Contributed Paper

Effectiveness of Scat-Detection Dogs in Determining Species Presence in a Tropical Savanna Landscape

CARLY VYNNE,*,‡‡ JOHN R. SKALSKI,† RICARDO B. MACHADO,‡§§ MARTHA J. GROOM,*§ ANAH T.A. JÁCOMO,¶ JADER MARINHO-FILHO,** MARIO B. RAMOS NETO,‡¶¶ CRISTINA POMILLA,†† LEANDRO SILVEIRA,¶ HEATH SMITH,* AND SAMUEL K. WASSER*

*University of Washington, Department of Biology, P.O. Box 351800, Seattle, WA 98195, U.S.A.
†University of Washington, School of Aquatic and Fishery Sciences, P.O. Box 355020, Seattle, WA 98195, U.S.A.
‡Conservation International Brazil, SAUS quadra 3, lote 2, bloco C, Ed. Business Point, Brasilia, DF 70070-934, Brazil
§University of Washington Bothell, Interdisciplinary Arts & Sciences, P.O. Box 358246, Bothell, WA 98011, U.S.A.
¶Jaguar Conservation Fund, Caixa Postal 193, Mineiros, GO, 75830-000, Brazil
**Zoology Department, University of Brasília, Institute of Biological Science, Campus Darcy Ribeiro, Brasilia, DF 70910-900, Brazil
††Global Felid Genetics Program, Sackler Institute of Comparative Genomics, American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024, U.S.A.

Abstract: *Most protected areas are too small to sustain populations of wide-ranging mammals; thus, identification and conservation of high-quality habitat for those animals outside parks is often a high priority, particularly for regions where extensive land conversion is occurring. This is the case in the vicinity of Emas National Park, a small protected area in the Brazilian Cerrado. Over the last 40 years the native vegetation surrounding the park has been converted to agriculture, but the region still supports virtually all of the animals native to the area. We determined the effectiveness of scat-detection dogs in detecting presence of five species of mammals threatened with extinction by habitat loss: maned wolf (*Chrysocyon brachyurus*), puma (*Puma concolor*), jaguar (*Panthera onca*), giant anteater (*Myrmecophaga tridactyla*), and giant armadillo (*Priodontes maximus*). The probability of scat detection varied among the five species and among survey quadrats of different size, but was consistent across team, season, and year. The probability of occurrence, determined from the presence of scat, in a randomly selected site within the study area ranged from 0.14 for jaguars, which occur primarily in the forested areas of the park, to 0.91 for maned wolves, the most widely distributed species in our study area. Most occurrences of giant armadillos in the park were in open grasslands, but in the agricultural matrix they tended to occur in riparian woodlands. At least one target species occurred in every survey quadrat, and giant armadillos, jaguars, and maned wolves were more likely to be present in quadrats located inside than outside the park. The effort required for detection of scats was highest for the two felids. We were able to detect the presence for each of five wide-ranging species inside and outside the park and to assign occurrence probabilities to specific survey sites. Thus, scat dogs provide an effective survey tool for rare species even when accurate detection likelihoods are required. We believe the way we used scat-detection dogs to determine the presence of species can be applied to the detection of other mammalian species in other ecosystems.*

Keywords: cerrado, detection dogs, detection probability, noninvasive sampling, scat, survey, wide-ranging species

Efectividad de Perros Detectores de Excretas para la Determinación de la Presencia de Especies en un Paisaje de Sabana Tropical

§§*Current address: Zoology Department, University of Brasília, Institute of Biological Science, Campus Darcy Ribeiro, 70910-900, Brasilia, DF, Brazil*
¶¶*Current address: Landscape Ecology Lab - World Wildlife Fund Brazil, SHIS EQ QL 6/8 – Brasilia DF*
‡‡*email cvynne@uw.edu*
Paper submitted January 12, 2010; revised manuscript accepted May 10, 2010.

