

POPULATION STATUS OF JAGUARS (*PANTHERA ONCA*) AND PUMAS (*PUMA CONCOLOR*) IN NORTHEASTERN SONORA, MEXICO

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ABSTRACT. Jaguars are endangered in Mexico and the United States, necessitating careful monitoring of population status. We determined minimum numbers of jaguars and sympatric pumas in a small population in northern Sonora, Mexico, the nearest known breeding population to the United States, by photographic captures supplemented by idiosyncratic features of tracks from track surveys (1999-2005). We also developed a discriminant function to differentiate species (jaguar v. puma) and sexes within species, which also aided in individual identification. Photographic captures identified 5 individual jaguars; this estimate was increased to 12 using idiosyncratic features and discriminant analysis of tracks. Jaguar kittens were only detected by track surveys. All jaguars identified by photographs were previously detected by tracks, but most (7 of 12) known from tracks were not captured in photographs. Jaguar presence was fluid; we identified 6 individual jaguars from 1999-2003, but only 3 of these were still present in 2004. We documented 4 new individuals during 2005, when none of the previously identified jaguars were detected. Similarly, we identified 14 individual pumas by tracks, but only 11 of these were captured in photographs. Four hindfoot measurements varied among species and sexes of jaguars and pumas, and these measurements were able to correctly classify 85-97% of tracks to the correct species and sex. Due to the high turnover of this jaguar population, which is at its fringe of the jaguar range in North America, we recommend constant monitoring of population status with camera traps and track surveys. If only limited resources are available, we recommend monitoring only with track surveys because they detected a greater number of individuals and all age classes of individuals.

Key words: Camera trap, Density, Jaguar, Mexico, *Panthera onca*, *Puma concolor*, Population status, Sonora, Track identification.

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RESUMEN. El jaguar se encuentra enlistado en peligro de extinción en México y los Estados Unidos. Por esta razón esta especie necesita monitoreos cuidadosos del estado de su población. El presente estudio se condujo en una región con una pequeña población de jaguares, que es la población reproductiva conocida más cercana a los Estados Unidos. En el noreste de Sonora, México, se determinó el número mínimo de jaguares y pumas simpátricos, por medio de capturas fotográficas, complementado por medio de rastreo de huellas y características idiosincráticas de las mismas (1999-2005). Desarrollamos un análisis discriminante que nos ayudó a diferenciar entre jaguares y pumas, además del sexo entre ambos y sirvió también de apoyo para diferenciarlos individualmente. Por medio de capturas fotográficas se identificaron 5 jaguares; esta estimación se incrementó a 12 jaguares usando características idiosincráticas y un análisis discriminante de las huellas. Los cachorros de jaguar sólo fueron detectados por el rastreo de huellas. Todos los jaguares que se identificaron por medio de fotografías fueron previamente identificados por huellas, pero la mayoría (7 de 12) que se conocieron por huellas no fueron capturados fotográficamente. La presencia del jaguar fue cambiante; se identificaron 6 individuos de 1999-2003, pero sólo 3 de éstos estuvieron presentes en 2004. Se documentaron 4 nuevos individuos durante 2005 y ninguno de los previamente identificados se volvió a detectar. De la misma forma se identificaron 14 pumas por medio de huellas pero solo 11 se detectaron por medio de capturas fotográficas. Se utilizaron 4 medidas de las patas que variaron entre especies y sexo de jaguares y pumas. Este análisis de medidas permitió clasificar correctamente del 85-97% de las huellas de la especie correcta y de la especie correcta y su sexo. Debido al cambio notorio de esta población de jaguar, la cual se encuentra en el límite de su rango de distribución en Norteamérica, se recomienda un constante monitoreo del estado de la población con trapeo fotográfico y rastreo de huellas. Si los recursos son limitados entonces se recomienda rastreo de huellas debido a que en esta región se detectaron un mayor número de individuos de todas las clases de edad.

Palabras clave: Trampas fotográficas, Densidad, Jaguar, México, *Panthera onca*, *Puma concolor*, Estado de la población, Sonora, Identificación de huellas.

