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Evaluating recovery strategies for an ocelot (*Leopardus pardalis*) population in the united states

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Abstract

The ocelot *Leopardus pardalis* population in the United States was listed as endangered in 1982, with only two known isolated breeding populations occurring in southern Texas. Conservation concerns for ocelots include loss of dense thornshrub habitat, mortality from ocelot-vehicle collisions, and genetic erosion. In this study, we used a population viability analysis (PVA) to evaluate four recovery strategies (i.e., supplementation of additional ocelots, reduced road mortality, habitat protection and restoration, and linkage of two breeding populations) for ocelot conservation management. We used the VORTEX (Version 9.42) program to conduct our PVA for an ocelot population located in Cameron County, Texas. Each scenario was simulated 500 times over 100 years. We compared the effectiveness of recovery strategies and combinations thereof with estimates of extinction probability and final population size. Model scenarios with no recovery strategies predicted an extinction probability of 0.65 for the Cameron population of ocelots over 100 years. The protection and restoration of thornshrub habitat was the most effective recovery strategy, followed by population linkage and reduced road mortality, with the supplementation of ocelots being the least effective strategy. Protection and restoration of ocelot habitat cannot be accomplished without the participation of private landowners. Using an adaptive management approach, future actions need to be taken to monitor ocelot populations and habitats and help to reduce the high probability of extinction predicted in our PVA for the ocelot population in Cameron County.

Keywords: Extinction; Ocelot; Population viability analysis; Recovery; Texas; United States

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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, 1982; and was included in Appendix 1 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) (Fig. 1). Currently, ocelot distribution within the U.S. is limited from southern Texas to the border with Tamaulipas, Mexico (Tewes and Everett, 1986) (Fig. 1). There are only two 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,

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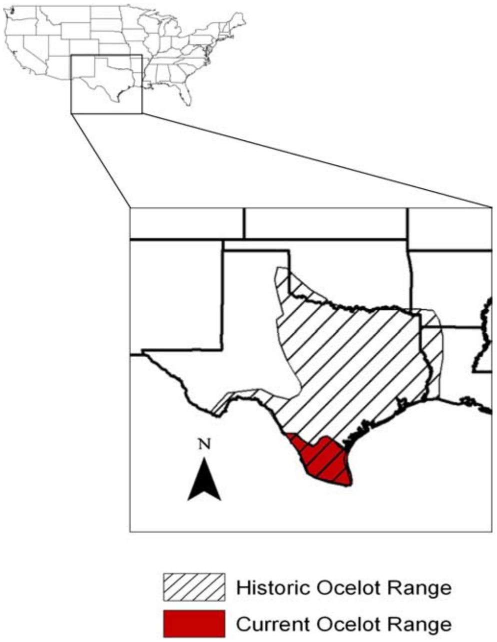

Fig. 1. Historic and current range of ocelots within the United States.

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, 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 $\geqslant 95\%$ 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 two 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 (Shaffer, 1981), and rank the vulnerability of a species (Mace and Lande, 1991). However, Possingham et al. (1993) and Noon and McKelvey (1996) doubted the PVAs ability 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 ($\mathrm{MH} = 0.370$, SE 0.09) compared to the Willacy ($\mathrm{MH} = 0.550$, SE 0.05) and northern Mexico ($\mathrm{MH} = 0.698$, 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 four 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 four 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 (Fig. 2). 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 °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 (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. Due to 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 1 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

