was below carrying capacity, then the dispersal rate decreased linearly as a function of the carrying capacity (Akcakaya, 2002). Furthermore, we defined environmental correlation between habitat patches, which was based on the rate of correlation of mean monthly rainfall over the last 50 years between weather stations adjacent to habitat patches (National Climatic Data Center; http://www.ncdc.noaa.gov) as a function of distance between habitat patches (Figure 7).

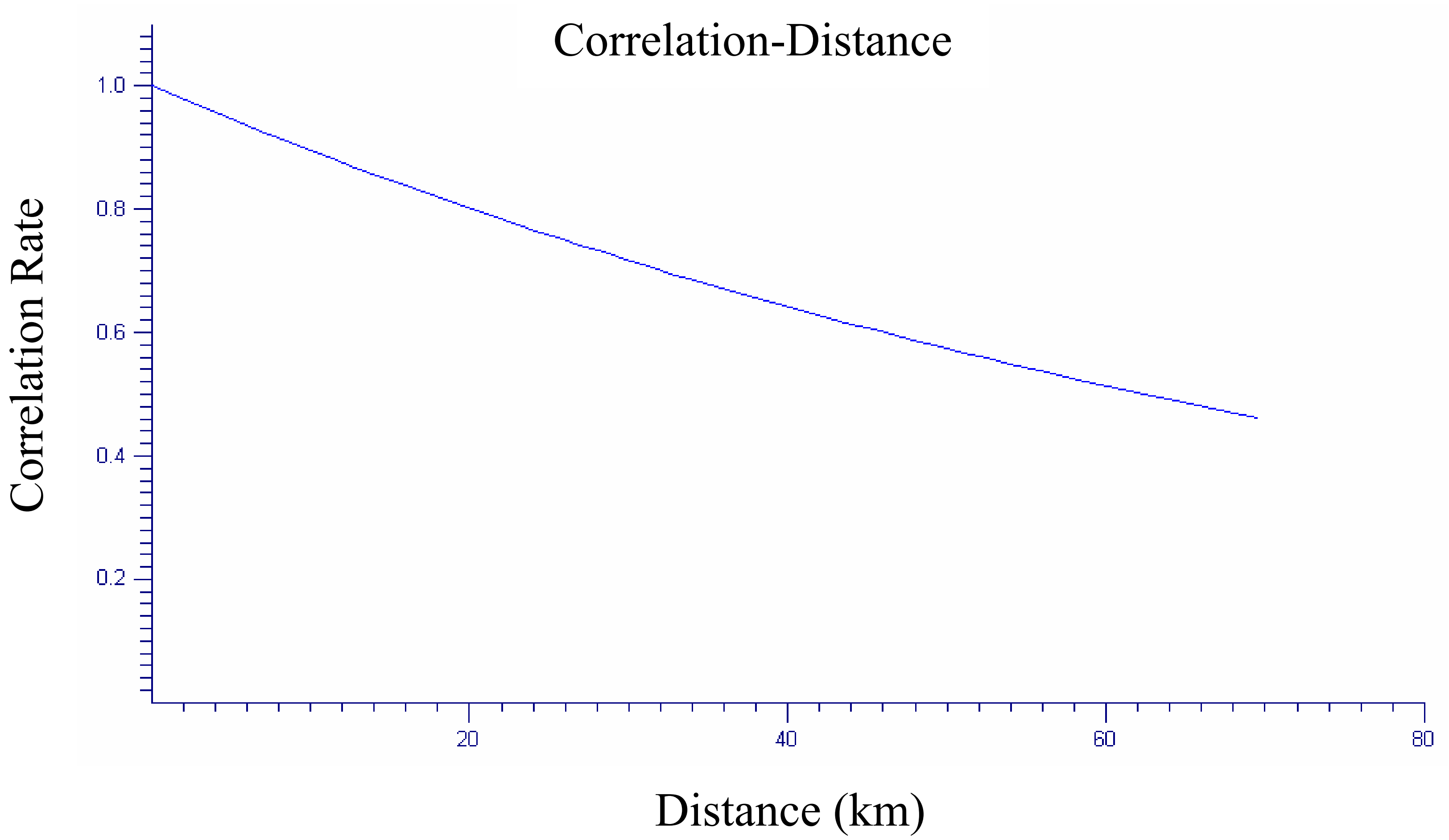
Fig. 7.