INTRODUCTION

Jaguars (*Panthera onca*) are endangered in Mexico and the United States (Federal Register 1997, SEMARNAT 2001). Recently, individual jaguars have been detected in the American southwest (Glenn 1996, McCain & Childs 2008), and these likely came from a breeding population located about 200 km south of the Sonora-Arizona border (Rosas-Rosas *et al.* 2008, 2010). However, jaguars are rare in northeastern Sonora, probably due to excessive harvest of prey species, illegal killing for predator control, and habitat degradation (López-González & Brown 2002, Rosas-Rosas *et al.* 2008, Rosas-Rosas *et al.* 2010). The concurrent presence of pumas (*Puma concolor*) further complicates viability of jaguars in northeastern Sonora, as many puma kills of livestock are attributed to jaguars, increasing the chances of illegal killing of jaguars (Rosas-Rosas *et al.* 2008).

Determining abundance trends is necessary to monitor the status of endangered jaguars. Most commonly, track surveys (Smallwood & Fitzhugh 1993, Beier & Cunningham 1996, Riordan 1998, Rosas-Rosas *et al.* 2003, Sharma *et al.* 2005, Isasi-Catalá & Barreto 2008) and capture-recapture models including radio-telemetry and camera-trapping (Hornocker 1969, Schaller & Crawshaw 1980, Rabinowitz & Not-

tingham 1986, Karanth 1995, Logan *et al.* 1996, Karanth & Nichols 1998, Silver *et al.* 2004, Karanth *et al.* 2004, Ceballos *et al.* 2007) have been used to estimate numbers and trends of large felids. Each of these methods has significant advantages and limitations. Individual identification by tracks has been criticized as being inaccurate and inadequate to provide information on distribution patterns, relative abundance, and density of large felids, mostly because of a tendency to overestimate minimum numbers, especially if not rigorously conducted (Karanth *et al.* 2003, Miller 2004, Isasi-Catalá & Barreto 2008). Similarly, camera trapping has failed to identify all components of the population, especially juveniles (Karanth & Nichols 2002).

Despite these limitations, each method has provided useful data for monitoring populations. Camera trapping has successfully identified minimum numbers of adults in multiple locations (Karanth & Nichols 1998, Salom-Pérez *et al.* 2007, Faller *et al.* 2007). Similarly, Isasi-Catalá & Barreto (2008) successfully identified individual jaguars by their tracks. Both methods allow recognition of individual behavior and habitat use; in addition, tracking allows identification of travel routes and territorial markings. Ultimately, however, no single technique used in large felid work has been adequately validated and each has several ecologically problematic assumptions (Karanth & Nichols 1998, Karanth *et al.* 2003). Consequently, using multiple techniques to corroborate population status is important not only to produce acceptable estimates, but also to serve as an independent validation of existing techniques. Additionally, multiple techniques allow violations of assumptions of individual techniques and statistical power limitations present in all techniques to be overcome through corroboration (Salmon 1979).

Consequently, we used camera-trapping photographic surveys supplemented by track surveys to determine the minimum number of jaguars and pumas in the area around Nacori Chico, Sonora, Mexico, a population of key conservation status because it is the northernmost breeding population of jaguars in North America. Our objective was to identify individual jaguar and pumas by photographic captures and track characteristics in order to estimate minimum numbers of jaguars and pumas in our study area.

Study area

Our study area was located in northeastern Sonora in the foothills of northern Sierra Madre Occidental, the largest mountain range in western Mexico (Figure 1). The Sierra Madre Occidental encompasses a variety of habitats, including pine (*Pinus* spp.) forest, oak (*Quercus* spp.) woodlands, semitropical thornscrub, and tropical deciduous forest (Brown 1982). Topography is rocky and rugged with several intermittent and perennial streams. Precipitation ranges from about 400 mm annually in the valleys to over 1000 mm in higher elevations (Marshall 1957). Seasons included a dry season