Conservation Biology, Volume **, No. **, ***-***

DOI: 10.1111/j.1523-1739.2010.01581.x

Resumen: *La mayoría de la áreas protegidas son demasiado pequeñas para sustentar poblaciones de mamíferos de distribución amplia; por lo tanto, la identificación y conservación de hábitat de alta calidad para esos mamíferos fuera de los parques es una alta prioridad, particularmente para regiones con conversión extensiva de suelo. Este es el caso en los alrededores del Parque Nacional Emas, una pequeña área protegida en el Cerrado Brasileño. En los últimos 40 años, la vegetación nativa que circunda al parque ha sido convertida a agricultura, pero la región aun soporta virtualmente a todos los animales nativos al área. Determinamos la efectividad de perros detectores de excretas para detectar la presencia de 5 especies de mamíferos amenazados de extinción por la pérdida de hábitat: lobo colorado (*Chrysocyon brachyurus*), puma (*Puma concolor*), jaguar (*Panthera onca*), hormiguero gigante (*Myrmecophaga tridactyla*) y armadillo gigante (*Priodontes maximus*). La probabilidad de detección de excretas varió entre las 5 especies y entre cuadrantes de muestreo de tamaño diferente, pero fue consistente entre equipos, temporada y año. La probabilidad de ocurrencia, determinada a partir de la presencia de excretas, en un sitio seleccionado aleatoriamente dentro del área de estudio varió desde 0.14 para jaguares, que ocurren principalmente en las áreas boscosas del parque, hasta 0.91 para lobos colorados, la especie más ampliamente distribuida en nuestra área de estudio. La mayoría de las ocurrencias de armadillos gigantes en el parque fue en los pastizales abiertos, pero en la matriz agrícola tendieron a ocurrir en los bosques ribereños. Por lo menos una de las especies estudiadas ocurrió en cada cuadrante de muestreo, y los armadillos gigantes, jaguares y lobos tuvieron una mayor probabilidad de ocurrencia en cuadrantes localizados dentro del parque que afuera. El esfuerzo requerido para la detección de excretas fue mayor para los 2 félidos. Pudimos detectar la presencia de cada especie de distribución amplia dentro y fuera del parque y asignar las probabilidades de ocurrencia a sitios de muestreo específicos. Por lo tanto, los perros detectores fueron una herramienta de muestreo efectiva para estas especies raras aun cuando se requirieron probabilidades de detección precisas. Consideramos que la manera en que utilizamos los perros detectores de excretas para determinar la presencia de especies se puede ampliar para la detección de otras especies de mamíferos en otros ecosistemas.*

Palabras Clave: cerrado, especies de distribución amplia, muestreo de excretas, muestreo no invasivo, perros detectores, probabilidad de detección

Introduction

In many areas conservation of large mammals depends on protecting and restoring linkages among networks of small reserves and private lands (Woodroffe 2001). Directing conservation efforts to the most important sites requires effective methods to evaluate how wide-ranging species respond to changes in land use. In particular, survey methods are needed that yield high detection rates independent of species density, enable simultaneous sampling of multiple species, and are efficient over large spatial extents.

Scat-detection dogs are a promising tool for monitoring animal populations because they can detect scats over large distances (Smith et al. 2003; Wasser et al. 2004; Long et al. 2007a), and the scats can be used to confirm species presence, evaluate and monitor population density and physiological health, and understand resource selection by animals (Wasser et al. 2004; Gobush et al. 2008; Wolf & Ale 2009). Dogs trained to locate feces of particular species detect carnivores more effectively than traditional methods, such as hair snares, scent stations, and camera traps (Wasser et al. 2004; Harrison 2006; Long et al. 2007b), and they are particularly effective in detecting wide-ranging, elusive, or rare species (Long et al. 2007a; Vynne et al. 2009). The effective use of detection dogs, however, requires quantification of the ability of the dogs to detect target species and evaluation of how this ability is influenced by survey design and other variables such as season and dog team.

In a 4-year study in and around Emas National Park in the Brazilian cerrado biome, we used scat-detection dogs to evaluate presence of five large mammals threatened with extinction by habitat loss: maned wolf (*Chrysocyon brachyurus*), jaguar (*Panthera onca*), puma (*Puma concolor*), giant anteater (*Myrmecophaga tridactyla*), and giant armadillo (*Priodontes maximus*). Although more than 55% of the cerrado has been cleared for agriculture and livestock grazing in the last 50 years (Klink & Machado 2005), federal law requires landowners to leave between 20% and 30% of the original land cover uncleared (Brannstrom et al. 2008). Thus, the landscape mosaic outside Emas National Park is dominated by large-scale agriculture and cattle pasture interspersed with forested riparian areas and woodland fragments. The region contains its full suite of historically present (AD 1500) large (>20 kg) mammals (Morrison et al. 2007), yet the park, by itself, is unlikely to support these populations over the long term (e.g., Silveira et al. 2009a). Because the influence of the surrounding landscape on the persistence of large mammals is unknown, it is important to determine the distribution of our study species within and around the park.