Rate of dispersal and correlation as a function of distances between habitat patches, (a) dispersal rate of ocelots of age class 2–3 as a function of distance between habitat patches, and (b) proportion of environmental correlation between habitat patches as a function of distance between patches.

(a)


Dispersal-Distance
Dispersal Rate
1.0
0.8
0.6
0.4
0.2
5
10
15
20
25
30
Distance (km)

(b)


Correlation-Distance
Correlation Rate
1.0
0.8
0.6
0.4
0.2
20
40
60
80
Distance (km)

3.4. Least-cost pathway

An ocelot cost raster map was developed for 2 breeding ocelot populations in southern Texas by classifying the cover map using the spatial analyst tool in ArcGIS 9.0. We ranked closed cover as most likely to be used by a dispersing ocelot followed by mixed cover, open cover, bare ground, and water as areas with decreasing likelihood for use by a dispersing ocelot. Based on the cost raster map, we defined a least-cost path or shortest distance path between habitat patch #6 (Cameron population) and habitat patch #3 (Willacy population) (Figure 8). The result of the least-cost path model represents the path an ocelot is most likely to select for movement between the Cameron and Willacy populations in the linkage scenario.

3.5. Model output

The control scenario, which represented the scenario that no recovery strategies would be implemented in the next 50 years, estimated that the probability of extinction for ocelots in southern Texas was 33% with a final population size of 5 individuals (Table 7). The most effective recovery strategy estimated by the model was the reduction of ocelot road mortality (Table 7). This recovery strategy ranked the highest of all other recovery strategies for ocelots over 50 years, producing a probability of extinction of only 5%, a final population size of 18 individuals, and maintaining 3 habitat patches with ocelot presence (Table 7). In addition, recovery scenario combinations that incorporated the reduction of ocelot road mortality estimated lower ocelot extinction risks, larger final population sizes, and more occupied habitat patches (Table 7).

Fig. 8.

Locations of 11 habitat patches (i.e., subpopulations) identified by the RAMAS/GIS Spatial Data program within and around the Willacy and Cameron ocelot breeding populations in southern Texas. Estimated least-cost pathways linking habitat patch 6 to other habitat patches with locations of potential culvert sites identified where least-cost pathways intersect main roads (UTM coordinates for potential culvert sites: A = 647737.73, 2931512.64; B = 652812.07, 2919643.93; C = 659547.62, 2898355.05; D = 657587.58, 2891004.28; E = 657478.55, 2886632.86; F = 656755.90, 2884213.88; all coordinates in zone 14R).