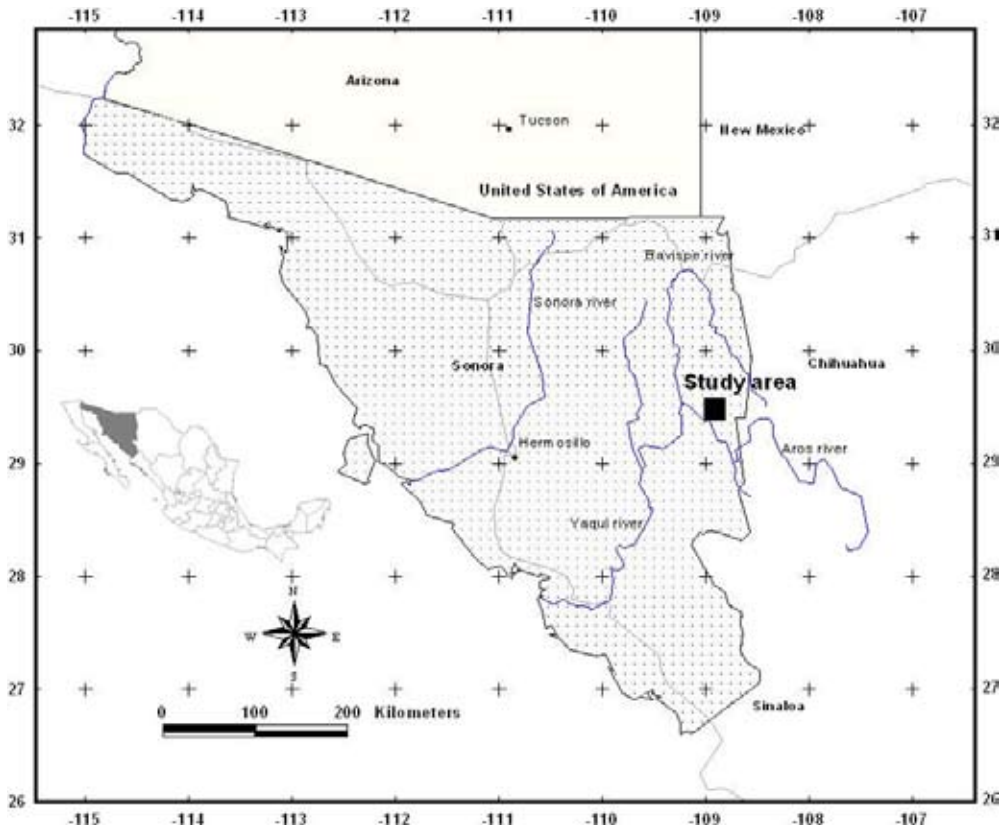


Figure 1. Jaguar study area located in the municipality of Nacori Chico, northeastern Sonora, Mexico, about 200 km south the United States-Mexico border.

(October-June) and a wet season (July-September), with the latter characterized by monsoonal rains (relatively frequent short duration, high intensity downpours).

Our study site encompassed approximately 400 km² including 16 private ranches and was located about 30 km southwest of the town of Nacori Chico. Elevations ranged from 500-1500 m. The main economic activity within the site is cattle ranching. Potential prey for jaguars and pumas included white-tailed deer, antelope jackrabbit (*Lepus* spp.), cottontail (*Sylvilagus audubonii*), coatimundi (*Nasua narica*), collared peccary (*Pecari tajacu*), opossum (*Didelphis* spp.), and cattle. Other carnivores present include coyote (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*), raccoon (*Procyon lotor*), bobcat (*Lynx rufus*), ocelot (*Leopardus pardalis*), skunks (*Mephitis macroura*, *Spilogale putorius*, *Conepatus mesoleucus*), ring-tailed cat (*Bassariscus astutus*), badger (*Taxidea taxus*), and river otter (*Lontra longicaudis*) (Hall 1981).

MATERIALS AND METHODS

Camera-trap surveys. During a reconnaissance survey, we conducted limited camera-trapping (Silver *et al.* 2004) from 2000-2004 primarily to determine jaguar presence or absence in our study area. For this survey, we placed one-sided camera-traps in areas we had previously detected jaguar and puma sign (fresh tracks, scrapes, raked trees, and fresh kills). We rotated 6 cameras (2 TrailMaster® TM-1500 [Goodson Associates Incorporated, Lenexa, Kansas, USA] and 4 CamTrakkers® [Cam Trak South Incorporated, Georgia, USA]) throughout our study site. We ran cameras for approximately 30 days in the same location, then moved cameras to different locations. This allowed us to cover 30 sites in our study area from May-July. We identified individual jaguars by spot-rosette variation of their pelage (Silver *et al.* 2004). For pumas we identified individuals using unique characteristics of individuals including scars, tail fractures, tadpoles, and body shape (Kelly *et al.* 2008). We also collected frontfoot and hindfoot tracks for both species from track traps at each camera station and used these to aid in identification of individual animals (see Track Surveys below).