Estimating the level of effort required to detect the presence of wide-ranging or rare species with a particular level of certainty furthers effective survey design. Such estimation requires consideration of the sources of observation error (Skalski & Robson 1992). Estimates of variation in the error term can then be used to determine the number of repeated surveys necessary to detect species presence with a given level of certainty. To quantify the level of effort required to detect species presence within our study area, we developed and applied models that determined the probability of detection of our study species by dog teams. We developed likelihood profiles for detecting a species for a sampling area of given size and a given level of effort. We determined whether the dogs located study species and distinguished them from other species; probabilities of species being present and detected by dog teams; and proportion of survey sites in our study area occupied by each species. We also evaluated whether detection rates, as a function of different study variables, were consistent; the influence of survey design and target species on detection probabilities; whether probability of occurrence varies as a function of location relative to a protected area; and level of effort required to assess the presence and absence of species.

Methods

Study Area

The 1320-km^2 Emas National Park and surrounding farms, which comprised our 4000-km^2 study area, are in the region of Goiás, Mato Grosso, and Mato Grosso do Sul states (18°S, 52°W), Brazil. Emas National Park lies within the cerrado biome, which comprises 21% of Brazil and is the world's largest, most biologically diverse, and most threatened tropical savanna (Silva & Bates 2002). The park protects large tracts of grassland plains and open shrublands (81%), woodlands and riparian forest (17%), and marshlands (1%). Crops (44%, primarily soy, cotton, corn, and sugar cane), cattle pasture (25%), and remnant vegetation (31%, Fig. 1a) comprise the area surrounding the park.

Dog Selection and Training

We trained and worked dogs in the field according to methods described in Wasser et al. (2004). Briefly, dogs with an obsessive drive to fetch a tennis ball were selected from animal shelters in Washington (U.S.A.). In 2004 professional training of dogs was conducted at Packleader Dog Training (Gig Harbor, Washington) and in 2006–2007 at University of Washington Conservation Canine facilities (Seattle and Eatonville, Washington). Dogs were taught to associate odor with a play reward. Once this association was made, dogs were taught to search for, locate, and indicate (by sitting) scats of target species.

We initially trained dogs with scats from 6–8 captive and wild individuals of maned wolves, jaguars, and pumas; after confirming wild-collected samples via DNA analysis we used a minimum of 12–15 samples for training in subsequent years. Training dogs to detect samples from multiple known individuals of a given target species allowed them to generalize detection to any sample from that species, regardless of its sex or reproductive status. In 2006, while in Brazil, we trained the dogs to detect giant armadillos and giant anteaters with scats from wild individuals we had identified visually ($n = 4$ for both species).

Field Surveys

One to three detection teams (comprised of a dog, dog handler, and field assistant) conducted 407 scat surveys at 70 sites between August 2004 and April 2008. We surveyed during three dry-season sessions of 10 weeks each (May-August 2004, 2006, and 2007) and one rainy-season session (January-April 2008). We conducted sampling in 5 × 5 km (25 km^2) sites (henceforth, quadrats) that were randomly spaced across the study area (5 × 5, $n = 57$) and in 3 × 3 km (9 km^2) quadrats (3 × 3, $n = 13$) that were contiguous (Fig. 1a). We sampled a different 2.5 × 2.5 km (6.25 km^2) quadrat during each visit to a 5 × 5 quadrat; thus, we did not sample the entire plot on any given visit. We sampled the entire 3 × 3 quadrat during each visit. We did not sample agricultural areas to the west of the park for reasons of safety.

Typically, we surveyed each quadrat three to five times per season. Teams walked freely (i.e., did not follow grid lines or transects) and dogs searched off-leash within designated search quadrats. This allowed the handler to guide the dog according to wind direction and to follow a dog pursuing a scent. Each team searched one quadrat on a given day and every team surveyed all quadrats at least once per season. When a dog located a scat, the handler rewarded the dog, recorded the geographic coordinates of the scat, and collected the sample. We did not collect samples that were odorless (to the human observer) or formless (e.g., scattered undigested seeds or hair). Otherwise, a portion of the sample was placed in a vial with 25 mL of 20% dimethyl sulfoxide buffer and frozen until DNA extractions could be conducted (Frantzen et al. 1998; Vynne 2010).