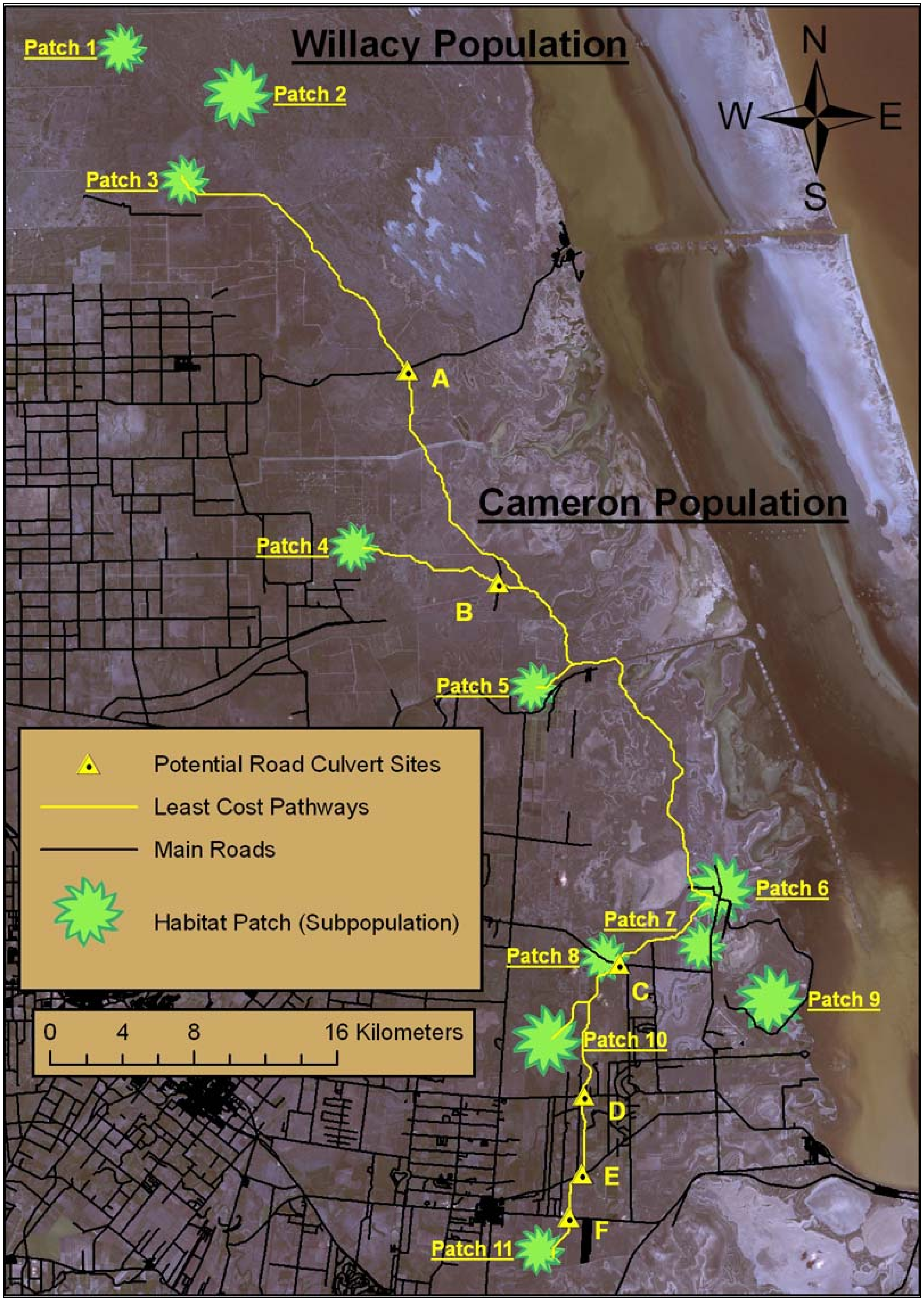

Willacy Population
Cameron Population
N
W
E
S
Patch 1
Patch 2
Patch 3
Patch 4
Patch 5
Patch 6
Patch 7
Patch 8
Patch 9
Patch 10
Patch 11
A
B
C
D
E
F
Potential Road Culvert Sites
Least Cost Pathways
Main Roads
Habitat Patch (Subpopulation)
0
4
8
16 Kilometers

Table 7.

Results of 16 habitat-based PVA scenarios for ocelots in southern Texas conducted over a 50-year duration (*Np*: mean number of occupied habitat patches, *PE*: probability of extinction, *N*: final population size, *R*: rank of recovery strategies from least to most effective based on the Kolmogorov-Smirnov test statistic of the terminal extinction risk curve with significance $p < 0.001$).

			N		
Scenario	*Np*	*PE*	$\bar{x}$	*SD*	*R*
Control	1	0.33	4.70	6.72	1
Linkage	2	0.33	4.84	6.78	1
Translocation	2	0.10	8.86	9.13	2
Translocation + Linkage	2	0.10	8.87	8.93	2
Habitat	2	0.23	11.00	13.77	2
Habitat + Linkage	2	0.22	11.48	13.80	2
Translocation + Habitat	3	0.08	18.49	17.02	3
Translocation + Habitat + Linkage	3	0.07	18.95	16.94	3
Reduced Road Mortality	3	0.05	17.98	13.25	3
Reduced Road Mortality + Linkage	3	0.05	17.76	13.21	3
Translocation + Reduced Road Mortality	4	0.01	23.76	13.30	4

Table 7. Continued.