In February 2005, we established a systematic camera trap grid to estimate the minimum number of jaguars in the study area. We ran camera traps from 9 February-9 April, 2005, using 42 CamTrakker and 24 DeerCam (DeerCam®, Saint Paul, Minnesota, USA) passive infrared systems. We placed 26 camera trap stations in areas where jaguars were previously photographed and in areas where jaguar detection was maximized, such as near raked trees and where fresh jaguar tracks and feces had previously been found along roads, trails or washes. We spaced camera traps approximately 3-4 km apart, which corresponded to the home-range size of jaguars in Chamela-Cuixmala Biosphere Reserve in Jalisco, west Mexico. There, female jaguars had home ranges of 25 km² during the dry season and 65 km² during the wet season (Nuñez *et al.* 2002). The habitat conditions in Jalisco are similar to the habitat conditions in northeastern Sonora: semi-tropical thornscrub and tropical deciduous forest as dominant vegetation types with marked dry and wet seasons.

We placed two cameras at each station, one on each side of each site, to ensure that a photograph was taken of both sides of the jaguar and for redundancy in case of camera failure. We positioned cameras approximately 40 cm above the ground and attached cameras to a tree or branch. We faced cameras slightly down the trail to prevent mutual interference, set cameras to shoot simultaneously (Silver *et al.* 2004), and aligned cameras to where a track trap was placed. We operated camera traps for 60 days using 24 exposure ASA 400 35-mm film, and we visited cameras every 7-10 days to ensure they were functioning. Lastly, we placed track traps directly between cameras and also 300 m up and down the trail. We used data from both the reconnaissance surveys and the 2005 camera-trapping grid to identify individual jaguars and pumas in the study area.

Track surveys. We conducted track surveys throughout the study area from July 1999-March 2005 during the dry and wet seasons of each year. Surveys were mainly conducted along washes, dirt roads, cattle trails, game trails, canyons and track plates. Once we identified positively a jaguar or puma track (Aranda 2000) we collected (made plaster casts, photographed) tracks and recorded location, vegetation type, elevation, and substrate. For analysis, we included tracks only if collected under the following criteria: 1) the surface of the terrain was flat; 2) the imprint was on loose dirt or silt substrate (no sand or mud); and 3) at least 1 front and 1 hindfoot track was collected. We collected tracks with plaster casts. We recorded 4 measurements from plaster casts of each hindfoot: total length (TL), total width (TW), total pad length (TPL), and total pad width (TPW) (Figure 2). We used MANOVA (Morrison 1990) to test whether hindfoot measurements of adult jaguars and pumas differed by species and gender. We also used linear discriminant analysis (Morrison 1990) to see whether these measures could differentiate tracks by species and genders. We also explored the ability of the resultant discriminant function to identify individual jaguars and pumas.

Additionally, we classified tracks by species and sex according to their shape and size, and differentiated individuals by different idiosyncratic diagnostic characteristics of their frontfoot tracks following the criteria of Rosas-Rosas *et al.* (2003) where

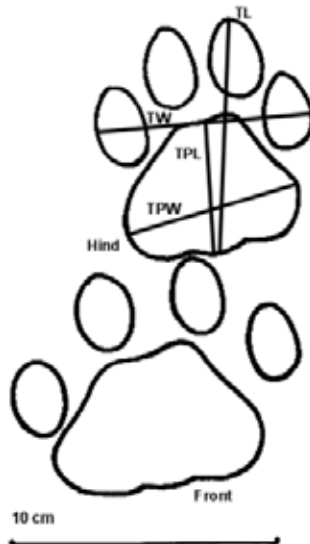


Figure 2. Four basic measurements including total length (TL), total width (TW), total pad length (TPL), and total pad width (TPW) of hindfeet that were used to differentiate between species and genders of jaguars and pumas.

possible. Idiosyncratic features included displaced toes, pad shape, scars, etc. We used this data to supplement photographic captures in individual identification.

RESULTS

Camera-trap surveys. We identified 5 individual jaguars by photographic captures using spot-rosette patterns, including 4 adult males and 1 adult female (Table 1). Three jaguars (2 adult males, 1 adult female) were identified during 2000-2003 and 2 (2 adult males) during 2005.

We also identified 11 individual pumas (7 adult males, 4 adult females) by photographic captures (Table 2). Although individual pumas were more difficult to identify by photographic captures, size differences between males and females were obvious in photographs, and in 2 cases, pumas could be differentiated based on scars on their faces and ears (Kelly *et al.* 2008). Tracks were also useful to corroborate identification of individuals, especially pumas that did not show unique markings (see below).