DNA Analyses

To confirm whether a scat was deposited by a maned wolf, puma, jaguar, or other species (e.g., ocelot [*Leopardus pardalis*] and fox [*Cerdocyon thous*]), we used DNA analysis. Giant anteater scats are easily identified by their shape, size, and contents (Chame 2003); thus, we did not conduct genetic analysis of these scats. Giant armadillo scats could potentially, though not easily, be confused with scat of other sympatric species of armadillo. Because putative giant armadillo scats typically occurred in proximity to other evidence of the presence of giant armadillos (tracks, paths, diggings, burrows, or sighting of the animal) and were not found in areas with

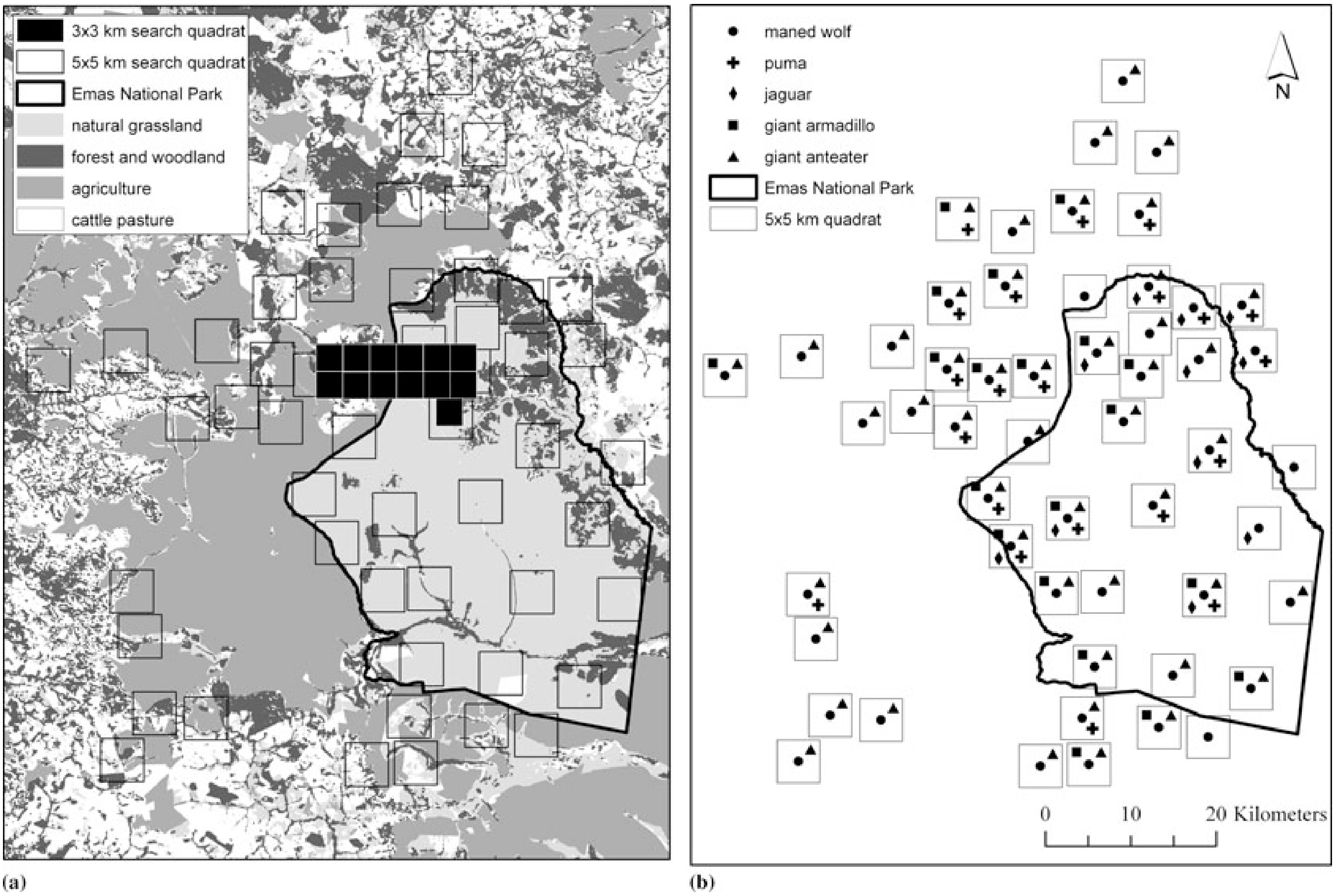

Figure 1. (a) Location of survey quadrats relative to Emas National Park and land-use categories and (b) presence of target species among 5 × 5 km quadrats.

activity by other armadillo species or sightings of other species, we are confident that species identification of these samples was accurate.