			N		
Scenario	*Np*	*PE*	$\bar{x}$	*SD*	*R*
Translocation + Reduced Road Mortality + Linkage	5	0.01	24.77	13.74	4
Reduced Road Mortality + Habitat	5	0.02	40.33	11.25	5
Reduced Road Mortality + Habitat + Linkage	5	0.02	39.21	24.96	5
Translocation + Reduced Road Mortality + Habitat	6	0.00	51.10	24.53	6
Translocation + Reduced Road Mortality + Habitat + Linkage	7	0.01	51.41	24.34	6

The least effective recovery strategy estimated by the model was the population linkage scenario. There was no significant difference in ocelot extinction risk by establishing dispersal between the Willacy and Cameron populations. In addition, population linkage did not lower ocelot extinction risk when combined with other recovery scenarios in the model (Table 7).

3.5. Sensitivity analysis

The only model assumption that significantly changed model results was running simulations over 100 years, which showed that restoring habitat was more effective over the long-term than translocating ocelots into southern Texas from Mexico (Table 8). However, reducing road mortality still produced the lowest probability of extinction and the lowest terminal extinction risk curve, whereas the linkage scenario produced the highest terminal extinction risk curve (Table 8).

4. Discussion

Our habitat-based PVA model identified the reduction of road mortality as the most effective strategy to decrease ocelot extinction probability in the U.S. This result differs from Haines et al. (2005 *[b]*) which identified the protection and restoration of thornshrub habitat as most important to the viability of ocelots. However, as with Haines et al. (2005 *[b]*), we found that combinations of recovery strategies minimized ocelot extinction probability and maintained ocelot population size.

Table 8.

Results of sensitivity analyses conducted for ocelots in southern Texas by reporting the probability of extinction after 50 years under the various recovery scenarios. The “Road” recovery scenario refers to reduced road mortality (* indicates significant difference in model results based on the Kolmogorov-Smirnov test statistic of the terminal extinction risk curve with significance $p < 0.001$).

	Recovery scenarios for the RAMAS/GIS simulation				
Model Inputs	Control	Translocation	Road	Habitat	Linkage
All Vital Rates Correlated (Fecundity, Survival, Carrying Capacity)	0.33	0.10	0.05	0.23	0.33
Vital Rates Not Correlated	0.35	0.12	0.06	0.25	0.37
Subpopulations 1 & 2 Included	0.33	0.10	0.05	0.23	0.33
Subpopulation 1 & 2 Not Included	0.41	0.13	0.10	0.27	0.41
Environmental Variation With Normally Distribution	0.33	0.10	0.05	0.23	0.33
Environmental Variation With Lognormal Distribution	0.33	0.10	0.05	0.23	0.33
Probability of Extinction Over 50 years	0.33	0.10	0.05	0.23	0.33
Probability of Extinction Over 100 years	0.96	0.93	0.57	0.83	0.96

Table 8. Continued.

	Recovery scenarios for the RAMAS/GIS simulation				
Model Inputs	Control	Translocation	Road	Habitat	Linkage
Initial Population Size					
10%	0.35	0.12	0.05	0.23	0.34
-10%	0.35	0.12	0.05	0.20	0.33
Density Dependant Dispersal					
10%	0.33	0.11	0.04	0.24	0.35
-10%	0.35	0.11	0.04	0.23	0.34
All Dispersal Rates					
10%	0.34	0.12	0.05	0.23	0.36
-10%	0.33	0.10	0.05	0.22	0.32
Correlation Rates (Function of b)					
10%	0.30	0.11	0.05	0.20	0.36
-10%	0.31	0.12	0.04	0.21	0.32

4.1. Habitat patches compared to continuous habitat

Differences in model results between this study and the previous PVA may have occurred because Haines et al. (2005 *[b]*) assumed both populations occurred in continuous habitat and thus had larger carrying capacities. However, based on the habitat analysis we found that each ocelot population was partitioned into smaller habitat patches or subpopulations connected by dispersal with each subpopulation having a carrying capacity of ≤10 individuals. For ocelot populations residing in smaller habitat patches, the extinction probability is greater because smaller populations have relatively more temporal variation in population size than larger populations and stochastic events have greater influence upon smaller populations (Reed and Hobbs 2004). Lande (1993) stated that populations with ≤25 individuals experienced demographic stocasticity that significantly increased the probability of extinction.

