The ocelot *Leopardus pardalis* in north-western Mexico: ecology, distribution and conservation status

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Abstract From July 1998 to July 2000 we collected locality information and habitat associations for 36 records of the Endangered ocelot *Leopardus pardalis* in the Mexican State of Sonora. Twenty-seven (75%) of the records for which we could determine the biotic community association were associated with tropical and subtropical habitats, namely subtropical thornscrub, tropical deciduous forest or tropical thornscrub. Only males (11.1% of the total records) have been recorded in temperate oak and pine-oak woodland, and we conclude that the few ocelots reported from these habitats in the US State of Arizona were probably dispersing individuals. Three models of ocelot distribution in Sonora, based on vegetation types, the GARP modelling system and the Adaptive Kernel home range estimator, all produced similar results, with the ocelot mostly associated with the mountainous Sierra region of eastern Sonora. Large tracts of land with a low human population density make Sonora a stronghold for the northernmost distribution of ocelots.

Keywords Arizona, bobcat, habitat association, *Leopardus pardalis*, *Lynx rufus*, Mexico, ocelot, Sonora.

Introduction

The ocelot *Leopardus pardalis* (Carnivora, Felidae) is considered to be in danger of extinction in the United States and Mexico (Favre, 1989; SEDESOL, 1994; USFWS, 1999). The US Endangered Species Act categorizes the ocelot as Endangered throughout its range (Arizona, Texas, Mexico, Central & South America; Endangered Species Program, 2003), whereas the IUCN Red List (IUCN, 2002) only categorizes the Texas subspecies *L. pardalis albescens* as Endangered (based on criteria D, i.e. population estimated to be <250 mature individuals). The most important causes of the decline of this species have been identified as poaching, over-harvesting when it was legal to hunt them, and habitat transformation (Nowell & Jackson, 1996). Historically the ocelot ranged from Arizona to Argentina, and has been associated with a wide range of habitats, including mangrove forests, savannah grasslands, thornscrub and tropical forests of all types. Ocelots typically occur at elevations below 1,200 m (Nowell & Jackson, 1996), and their presence is linked to thick vegetation cover (Tewes, 1986; Oliveira, 1994; Murray & Gardner, 1997).

The subspecies *Leopardus pardalis sonoriensis* in the Mexican state of Sonora was described by Goldman (1943) on the basis of four specimens, three male and one female, obtained near Camoa in southernmost Sonora. Records of ocelots from the Mexican state of Sonora are scarce (Leopold, 1959). In former times ocelots probably ranged along the western slopes of the mountains of eastern Sonora (Caire, 1997). Burt (1938) procured a specimen from near Guirocoba that was found in tropical deciduous forest near the town of Alamos. However, despite the lack of museum specimens, ocelots are known to occur in central and northern Sonora. The Lee brothers killed an ocelot in 1935 in subtropical thornscrub near the junctions of the Aros, Bavispe and Yaqui rivers (McCurdy, 1981). A hunter killed a male in *c*. 1966 in oak woodland in the Sierra Azul in northern Sonora (Sewell Goodwin, pers. comm.), and another ocelot was killed in this same area in 1974 (Bill Robinson, pers. comm.).

Ocelots documented from the south-western United States are one hide sent to the US National Museum from Fort Verde, Arizona, by E.A. Mearns in 1887, a skull from an archeological site on the San Pedro River near Redington (Burt, 1961), one reportedly killed by a US Biological Survey predator control agent during 1931–1932 (Brown, 1989), a male killed and photographed in 1964 on Pat Scott Peak in the Huachuca Mountains (Brown, 1985; Sewell Goodwin, pers. comm.), and a male that had been run over near the town of Oracle in 1967 (Jack Childs, pers. comm.).

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The state of Sonora is the second largest state in Mexico, and has one of the lowest human population densities in the country. Relatively intact patches of continuous habitat therefore make this area a stronghold for rare species such as the jaguar *Panthera onca* and river otters *Lontra longicaudis* (López González & Brown, 2002; Gallo, 1996), and potentially also for the ocelot. In this paper we address the paucity of information on the distribution, habitat associations and conservation status of the ocelot in Sonora by drawing together both historical and recent information on the species. We use this data to model the species' distribution in Sonora, and to discuss the potential for colonization by the ocelot of the south-western United States.