We conducted DNA extraction and analysis of scat samples at the Center for Conservation Biology, University of Washington (Seattle) with the Qiagen QiaAmp Stool and Blood/Tissue kits (Qiagen, Valencia, California) with modified protocols (Vynne 2010). To identify the species, we used fragment analysis from PCR amplification of the mitochondrial control region (D-loop) (Wasser et al. 1997). Species assignment for a subset of the samples was also confirmed by sequencing at the Sackler Institute of Comparative Genomics with primers adapted to amplify the 16S ribosomal RNA gene (C.P., unpublished data). We excluded samples that did not yield DNA that could be used to identify species or were from a nontarget or unidentified species.

Species-Detection Probabilities and Distributions

We derived the conditional probability of detecting a species (i.e., event A) when it is present (i.e., event B), $p(A|B)$, by summing detections across quadrats and pooling by team and year (when not significantly different according to chi-square test) and then dividing the number of detections (1s) by the number of surveys (1s and 0s). We based this approach on Manly-Parr's (1968) technique of estimating detection probabilities. We assumed species were never falsely detected in a quadrat when absent and that an animal may have been detected in a quadrat when present. Once presence was confirmed in a quadrat, subsequent detections or lack of detections represented dog-team successes or failures to detect the species. We calculated $p(A|B)$ with data from all sites that were visited two or more times that had ≥ 1 detection and at least one subsequent visit to that site following a confirmed detection.

We used data from all sites to calculate the joint probability of a species being present and detected $p(AB)$.

$$p(AB) = \hat{p} = \frac{\sum_{i=1}^{n} \frac{x_i}{m_i}}{n},$$

where x_i is the number of successful detections at the ith quadrat ($i = 1 \ldots n$), m_i is the number of visits to the *i*th quadrat ($i = 1 \ldots n$), and n is the number of unique quadrats.

We then determined the probability of presence for each of the study species in a randomly selected quadrat by calculating the proportion of quadrats, $p(B)$, in which each of the species was present. By definition, $p(AB) = p(A|B) \bullet p(B)$. Thus, $p(B) = \frac{p(AB)}{p(A|B.)}$. We averaged all observed and predicted probabilities for the study area as a whole; thus, they do not reflect land use or vegetation-specific rates of occurrence.

We used chi-squared analyses to test whether variation in detection probabilities was significant on the basis of Manly and Parr (1968) capture data. We summed the number of successful and unsuccessful detections of each species, given that the species was present at a quadrat. We used contingency tables to test for homogeneity across five variables: session, team, number of study species, year, and season. For all tests, alpha was 0.05.

To evaluate whether probability of presence of our study species was associated with proximity of the location to the park and hence to the level of human activity, we categorized sampling quadrats as inside, outside, or on the border of Emas National Park. The probability of an animal being present $p(B)$ was then derived as described above for each of these three categories.

Sampling Effort Requirements

We used our method of estimating detection probabilities to calculate the optimal study design for determining species presence in a region with each of three given levels of certainty. To determine the number of quadrats and visits associated with a given probability of detection (P_D), we used a binomial sampling model.

$$P_D = [1 - (1 - p(A|B))^n] \bullet [1 - (1 - p(B))^m],$$

where 1-$p(A|B)$ is the probability that the species is not detected on a given visit; 1-$p(A|B)^n$ is the probability that the species is not detected on n visits; $[1 - (1 - p(A|B))^n]$ is the probability of detecting a species on n visits; and $[1 - (1 - p(B))^m]$ is the probability that a species is present in m quadrats.

We set this equation equal to a given probability of detection (= 0.95, 0.90, and 0.80) and then solved for the required number of visits (n) and quadrats (m). For the 3 × 3 quadrats, minimum effort requirements are reported only for maned wolves, pumas, and giant anteaters because grassland vegetation types were overrepresented in the 3 × 3 quadrats and thus resulted in levels of detection effort that, relative to the study area as a whole, were too high for jaguar and too low for giant armadillo.

Results

The number of target species, teams, quadrats, visits per quadrat, and kilometers walked varied among years (Supporting Information). The mean daily survey distance was 7.7 km/team and the total distance surveyed was 3175 km. The mean number of scats found in quadrats where at least one sample was detected varied from 0.09 scats/km for jaguars to 0.3 scats/km for maned wolves.