Based on model simulations of 30 vertebrate species with natural populations, Reed (2004) concluded that a single population in a continuous habitat seemed to have consistently lower risk of extinction than multiple isolated populations in a fragmented landscape with equivalent carrying capacity. In addition, Reed (2004) concluded that dispersal between fragmented populations ameliorates, but does not eliminate, the negative effects of fragmentation. To test the assumption made by Haines et al. (2005 *[b]*), we ran our habitat-based PVA model under the assumption that both the Willacy and Cameron populations reside within continuous habitats under the control scenario. We found that all recovery scenarios significantly lowered extinction risk curves, with habitat restoration having the lowest extinction risk curve followed by reduced road mortality. Translocation and population linkage both would have similar extinction risk curves. Thus, model results were similar to Haines et al. (2005 *[b]*) when spatial data were excluded.

4.2. Other benefits of habitat restoration

When incorporating spatial data into the model, we found that after 50 years the recovery strategy that decreased ocelot probability of extinction the greatest was reduced road mortality. However, there are potential benefits of increasing ocelot habitat not specified in this model. Creation of habitat between habitat patches would increase ocelot population stability by making habitat more continuous for both populations. In addition, Haines et al. (2005 *[a]*) stated that ocelot mortality might be indirectly related to anthropogenic habitat fragmentation, with reduced habitat availability causing ocelot populations to be more crowded, thus increasing intraspecific conflict, competition, and transient behavior. Thus, increasing ocelot habitat may help reduce these sources of mortality. Furthermore, Haines et al. (2005 *[b]*) concluded that an increase in ocelot habitat would not only increase ocelot carrying capacity but also enhance dispersal potential between the Cameron and Willacy populations. Increasing the amount of habitat would increase dispersal between habitat patches, and potentially create linkage between the 2 breeding populations in the form of corridors.

4.3. Reducing road mortality and increasing corridors

In the short-term, the restoration of habitat will not have immediate benefits to the ocelot populations because of the extended time required for development of thornshrub communities. Based on data presented by Archer et al. (1988), Haines et al. (2005 *[b]*) assumed that a 40-year period was needed in southern Texas for discrete woody clusters scattered throughout a continuous grassland matrix to move toward a monophasic woodland. However, active management and reestablishment efforts can potentially accelerate the development of ocelot thornshrub cover.

As indicated by the model, benefits can be effectively achieved in a shorter period by reducing road mortality. We assumed that proper placement and construction of culverts (e.g., bridges and overpasses), based on the recommendations of Tewes and Hughes (2001) and Cain et al. (2003), would decrease ocelot-vehicle collisions by 50%. Thus, we identified potential areas of correct placement for culverts by overlaying our map of ocelot habitat patches with major roads in Willacy and Cameron counties and conducting a least-cost distances analysis between habitat patches in Cameron County. Least-cost paths from Patch #6 to ocelot patches #4, #5, #8, #10, and #11 were identified (Figure 7). No least-cost distance analysis was conducted between the Willacy habitat patches because of the lack of roads surrounding these patches (Figure 7).

We believed that the best potential sites for culvert placements that would reduce ocelot-vehicle collisions would occur where least-cost pathways intersect with major roads (Figure 7). Providing the locations of potentially successful culvert sites (Figure 7) allows researchers to analyze and validate these sites and determine if these sites warrant the construction of culverts based on the recommendations of Tewes and Hughes (2001) and Cain et al. (2003).

Proper placement of ocelot culverts could reduce mortality of resident and transient ocelots and increase successful dispersal by providing safer linkages with travel corridors. However, the benefit of corridors is greater when carrying capacity of habitat patches are larger (Hudgens and Haddad, 2003). In addition, Hudgens and Haddad (2003) concluded that species with slow-growing populations would only benefit from corridors in the long-term. Thus, similar to the habitat scenario, the benefits of dispersal become more apparent over a longer period when carrying capacity increases with increased habitat. Potential benefits of dispersal (i.e., primarily genetic benefits) could be maintained in the short-term by releasing ocelots from northern Mexico into the U.S., at least until a dispersal corridor between the Cameron and Willacy population is developed.