Track surveys. We collected 208 jaguar tracks including 105 from a hindfoot and 103 from a frontfoot, 1999-2005. We identified 12 individual jaguars by idiosyncratic features of their frontfeet (including displaced toes and disfigured pads; Table 1), including 4 adult males (Figure 3), 6 adult females (Figure 4), and 2 kittens. Eight of these (2 adult males and 4 adult females, including 2 with 1 kitten each) were present from 1999-2003, but only 3 remained in 2004 (Table 1). During 2005, we identified 2 new adult males and 2 new adult females; none of the previously identified jaguars were present on the area in 2005. Identification of 5 individuals (4 adult males, 1 adult female) was corroborated by photographic captures (Table 1). Conversely, we

Table 1. Individual adult male, adult female, and juvenile jaguars identified from track characteristics and photographs, 1999-2005. Numbers correspond to the same individual (i.e., M1 = M1 through years and technique) and kittens are referenced to their mother.

Year	Tracks			Photographs		
	Males	Females	Kittens	Males	Females	Kittens
1999	M1	F1, F2				
2000	M1, M2	F1, F2, F3, F4	K1(F3) K2(F4)	M1, M2		
2001	M1, M2	F1, F2, F3,		M1		
2002	M1	F1, F3, F4		M1		
2003	M1	F2, F3		M1	F3	
2004	M1	F3, F4				
2005	M3, M4	F5, F6		M3, M4		

Table 2. Individual adult male, adult female, and juvenile pumas identified from track characteristics and photographs, 1999-2005. Numbers correspond to the same individual (i.e., M1 = M1 through years and technique) and kittens are referenced to their mother.

Year	Tracks			Photographs		
	Males	Females	Kittens	Males	Females	Kittens
1999	M1, M2	F1		M1	F1	
2000	M1, M2	F2,	K1(F2)	M2		
2001	M1, M2, M3, M4	F2, F3				
2002	M3	F3, F4		M3		
2003	M3, M4	F4		M4		
2004	M3, M5, M6	F3, F4, F5	K2(F4)	M4	F3	
2005	M1, M5, M6, M7	F4, F5		M4, M5, M6, M7	F4, F5	

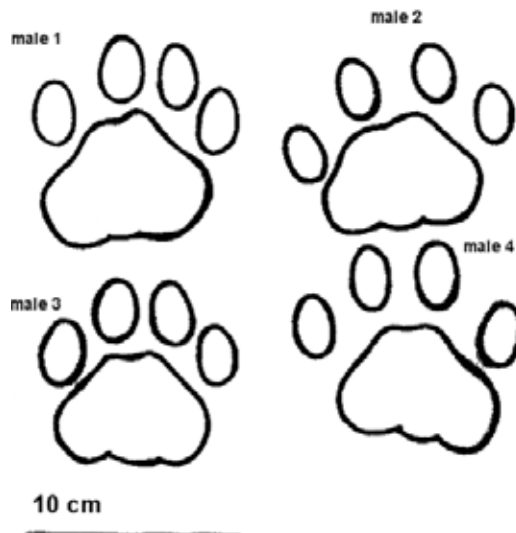


Figure 3. Diagnostic track characteristics found consistently and used to differentiate 4 male jaguars in northeastern Sonora, Mexico. Note the comparative differences in the width of the front pad and distance between toes and main pad.

photographed all adult males that were identified by tracks, but only 1 of 6 known adult females and no kittens (Table 1). During our study, males showed a periodicity of approximately 30 days and females about 20 days between return visits to the same area.