Methods

We began obtaining ocelot records from the Mexican State of Sonora during a state-wide jaguar survey (López González & Brown, 2002); additional records were collected opportunistically by JPGR. The state of Sonora is situated in north-western Mexico, immediately to the south of the US state of Arizona (Fig. 1), and

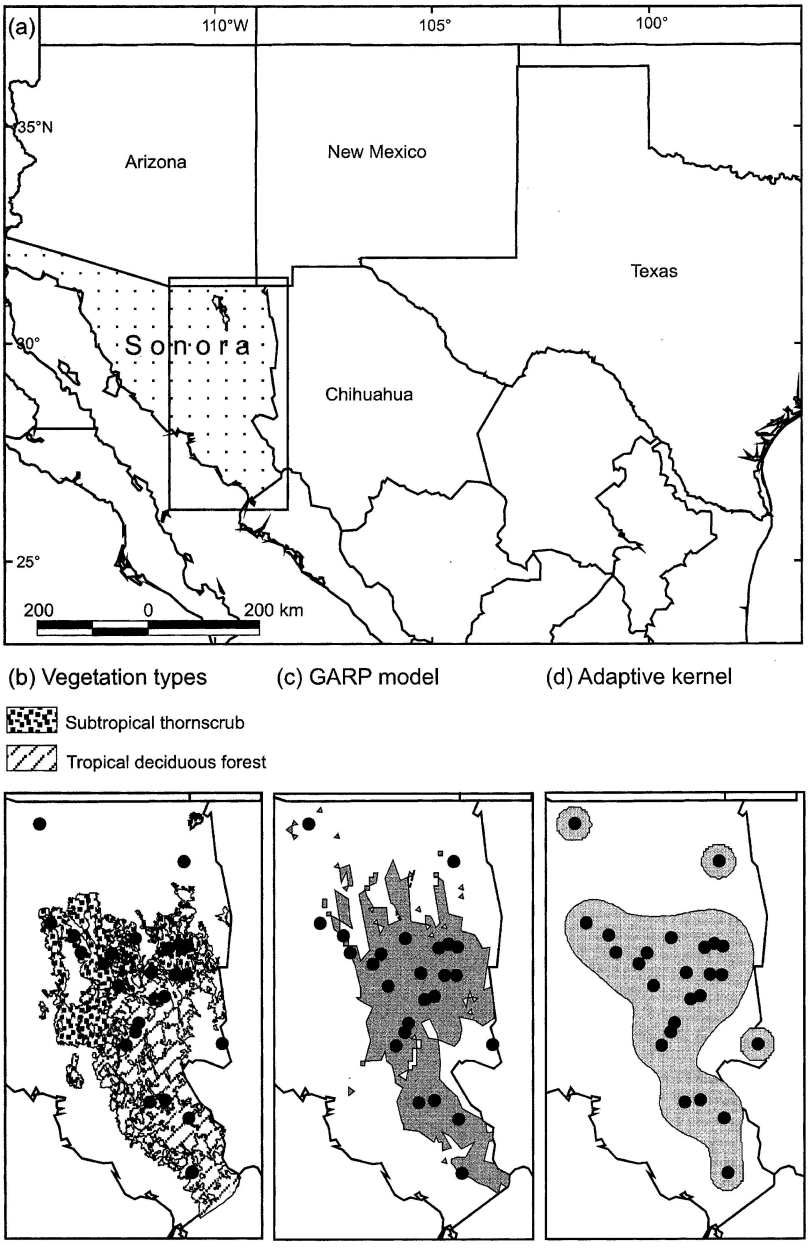

Fig. 1 (a) The State of Sonora in north-western Mexico; the rectangle indicates the location of Figs b–d. (b) Vegetation types where most of the ocelot records were located. (c) GARP model predicting the distribution of ocelots. (d) Adaptive Kernel model for ocelot distribution, with the 95% probability contour. (Figs b–d, see text for details.)

encompasses *c*. 182,000 km². It is a complex mosaic of temperate and tropical biotic communities, and includes the northernmost limits of the neotropics (Brown *et al*., 1998; Reichenbacher *et al*., 1998). We used the vegetation and land use categories defined by the Mexican National Commission for Knowledge and Use of Biodiversity (CONABIO, 1999), which recognizes the following biotic communities in the state of Sonora: agricultural lands, low open forest, oak woodland, oak-pine woodland, gallery forest, pine forest, pine-oak forest, juniper forest, chaparral, mangrove forest, desert thornscrub, subtropical thornscrub, mesquite forest, grasslands, tropical deciduous forest, tropical thorn forest, halophile vegetation, sand desert, sand dunes, and others (urban areas, lakes, no apparent vegetation).