4.4. Future research

As recommended by Beissinger and Westphal (1998), Ludwig and Walters (2002), and Haines et al. (2005 *[b]*), an adaptive management approach needs to be applied to conservation by monitoring populations and habitats, and continuing species research to continually update and validate modeling results. In addition, validation of the potential benefits that recovery strategies provide ocelots in southern Texas are needed. However, we believe the recovery strategies, as specified in the model scenarios, represent viable benefits for the ocelot populations in southern Texas (Haines et al. 2005 *[b]*).

Future research should include monitoring of ocelots along major roadways and associated corridors identified for the Cameron and Willacy populations. In addition, other techniques that could reduce ocelot-vehicle collisions (e.g., placement of wildlife crossing caution signs in specified areas to reduce speed) need to be evaluated for their effectiveness.

Results of this study suggest that the spatial distribution of ocelot habitat patches affects the viability of the ocelot population. Additional research is needed on the distribution of habitat quality, quantity, and their changes across the landscape of southern Texas over time. Results from this assessment could be incorporated into future habitat-based models to predict potential impacts of habitat change to ocelot carrying capacity and dispersal. Another major aspect of ocelot life history, which was not incorporated in the model, was the genetic heterozygosity and possible inbreeding depression. Thus, the model may have underestimated the importance of ocelot supplementation and ocelot population linkage as recovery strategies because the potential genetic benefits these recovery strategies may provide were not incorporated into the model. Haines et al. (2005 *[b]*) recommended research on relevant ocelot genetic patterns (e.g., number of lethal equivalents, percentage of recessive alleles) and models that incorporate this genetic information.

4.5. Conclusion

Reduction of ocelot road mortality was the most effective recovery scenario that reduced ocelot extinction probabilities in the U.S. Combinations of recovery strategies reduced ocelot extinction probabilities in the U.S. even further. Recovery strategies that provided short-term benefits to the ocelot populations in southern Texas included reduction of ocelot road mortality, and the supplementation of ocelots into the U.S. from northern Mexico. Successful mitigation of ocelot-vehicle collisions could be accomplished by constructing properly placed culverts with appropriate design along major roadways in southern Texas. Recovery strategies that provided long-term benefits to the ocelot populations included the restoration of habitat between ocelot habitat patches and the establishment of an ocelot dispersal corridor between the Willacy and Cameron populations. We believe these recommendations provide a model to maintain and increase ocelot population viability in the U.S. In addition, future research and monitoring of the ocelot populations are needed to validate model results and assumptions, and update input parameters for future modeling efforts.

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APPENDIX A

Vortex model input parameters specified for each scenario: control, translocation, road, habitat, linkage. The ‘Road’ scenario refers to reduced road mortality. Text in bold italics indicates input parameters specific to each scenario.

	Recovery Scenarios For The Vortex Simulation				
Model Inputs	Control	Translocation	Road	Habitat	Linkage
Inbreeding Depression	Yes	Yes	Yes	Yes	Yes
Lethal Equivalents	3.14	3.14	3.14	3.14	3.14
% Due to Recessive Alleles	50	50	50	50	50
Reproduction Correlated with Survival	Yes	Yes	Yes	Yes	Yes
Long-Term Polygamous Mating System	Yes	Yes	Yes	Yes	Yes
Age 1st Female Reproduction	3	3	3	3	3
Age 1st Male Reproduction	4	4	4	4	4
Maximum Age of Reproduction	11	11	11	11	11
Sex Ratio at Birth	50/50	50/50	50/50	50/50	50/50
Maximum Litter Size	3	3	3	3	3