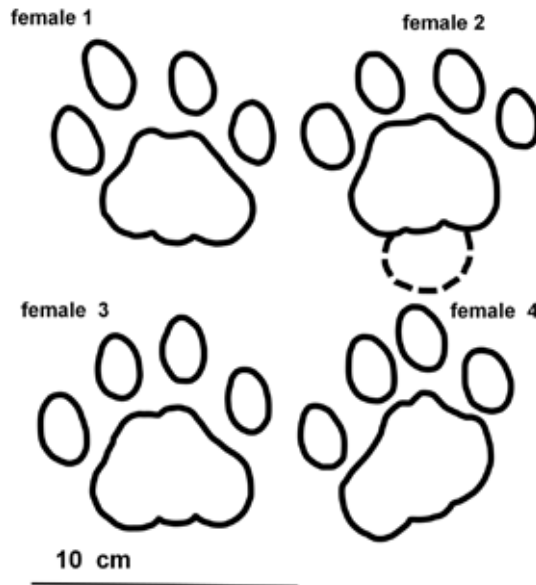


Figure 4. Diagnostic characteristics of tracks of 4 individual female jaguars. Note the leading out of place toe of female 1, the calluses in the rear of the pad of female 2, and the oblong main pad of female 4 compared to the rounder shape of female 3. Female 3 can also be differentiated by the shape of the pad.

We also collected 159 puma tracks, including 97 hindfoot and 62 frontfoot tracks. We identified a minimum of 14 different pumas from track features, including 7 males, 5 females, and 2 kittens (Table 2). Eleven of these (7 adult males, 4 adult females) were corroborated by photographs (Table 2). Similar to jaguars, all adult male pumas identified by track characteristics were also photographed, while only 4 of 5 adult females identified by track characteristics and no kittens were photographed (Table 2).

Hindfoot measurements of adult jaguars and pumas varied ($F_{12,514} = 44.7$; $p < 0.0001$) by species and sex in TL ($F_{3,197} = 117.7$; $p < 0.0001$), TW ($F_{3,197} = 45.8$; $p < 0.0001$), TPL ($F_{3,197} = 70.9$; $p < 0.0001$), and TPW ($F_{3,197} = 86.5$; $p < 0.0001$) (Table 3). Jaguar males, jaguar females, puma males, and puma females each differed in TPL ($p < 0.0001$) and TPW ($p < 0.037$). Similarly, each sex and species differed in TL ($p < 0.0004$) except for jaguar and puma females which were similar ($p = 0.351$) and in TW ($p < 0.0003$) except for jaguar and puma males, which were similar ($p = 0.495$) (Table 3). Discriminant functions correctly classified 90.9% and 93.1% of male and female jaguar tracks, and 85.2% and 97.0% of male and female puma tracks. When we pooled both species into the same dataset, the resultant discriminant functions

Table 3. Means (SE) total length (TL), total width (TW), total pad length (TPL), and total pad width (TPW) in mm of hindfeet tracks from of adult jaguars and pumas, northeastern Sonora, Mexico.

Species	Sex	TL	TW	TPL	TPW	N
Jaguar	Male	90.9 (0.8) B	83.1 (1.3) A	51.7 (0.6) A	63.8 (0.8) A	33
Jaguar	Female	80.3 (0.4) C	73.3 (0.7) B	43.5 (0.4) C	54.5 (0.4) C	72
Puma	Male	94.7 (0.9) A	82.0 (0.9) A	47.5 (0.5) B	56.7 (0.6) B	63
Puma	Female	81.3 (0.6) C	68.1 (1.1) C	40.1 (0.6) D	47.5 (0.7) D	43

had a total successful classification of 87.8% and 84.9% for male and female jaguars and 73.7% and 82.3% for male and female pumas, respectively. In a further analysis to explore the ability of the discriminant function to identify individual jaguars and pumas, the discriminant function correctly identified all individual male jaguars (4 of 4), 5 of 7 male pumas (two were incorrectly identified as 2 different female jaguars), 5 of 6 female jaguars (one individual was incorrectly identified as a female puma), and 5 of 5 female pumas as identified by tracks and photographs, supporting individual identifications from these methods.

Jaguar and puma density. Including an exterior buffer of $\frac{1}{2}$ the mean home range of adult female jaguar (Nuñez *et al.* 2002, Karanth & Nichols 2002), our camera grid covered a total area of approximately 360 km² for 1560 trap nights, February 9th-April 9th, 2005. We documented a minimum of 4 jaguars (2 adult males from both tracks and photographs; 2 adult females from tracks) and 6 pumas (3 adult males and 2 adult females from both tracks and photographs; 1 adult male from tracks) in 2005 from combined track identification and photographic captures. A minimum density estimate for jaguars was 1.1/100 km² (4/360 km²), assuming each adult male has a home range that overlaps exclusively with at least 1 female (Schaller & Crawshaw 1980). Similarly, puma density from track and camera surveys was estimated at 1.7/100 km².