Detections of Species and Variation in Detection Probabilities

We detected a total of 2683 putative scats of study species; overall average was 6.6 scats per team per search day. We did not collect 433 samples because they were without odor and form (i.e., very old scats), and we could not amplify DNA of one of the three target species from 650 samples. A greater number of scats of maned wolves ($n = 936$) were detected than of giant anteaters ($n = 505$), jaguars ($n = 33$), pumas ($n = 70$), or giant armadillos ($n = 56$). The percentage of scats that were confirmed by DNA analysis as being from study species varied annually (range 60% in 2004 to 85% in 2008) (Supporting Information). Seventy-one percent (1105 of 1566) of scat samples were not found on roads and thus would have been extremely unlikely to have been found by human observers (Table 1).

The conditional probability of detection given presence, joint probabilities of presence and detection, and probability of a species being present in a randomly selected quadrat varied among species and quadrat sizes (Table 2). Jaguars were detected only once in the 3 × 3 quadrats, but the probability of detection of jaguar scat in 5 × 5 quadrats was 0.57. In quadrats of both sizes, the joint probabilities of a species being present and detected were highest for maned wolves and giant anteaters, followed in decreasing order by armadillos, pumas, and jaguars (Table 2). The probability of animal presence was highest in the 3 × 3 quadrats for giant armadillos and in the 5 × 5 quadrats for maned wolves (Table 2).

Detection probabilities did not differ as a function of session, team, season, and year for all species except giant anteaters. One team had lower probability of detecting

Table 1. Number of scat samples found on roads, animal trails, or off roads and trails (neither) by species.

Species	*Road**	*Trail*	*Neither*	*No data*	*Total*
Maned wolf	425	44	467	0	936
Puma	10	21	36	3	70
Jaguar	9	13	11	0	33
Giant armadillo	12	7	31	6	56
Giant anteater	5	6	469	25	505
Total	461	91	1014	34	1600

**Roads include dirt roads inside Emas National Park, which on average have <1 vehicle/day, and private roads on farms outside the park.*

Table 2. Joint, conditional and overall probabilities of scat detection by dog teams for each of the study species and sizes of quadrats sampled.[a]

Quadrat size (km)[b]	*Species*	*p(AB)*	*SE*	*p(A|B)*	*SE*	*p(B)*	*SE*
3 × 3	maned wolf	0.70	0.055	0.97	0.032	0.72	0.125
5 × 5	maned wolf	0.72	0.026	0.79	0.032	0.91	0.039
3 × 3	puma	0.10	0.036	0.38	0.170	0.26	0.122
5 × 5	puma	0.16	0.021	0.50	0.089	0.32	0.063
3 × 3[c]	jaguar	0.02	0.015				
5 × 5	jaguar	0.08	0.016	0.57	0.105	0.14	0.047
3 × 3	giant armadillo	0.23	0.051	0.29	0.122	0.79	0.113
5 × 5	giant armadillo	0.18	0.026	0.67	0.192	0.27	0.064
3 × 3	giant anteater	0.62	0.058	0.73	0.084	0.85	0.099
5 × 5[d]	giant anteater	0.53–0.75	0.071–0.062	0.38–0.76	0.063–0.116	0.82–1.00	0.055–0

[a] *For a given species and quadrat size:* p(AB)*, probability of a given species being both present and detected;* p(A|B)*, probability of the species being detected given it is present;* p(B)*, probability of the species being present (in a randomly selected quadrat from within the study area).*
[b] *The 3 × 3 quadrats were contiguous and the 5 × 5 quadrats were spaced randomly throughout the study area.*
[c] *No value indicates the species presence and detection probabilities were too low for a likelihood value to be derived.*
[d] *Detection probabilities between years and dog teams differed, so data could not be pooled and range is reported.*

anteaters in 2006 than the other two teams ($\chi^2 = 10.58$, df $= 2$, $p < 0.005$). The ratio of observed to expected detections fell between 2006 and 2007 ($\chi^2 = 10.88$, df $= 1$, $p < 0.001$) and again between 2007 and 2008 ($\chi^2 = 17.35$, df $= 1$, $p < 0.001$). Training the dogs to detect additional target species (giant anteaters and giant armadillos) after 2004 did not reduce their ability to detect the other species and did not reduce the accuracy of their detections of the original study species.