The state is divided into 72 municipalities. We visited all of these and asked ranchers, cowboys, cattle associations and outfitters if they knew of any ocelots killed in the area. We attempted to corroborate all ocelot reports by locating photographs, skins, skulls and other evidence. When possible these materials were photographed and catalogued as to owner, sex, age, and location. Verified records are those for which we were able to unambiguously document an individual ocelot and observe the locality of capture. These were located on 1:250,000 topographical maps (INEGI, 1973) and then plotted on a digitized vegetation and land use map (scale 1:250,000; CONABIO, 1999), and the approximate elevation was recorded. Notes were also taken on the habitat affiliation of each record, and the human density and land-use of the area.

We constructed three distribution models: one based on broad vegetation types present in the state of Sonora, a second using ecological niche models using the *Genetic Algorithm for Rule-Set Production* (GARP) modelling system (Stockwell & Noble, 1991; Stockwell & Peters, 1999), and a third one using the Adaptive Kernel home range estimator (Worton, 1989). GARP identifies correlations between a species distribution and environmental characteristics through an iterative process of rule selection, evaluation, testing, and incorporation or rejection. A rule is a pattern in the environment, and has the basic form: ''if something is true then something necessarily follows''. The ''if'' part of the rule is the precondition, and the ''then'' part the conclusion; the preconditions of rules in GARP are simple conjunctive expressions. A rule set is an unordered list of rules (Stockwell & Noble, 1991; Stockwell & Peters, 1999). The GARP algorithm runs for 10,000 iterations, or until rule testing has no appreciable effect on the accuracy measure. Complete details and documentation are available elsewhere (Stockwell & Noble, 1991; Stockwell & Peters, 1999; DesktopGarp, 2003). Geographic themes consisted of four coverages provided by CONABIO (1999): elevation (500 m intervals), mean annual precipitation (10 categories), annual mean temperature (5 categories), and vegetation (Rzedowski, 1979). Because GARP generates distributional predictions based on random rule selection, and predictions vary somewhat from one run to the next, we generated six GARP models, each having 10,000 simulations. To obtain a single representative prediction the six were overlain, and only retained pixels for which all models predicted ocelot presence.

The Adaptive Kernel method is a home range estimator that can be used to calculate the area used by a population. This method was used by Lopez Gonzalez (1999) to delineate reserve sizes for pumas *Puma concolor*, and by Bader (2000) to estimate the distribution of grizzly bear *Ursus ursus*. The method uses probability to construct a distribution using the individual location records. For the present study we constructed a distribution based on the 95% probability contour.

Results

We obtained a total of 36 verified ocelot records for Sonora (Table 1, Fig. 1), 35 of which were records of single individuals and one of four individuals; 29 of the records were from our surveys and seven from the literature and personal communications. Five of the records lacked information on date killed and/or locality, and of the remaining, 21 were killed after and 10 before 1990. The approximate range of ocelots in Sonora as defined by our records and estimated through available vegetation types was 39,093 km² (Fig. 1b). The estimate of ocelot range using the GARP model covers an area of 35,525 km² (Fig. 1c), and that using the Adaptive Kernel home range estimator (Worton, 1989) was 44,459 km² (Fig. 1d) for a 95% probability of occurrence.

27 of the 36 records (75%) of ocelots in Sonora were associated with tropical or subtropical habitats, namely subtropical thornscrub, tropical deciduous forest and tropical thornscrub (Table 2). The mean elevation of the 33 records located with precision was 700 ± 450 m, at which altitudes subtropical thornscrub is the main habitat.

Individual male records comprised 48.7% ($n = 19$) and females 15.4% ($n = 6$, including one tentatively identified as female). We were not able to determine the sex for the remaining 35.9% of the records as they were either poorly preserved or their sex was not documented in the literature. The most northerly limit of a record of a female, typically indicative of a breeding population, was 30°30′ latitude. There was only one record of a kitten, in the southern part of the State.