DISCUSSION

Camera-trapping has received considerable recent support (Karanth *et al.* 2004, Ceballos *et al.* 2007, Salom-Pérez *et al.* 2007) and can be useful for monitoring large felid populations, but it has limitations. Logistical problems related to monitoring camera-traps in remote areas characterized by rugged topography were the most common problems we encountered. Topography, cattle, long distances between camera stations, and the lack of roads were the main constraints for checking and maintaining cameras. It was difficult to conduct camera-trapping in areas occupied by cattle because cattle triggered numerous cameras. On 3 occasions jaguars, as evidenced by tracks, could not have been photographed because cattle triggered most of the expo-

tures before the jaguar moved between the cameras. Also, cameras were not completely effective in photographing individuals at traps; 2 jaguars and 5 pumas stepped on track traps but were not detected by cameras and, as seen elsewhere, kittens were never photographed (Karanth & Nichols 2002). There were similar difficulties with track surveys; the same logistical problems applied to monitoring track plates and surveys, and identification from tracks (using either idiosyncratic features or discriminant functions) was often impossible due to cattle and extreme weather conditions. Thus, we conclude that a combination of photographic captures and identification from tracks provided the most complete and defensible enumeration of jaguars in northeastern Sonora. Because rugged topography, hard soils, absence of roads, and harsh weather conditions make it less reliable to use only one technique, using 2 different techniques allowed detection of a greater number of jaguars and pumas and thus a better understanding of the population status and trend.

Karanth *et al.* (2003) and Miller (2004) concluded that identification of individual felids such as Asiatic tigers (*Panthera tigris*) and jaguars from tracks was not feasible or reliable due to several variables which cannot be controlled, such as different substrates and small sample sizes collected from each individual. Consequently, Karanth *et al.* (2003) recommended that track surveys not be used for conservation decisions due to the lack of reliability of the technique and recommended camera-trapping as an alternative. However, we found that track surveys, in conditions such as northeastern Sonora, whether based on idiosyncratic features or discriminant analysis, corroborated photographic identification and detected more individuals of all age classes than did camera traps. Individual identification from idiosyncratic features of frontfoot was also supported by successful classification of species and sex (and, to a lesser extent, individuals) by discriminant analysis of hindfeet. Additionally, when identification from idiosyncratic features and discriminant analysis differed, the discriminant function always assigned individuals to the other species, an error not present when simply identifying species by track shape (Aranda 2000). Sample sizes were also adequate despite the constraints we placed on tracks included in analyses; we detected and measured tracks of individual jaguars from 2-33 times ($\bar{x} = 12$; SE = 3) and 2-14 ($\bar{x} = 8$; SE = 1) times for pumas. Most importantly, camera-traps missed jaguars (and pumas) detected by track traps, but no jaguars (or pumas) that were photographed were not previously captured in track traps. Thus, camera trapping and track surveys in combination provided a much more complete enumeration of the jaguar and puma population. Similarly, Karanth & Nichols (1998) only detected tiger cubs from track surveys, as cubs were not photographed at camera traps.

Miller (2004) concluded that it was not possible to differentiate jaguars and pumas from tracks. In contrast, we found that following a protocol of only collecting tracks from flat areas, dirt or silt substrates, and at least 1 front and 1 hindfoot of the same individual, both qualitative (idiosyncratic features) and quantitative (4 basic mea-

surements) analyses showed that tracks could reliably identify species and gender of jaguars and pumas with a range of 74-87% accuracy. Our results supported those results of Isasi-Catalá & Barreto (2008), who differentiated individual jaguars using discriminant analysis. We were also able to differentiate species and sex using only 4 simple measurements, as compared to ≥ 15 in previous analyses (Smallwood & Fitzhugh 1993, Riordan 1998, Sharma *et al.* 2005). Moreover, discriminant analysis showed the potential to correctly classify hindfoot tracks to individuals as well, facilitating and corroborating the ability of idiosyncratic features of frontfoot tracks to identify individuals as well as species and sex.