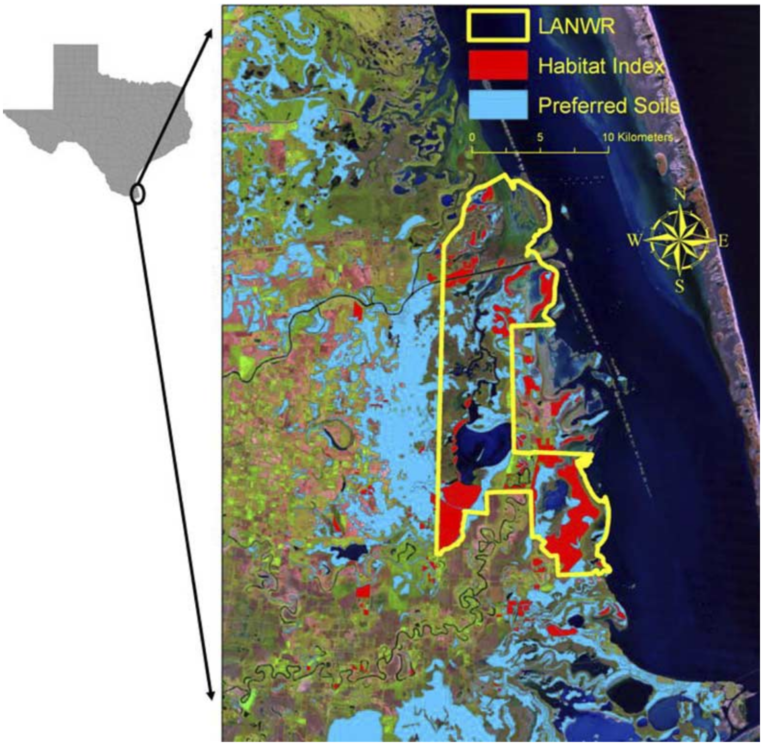

Fig. 2. Map of Laguna Atascosa National Wildlife Refuge (LANWR) and surrounding area showing an index of ocelot habitat patches (dense thornshrub) and areas of preferred soil types for ocelot habitat restoration located in the Lower Rio Grande Valley (LRGV), Cameron County, TX, USA.

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 three 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 $10.5\ \text{km}^2$ ($\text{SD} = 5.1\ \text{km}^2$), whereas adult female ocelots averaged $6.5\ \text{km}^2$ ($\text{SD} = 2\ \text{km}^2$) (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, CA). The amount of dense thornshrub habitat available for the Cameron ocelot population was $75\ \text{km}^2$. This included dense thornshrub in LANWR and within a 15 km buffer surrounding the refuge (Fig. 2). 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 (5, 7, 14; SD = 4.7) and female (9, 12, 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 1).

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 refuge 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, CA). 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% × 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, since 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 and 3 years of age. In addition, Haines et al. (2005) calculated survival rates for dispersing ocelots, which he labeled 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 given 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 dropped by 25% during a drought year. These model assumptions were then tested in a sensitivity analysis.

3. Results

3.1. Model results

Under the control scenario, the probability of extinction for ocelots on LANWR over the next 100 years was estimated at 65% (PE), with a negative stochastic exponential growth rate (r) of −0.001 (Table 1). The single most effective recovery strategy to minimize the probability of extinction and increase population size for the Cameron population of ocelots was the protection and restoration of preferred habitat. This was followed by both linkage between the Cameron and Willacy population and reduced road mortality being relatively equally effective, while the translocation of ocelots into the Cameron population was the single least effective recovery strategy (Table 1). 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 1). 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 starting 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 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 2. 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 2). This was followed by both linkage between the Cameron and Willacy population and reduced road mortality being relatively equally effective, while the translocation of ocelots into the Cameron population was the single least effective recovery strategy (Table 2). 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 population. However, all recovery strategies under this scenario gave a relatively high probability of extinction.

Table 1
Results of 16 PVA scenarios for the Cameron breeding population of ocelots conducted over the next 100 years (r = mean stochastic growth rate; PE = probability of extinction; N = final population size)

Scenario	r	PE	N	
			$\bar{x}$	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
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

Table 2
Results of the sensitivity analysis conducted over the next 100 years for the Cameron breeding population of ocelots by reporting the probability of extinction under the various recovery scenarios

Model inputs	Recovery scenarios for the vortex simulation				
	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
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% at Low density 25% at High density	0.97	0.85	0.77	0.76	0.51
85% at Low density 65% at High density	0.65	0.44	0.27	0.11	0.20
100% at Low density 75% at 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 and reproduction rate during a catastrophe					
5% and 15%	0.63	0.45	0.26	0.08	0.18
10% and 25%	0.65	0.44	0.27	0.11	0.20
15% and 35%	0.66	0.45	0.31	0.13	0.17
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

The ‘Road’ recovery scenario refers to reduced road mortality.

Within the sensitivity analysis, four 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.

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 bridge the gap between 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.

4.1.1. 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. VORTEX 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.

4.1.2. 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. Due to 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 reasoning for cautiously 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 been shown to have 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 assessed. Furthermore, the estimates of the amount of potential habitat that can be protected and restored may be overly 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 index 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 species 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 lead to a population and habitat viability analysis. Thus, allowing 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 what management actions can be taken with the monetary resources available.

5. 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 effectively reduce the ocelot probability of extinction over the next 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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Appendix 1

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.

Model inputs	Recovery scenarios for the vortex simulation				
	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
% 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)
% 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

(*continued on next page*)

Appendix 1 (*continued*)

Model inputs	Recovery scenarios for the vortex simulation				
	Control	Translocation	Road	Habitat	Linkage
Age/sex of supplemented cats	None	***Femaleladult***	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***
% Survival of dispersers	0	0	0	0	***100%***
Annual probability of dispersal from one population to another	0	0	0	0	***5%***

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