Table 1 Ocelots *Leopardus pardalis* known to have been killed in the Mexican State of Sonora between 1898 and 2000, in reverse chronological order.

Year	Collector or reporter (evidence or reference)[1]	Sex	Locality or Municipality	Biotic community
2000	Cowboy (CALG saw skin; photos)	M	Rancho Tapila, Agua Prieta	Pine-oak forest
2000	Cowboy (CALG saw skin)	M	Sierra Los Chinos, Sahuaripa	Temperate Oak woodland-subtropical thornscrub
1999	Cowboy (CALG has skin)	M	Basopa, Sahuaripa	Subtropical thornscrub
1999	Rancher (photo)	M	Rancho La Placita, Sahuaripa	Subtropical thornscrub
1999	Rancher (CALG saw skin)	M	Rancho Los Taraices, Aconchi	Subtropical thornscrub
1999	Rancher (CALG saw skin)	M	Sierra de Alamos, Alamos	Tropical deciduous forest
1999	Rancher (CALG saw skin)	M (kitten)	9 km W. of Rosario de Tezopaco	Tropical deciduous forest
1999	Rancher (CALG saw skin)	F	Rosario de Tezopaco	Tropical thornscrub
1997	Houndsman (photo)	M	Sierra de los Chinos, Sahuaripa	Subtropical thornscrub
1995	Houndsman	F	San Javier	Tropical deciduous forest
1995	Houndsman (photo)	M	San Javier	Temperate Oak woodland
1995	Rancher (CALG saw skin)	F	Rio Moctezuma, Moctezuma	Subtropical thornscrub
1995	Rancher (CALG saw skin)	M	Rio Moctezuma, Moctezuma	Subtropical thornscrub
1995	Rancher (JPGR has skin)	?	4 km E. of San Bernardo, Alamos	Tropical deciduous forest
1995	Rancher (JPGR has skin)	?	Rancho Carrizal Quemado, Granados	Subtropical thornscrub
1994	Rancher (JPGR has skin)	M	Granados/Sahuaripa	Subtropical thornscrub
1994	Rancher	M	Rancho San Vicente, Quiriego	Temperate oak woodland-tropical deciduous forest
1993	Rancher	M	Arroyo de la Junta, Ures	Subtropical thornscrub
Before 1992	Peter Warren, pers. comm.	?	E. of Soyopa, Soyopa	Tropical deciduous forest
Before 1992	Peter Warren, pers. comm. (animal taken to Centro Ecologico de Sonora)	F?	Tonichi	Tropical deciduous forest
1991	Houndsman	?	Bacanora	Desert thornscrub
Before 1990	Rancher	M	Rancho de los Nogales, Opodepe	Subtropical thornscrub
1989	Pete Manes pers. comm. (road kill; photo)	F	Hwy # 9, Rosario	Tropical deciduous forest
1988–1989	Hunter (Arturo Ortega)	?	Rancho La Montosa	Subtropical thornscrub
1974	Houndsmen (Bill Robinson pers. comm.)	?	Near Casitas, Nogales	Temperate oak woodland
1970	Kelly Neal saw trapped animal	?	Rancho El Valle, Arizpe	Temperate oak woodland
1966	Houndsmen (Sewell Goodwin, L. Elias; photo)	M	Sierra Piñitos, E. of Casitas, Nogales	Temperate oak woodland
Before 1965	Houndsman (CALG saw skin)	M	Sierra de Alamos, Alamos	Tropical deciduous forest
1935	Dale Lee *et al*. (McCurdy, 1981)	?	Junction of the Aros and Bavispe, Sahuaripa rivers	Subtropical thornscrub
Before 1938	W.H. Burt (Burt, 1938)	?	Guirocoba, S. of Alamos	Tropical deciduous forest
1898	E.A. Goldman (Goldman, 1943)	3 M, 1 F	Near Camoa, Alamos	Tropical deciduous forest
?	Rancher	?	San Pedro de la Cueva	Temperate Oak woodland-subtropical thornscrub
?	Rancher (CALG saw skin in Hermosillo)	?	Nacori Chico, Baviacora	Subtropical thornscrub
?	Hunter (CALG saw skin in Hermosillo)	?	?	?
?	Hunter (CALG saw skin in Hermosillo)	?	N. of Ures	?
?	Hunter (CALG, saw skin in Hermosillo)	?	Suaqui Grande	?