Use of idiosyncratic features of frontfoot to identify individual jaguars and pumas in our study area was supported by the results of both photographic recaptures and discriminant analysis. Jaguar tracks frequently showed readily identifiable diagnostic characteristics on their frontfoot (Table 2; Figures 3 and 4). Predators such as jaguars primarily use their forefeet to subdue their prey and in territorial confrontations, and can sustain injuries by being caught in predator control traps. Thus, they were more likely to show deformations in their frontfoot morphology such as bent toes, displaced toes, disfigured toes, and disfigured pads (Figures 3, 4). In contrast, we found that individual pumas were more difficult to identify by idiosyncratic characteristics of their frontfoot. Identification of individuals from tracks was also easier for jaguars than pumas because the larger and rounder shape of the jaguar forefoot allowed observers to more readily detect diagnostic characteristics. Anecdotally, the low numbers of jaguars in our study area likely allowed for greater familiarity with, and consequently easier recognition of their tracks. After several years (1999-2004) of tracking the same individuals, recognizing their tracks was not difficult.

Total numbers of jaguars present varied over our study, as did the individuals in the population (Table 1). Of the original 6 jaguars identified from 1999-2003, only 3 were detected by 2004 and none were seen in 2005, when 4 new jaguars were identified. Thus, the jaguar population in northeastern Sonora showed a high turnover of individuals and significant year-to-year variation in population size. This may be due to high rates of immigration and emigration as well as continued illegal killing of jaguars due to livestock conflicts (Rosas-Rosas *et al.* 2008). Regardless, the turnover and large annual variation in numbers makes frequent monitoring of this population critical if it is to persist in northeastern Sonora. Moreover, the high turnover, if not solely due to illegal killing, suggests that individual survival or suitability of habitats may be limited by other environmental factors. Relatedly, the population may simply be transitory in nature, although lack of evidence of establishment of other populations further away from core jaguar habitats in the Sierra Madre Occidental argues against this. Regardless, efforts to determine the fates of individual jaguars in this population are needed to judge the viability of the population for long-term conservation of jaguars in northeastern Sonora.

Lastly, the estimated jaguar density reported in our study (1/100 km²) was less than in Jalisco, Mexico (2/100 km²; Nuñez *et al.* 2002), the Maya Biosphere Reserve, Guatemala (2/100 km²; Novack 2003), the Yucatan peninsula (3-7/100 km²; Chávez *et al.* 2007; Faller *et al.* 2007), Campeche, Mexico (1/27 km²; Aranda 1998), and the Cockscomb Basin, Belize (9/100 km²; Silver *et al.* 2004). The lower density in northeastern Sonora probably reflects its location at the fringe of jaguar range, where fluctuations of jaguar populations would be expected due to resource variability (Urness 1981) and illegal killing due primarily to livestock conflicts (Rosas-Rosas *et al.* 2008, 2010).

Jaguars are endangered and protected in Mexico (SEMARNAT 2001), and the Sierra Madre Occidental is considered a priority area for long-term jaguar conservation (Sanderson *et al.* 2002). The high turnover of individuals, the large year-to-year fluctuations in population size, and the low jaguar density all make the viability of this northernmost breeding population of jaguars uncertain. Thus, it is critical that this population be carefully monitored. Because of inherent limitations with either method, we recommend that monitoring include both photographic camera trapping and track surveys, as use of multiple methods provide valuable corroboration of minimum estimates not possible with use of one technique alone. If constraints preclude use corroborating techniques, we recommend track surveys for use in northeastern Sonora because of the ability to more thoroughly enumerate individuals, because conditions are logistically difficult to efficiently conduct camera-trapping, and track surveys consistently identified all sex and age classes of the population. However, we caution that this data be rigorously collected and carefully evaluated, as in our analysis, by managers highly familiar with jaguars and pumas. Further development and testing of discriminant functions on a larger number of known individual could significantly facilitate this approach, although discriminant functions are best developed locally because of morphological variation in mean size of jaguars and puma throughout their range (Seymour 1989, Iriarte *et al.* 1990). While camera-trapping alone in other areas such as portions of Central and South America may be an adequate technique, many of these areas have much gentler terrain and greater access, which facilitates visiting camera stations (Silver *et al.* 2004). In our study, approximately 360 km² were monitored using 26 camera stations. Camera-trapping may have been more successful if only 200 km² had been monitored for a period of 45 days, and then cameras moved to the other 200 km² for another 45 days. This may have allowed more frequent monitoring of cameras by personnel and allowed for additional sets of cameras in areas where cattle were concentrated. Additionally, sole use of digital cameras with large memory cards could mitigate some of the problems we experienced, such as cattle triggering camera-traps, by allowing much faster camera cycling intervals.

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