	Recovery scenarios for the vortex simulation				
Model Inputs	Control	Translocation	Road	Habitat	Linkage
% Females with Litter/Year (SD)					
at Low Density	85 (10)	85 (10)	85 (10)	85 (10)	85 (10)
at High Density	65 (10)	65 (10)	65 (10)	65 (10)	65 (10)
% Litter of Size 1	62	62	62	62	62
% Litter of Size 2	37	37	37	37	37
% Litter of Size 3	1	1	1	1	1
Female Mortality at Year 0-1 (*SE*)	29 (5)	29 (5)	***28*** (5)	29 (5)	29 (5)
Female Mortality at Year 1-2 (*SE*)	13 (2)	13 (2)	***11*** (2)	13 (2)	13 (2)
Female Mortality at Year 2-3 (*SE*)	22 (5)	22 (5)	***17*** (5)	22 (5)	22 (5)
Adult Female Mortality (*SE*)	13 (2)	13 (2)	***11*** (2)	13 (2)	13 (2)
Male Mortality at Year 0-1 (*SE*)	29 (5)	29 (5)	***28*** (5)	29 (5)	29 (5)
Male Mortality at Year 1-2 (*SE*)	13 (2)	13 (2)	***11*** (2)	13 (2)	13 (2)
Male Mortality at Year 2-3 (*SE*)	37 (10)	37 (10)	***26*** (10)	37 (10)	37 (10)
Adult Male Mortality (*SE*)	13 (2)	13 (2)	***11*** (2)	13 (2)	13 (2)
Number of Catastrophes (Probability)	1 (0.11)	1 (0.11)	1 (0.11)	1 (0.11)	1 (0.11)

	Recovery scenarios for the vortex simulation				
Model Inputs	Control	Translocation	Road	Habitat	Linkage
% Reduction in Reproduction (Catastrophe)	25	25	25	25	25
% Reduction in Survival (Catastrophe)	10	10	10	10	10
% of Adult Males Breeding	50	50	50	50	50
Starting Population Size	38	38	38	38	76
Carrying Capacity (*SD*)	38 (4.4)	38 (4.4)	38 (4.4)	38 (4.4)	76 (8.8)
# of Years of Change in K due to Habitat	40	40	40	40	40
% Change in K/Year	-0.5	-0.5	-0.5	***1.7***	-0.5
Population Supplementation	No	***Yes***	No	No	No
# of Years of Supplementation	0	***40***	0	0	0
Age/Sex of Supplemented cats	None	***Female/ Adult***	None	None	None
# of Ocelots Supplemented/Year	0	***1***	0	0	0
Number of Populations	1	1	1	1	***2***
% Environmental Variation Among Populations	0	0	0	0	***75%***
Age Range of Dispersers	0	0	0	0	***2-3***

	Recovery scenarios for the vortex simulation				
Model Inputs	Control	Translocation	Road	Habitat	Linkage
% Survival of Dispersers	0	0	0	0	***100%***
Annual Probability of Dispersal From One Population To Another	0	0	0	0	***5%***

APPENDIX B

Input parameters specified for each recovery scenario (i.e., control, translocation, road, habitat, linkage) to be incorporated into the RAMAS/GIS Metapopulation program. The 'Road' scenario refers to reduced road mortality. Text in bold italics indicates input parameters specific to each recovery scenario (K = Carrying capacity).

	Recovery scenarios for the RAMAS/GIS simulation				
Model Inputs	Control	Translocation	Road	Habitat	Linkage
Density Dependence Effects All Vital Rates	Yes	Yes	Yes	Yes	Yes
Density Dependence Model	Ceiling	Ceiling	Ceiling	Ceiling	Ceiling
Ocelot Age Class Excluded From Density Dependence	0-1	0-1	0-1	0-1	0-1
Reproduction, Survival, And Carrying Capacity Correlated	Yes	Yes	Yes	Yes	Yes
Dispersal Between Cameron And Willacy Population	No	No	No	No	Yes
Annual Probability Of Dispersal From One Population To Another	0	0	0	0	***10%***
Density Dependant Dispersal	Yes	Yes	Yes	Yes	Yes
Relative Dispersal Rate For Female Ocelots Age Class 2-3	0.5	0.5	0.5	0.5	0.5
Relative Dispersal Rate For Male Ocelots Age Class 2-3	1.0	1.0	1.0	1.0	1.0
Polygamous Mating System (1 Male to 2 Females)	Yes	Yes	Yes	Yes	Yes