[1]Initials refer to authors of the present paper.

Discussion

The three models of the distribution of ocelots gave similar results, with differences of 10–25% in area occupied. Carrillo & Lopez Gonzalez (2002) estimated that ocelots occur at a density of 5.7 ($\pm$1.9) ocelots per 100 km^2 in this region, and using this value and the most conservative estimate of ocelot distribution, based on the GARP model, gives an estimate of 2,025 $\pm$ 675 ocelots in Sonora. Local ranchers and cowboys reported to us that the *gato galavis* (as ocelots are known locally) is relatively common, although during field surveys we rarely located ocelot tracks in comparison with bobcat *Lynx rufus* sign (C. A. López González, unpub.

Table 2 Summary of habitat associations for the 36 records of ocelots (see Table 1).

Biotic community	Number of records (%)
Subtropical thornscrub	13 (36.1)
Tropical deciduous forest	10 (27.8)
Temperate oak woodland	4 (11.1)
Temperate oak woodland-subtropical thornscrub or Temperate oak woodland-tropical deciduous forest	3 (8.3)
Tropical thornscrub	1 (2.8)
Desert thornscrub	1 (2.8)
Pine-oak forest	1 (2.8)
Data unavailable	3 (8.3)

data). Ocelot tracks can be distinguished because they tend to be rounder and relatively larger than those of bobcats, and the more elongated toes of the bobcat leave an imprint that is recognizably different from that of the ocelot.

Ocelots are associated largely with the mountainous Sierra region of eastern Sonora. Records closer to the Sonoran desert biome were mainly associated with riparian areas, where the shrub cover is relatively thicker than the surrounding areas. The transformation of desert grassland by the invasion of mesquite *Prosopis* spp. or other shrubs may actually benefit the ocelots by artificially creating a structurally closed habitat that is preferred by this species (Tewes, 1986; Laack, 1991). A few ocelots in Sonora were recorded in oak woodlands, but all of these records were males. Historically, ocelots occurred in oak/juniper communities of central Texas (Bailey, 1905), but unfortunately they were extirpated there before anybody could describe their natural history in this habitat. Today the ocelot occurs in other, subtropical, habitats of eastern and central Texas (Navarro *et al.*, 1993). The thornscrub in which ocelots mostly occur in Sonora is comparable in structure to the tropical deciduous forest of the coast of Jalisco, Mexico, where López González *et al*. (2000) found radio-collared ocelots to be preferably selecting pristine tropical deciduous forest and mature secondary growth. Given the paucity of records for southern areas of the US State of Arizona, which borders Sonora, it is unlikely that ocelots were ever native there. There are conflicting opinions regarding the historical distribution of both ocelots and jaguar in this region (Brown & López González, 2000). In this context Laack (1992) noted that sightings, without documentation, do not provide conclusive evidence of a population of ocelots.

Competition with bobcats may be a factor limiting the number of ocelots able to reach more northerly latitudes, whereas in more southerly, tropical environments ocelots may be limiting the presence of bobcats (López González *et al*., 1998). In Texas, ocelots and bobcats take the same prey species, and in similar proportions (Tewes *et al*., 1997). If bobcats are more numerous and feeding on the same prey species as ocelots, any collapse in prey populations would reduce the survival of ocelots because they invest more resources to raise a litter than do bobcats (Emmons, 1988; Sunquist, 1992).

Although ocelots in Sonora are protected in the Sierra Alamos-Rio Cuchujaqui Reserve, in the south of the State, our data indicates that they still occur elsewhere. Our distributional analysis could help identify areas that would, if protected, help to maintain the connectivity of tropical habitats suitable for the ocelot. In this context, natural resource managers will need to give special consideration to the short dispersal distances that characterize ocelots. Although there is no information on this in Sonora, dispersal distances of ocelots elsewhere in Mexico and in Argentina are typically 5–25 km (Caso, 1994; Crawshaw, 1995; López González *et al*., 2000). Large unpopulated tracts of land remain in the central portion of the State of Sonora, making it one of the few areas in which ocelots may persist in substantial viable populations in its northern range. As noted for other threatened species, the most distant portions of species' distributions have been the last refuge for their survival (Channell & Lomolino, 2000), and this may also be the case for the future of the ocelot in North America.

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