	Recovery scenarios for the RAMAS/GIS simulation				
Model Inputs	Control	Translocation	Road	Habitat	Linkage
Age of 1st Female Reproduction	3	3	3	3	3
Age Of 1st Male Reproduction	>3	>3	>3	>3	>3
Sex Ratio At Birth	50/50	50/50	50/50	50/50	50/50
Mean Litter Size (Standard Deviation)	1.2 (0.44)	1.2 (0.44)	1.2 (0.44)	1.2 (0.44)	1.2 (0.44)
% Adult Females With Litter/Year	75%	75%	75%	75%	75%
Female Mortality At Age Class 0-1 (*SE*)	32 (5)	32 (5)	***31*** (5)	32 (5)	32 (5)
Female Mortality At Age Class 1-2 (*SE*)	13 (2)	13 (2)	***11*** (2)	13 (2)	13 (2)
Female Mortality At Age Class 2-3 (*SE*)	22 (5)	22 (5)	***17*** (5)	22 (5)	22 (5)
Adult Female Mortality (*SE*)	13 (2)	13 (2)	***11*** (2)	13 (2)	13 (2)
Male Mortality At Year 0-1 (*SE*)	32 (5)	32 (5)	***31*** (5)	32 (5)	32 (5)
Male Mortality At Age Class 1-2 (*SE*)	13 (2)	13 (2)	***11*** (2)	13 (2)	13 (2)
Male Mortality At Age Class 2-3 (*SE*)	37 (10)	37 (10)	***26*** (10)	37 (10)	37 (10)

	Recovery scenarios for the RAMAS/GIS simulation				
Model Inputs	Control	Translocation	Road	Habitat	Linkage
Adult Male Mortality (*SE*)	13 (2)	13 (2)	***11*** (2)	13 (2)	13 (2)
Number of Catastrophes (Probability)	1 (0.11)	1 (0.11)	1 (0.11)	1 (0.11)	1 (0.11)
% Reduction In Reproduction (Catastrophe)	25	25	25	25	25
% Reduction In Survival (Catastrophe)	10	10	10	10	10
Number Of Habitat Patches	11	11	11	11	11
Starting Population Size	71	71	71	71	71
Carrying Capacity (*SD*)	82 (10)	82 (10)	82 (10)	82 (10)	82 (10)
# Of Years of Change In K Due To Habitat	0	0	0	***40***	0
% Increase In K	0	0	0	***50***	0
Population Supplementation	No	***Yes***	No	No	No
# Of Years Of Supplementation	0	***40***	0	0	0
Age/Sex Of Supplemented Cats	None	***Female/ Age 2-3***	None	None	None
# Of Ocelots Supplemented/Biannually	0	***1***	0	0	0

VITA

My name is Aaron M. Haines and I graduated from Virginia Tech Spring during 1998 with a B.S. degree in wildlife management. After graduation, I worked as a naturalist for the Northern Virginia Regional Park Authority, and during fall 1998, I worked for the U.S. Fish and Wildlife Service as a Biological Technician/Environmental Educator for the Eastern Shore of Virginia National Wildlife Refuge and Chincoteague National Wildlife Refuge. During Fall 1999, I worked as a wildlife biologist for the Center for Conservation Research and Technology using satellite telemetry. During Spring 2001, I was a field biologist for the Smithsonian Environmental Research Center working with ovenbirds.

In August 2003, I graduated from Texas A&M University-Kingsville with a M.S. in range and wildlife management after working with Drs. Fidel Hernandez and Scott Henke investigating the effects of ranch road baiting on northern bobwhite quail. During July 2003, I initiated my doctorate developing a population and habitat viability analysis for ocelots in southern Texas.

Currently, I have given 23 scientific presentations and published 14 peer-refereed articles. In addition, I received the Graduate Student Excellence Award in 2003 and 2005 from the College of Human and Agriculture Sciences. My current address is 600 E. General Cavazos Blvd. Apt. 1104 Kingsville, Texas, and my e-mail address is ksamh03@tamuk.edu.