Species Presence in Study Area

We detected maned wolves in 69 of 70 (99%) quadrats, jaguars in 11 of 70 (16%), pumas in 21 of 70 (30%), giant armadillos in 20 of 63 (32%), and giant anteaters in 57 of 63 (90%). Presence of at least one target species was confirmed in all quadrats. Jaguars were restricted to quadrats in riparian forest or forested valleys and cattle pastures that bordered riparian forest (Fig. 1). Pumas were present in 73% (8 of 11) of the quadrats in which jaguars were present.

The probability of presence of pumas and giant anteaters was equal in quadrats located inside, outside, or on the park border, whereas the probability of detecting giant armadillos was three times greater inside the park ($p(B)_{\text{inside}}$[SE] $= 0.46$ [0.133]) than at the park border or outside ($p(B)_{\text{border}} = 0.12$ [0.128]; $p(B)_{\text{outside}} = 0.13$ [0.104]). Maned wolves were present in all surveyed quadrats within park boundaries and had slightly lower probabilities of presence in quadrats outside the park ($p(B)_{\text{outside}} = 0.92$ [0.054]) or on the park border ($p(B)_{\text{border}} = 0.82$ [0.078]). Although probabilities of jaguar presence were equivalent for quadrats occurring inside ($p(B)_{\text{inside}} = 0.35$ [0.126]) and on the border ($p(B)_{\text{border}} = 0.30$ [0.030]), the probability of presence in quadrats outside the park was approximately zero.

In three quadrats maned wolves were the only study species detected. Each of these quadrats was adjacent to the park and two of them included major roads and groups of farm buildings, where levels of human activity were relatively high. One quadrat in which maned wolves were not detected was >12 km from the park in a region dominated by pastures. In 10 quadrats >20 km from the park border, pumas and giant armadillos were detected only once. Outside of the park, giant armadillos were detected in quadrats with remnant woodland and forest, whereas inside the park most detections of armadillos were associated with grasslands.

Survey Effort

The number of visits and quadrats required to attain a given probability of detection varied among species, quadrat sizes, and desired probability (Table 3). Species with higher vegetation-type specificity and more limited distribution within our study site (jaguar, giant armadillo. required a proportionally higher number of quadrats (m) to visits (n) to be detected.

Discussion

Distribution of Study Species

We identified the vegetation and land-use types associated with presence of the focal species within and outside Emas National Park. Our data suggest that all species used the network of private lands outside the park either for dispersal or as part of their active home ranges. All species consistently were present in areas outside the park throughout the year, and individual maned wolves, giant anteaters, pumas, and, to a limited extent, giant armadillos are likely to have active home ranges established outside the park. These results indicate that species persistence may be enabled by offering conservation incentives to owners of land near park borders. Although existing and proposed nature reserves cover only 4% of

Table 3. Most parsimonious combinations of visits by dog teams per 5 × 5 km quadrat and 3 × 3 km quadrat and number of sites required for 0.95, 0.90, and 0.80 probability of detection for each of the species.

Quadrat and species	*Visits 0.95*	*Quadrats 0.95*	*Visits 0.90*	*Quadrats 0.90*	*Visits 0.80*	*Quadrats 0.80*
5 × 5 km						
Maned wolf	2[a]	3[a]	3	1	2	1
Jaguar	4	28	4	18	3	14
Puma	6[b]	9[b]	5	7	4	5
Giant armadillo	3	14	3	9	2	8
Giant anteater (hi)[c]	3	1	2	1	2	1
Giant anteater (lo)	9	2	6	2	4[d]	2[d]
3 × 3 km						
Maned wolf	1	4	1	3	1	2
Puma	8	12	7	9	4[e]	10[e]
Giant anteater	2[f]	3[f]	2	2	3	1

[a] *Three visits to two quadrats are associated with the same probability of detection.*
[b] *Nine visits to six quadrats are associated with the same probability of detection.*
[c] *Because there was a difference among years in detection probabilities of giant anteaters in the 5 × 5 km quadrats, minimum required detection efforts for this species are reported for year with highest and lowest detection probability.*
[d] *Eight visits to one quadrat are associated with the same probability of detection.*
[e] *Ten visits to four quadrats, five visits to eight quadrats, and eight visits to five quadrats are associated with the same probability of detection.*
[f] *Three visits to two quadrats are associated with the same probability of detection.*

the maned wolves presumed global extent, for example, their ubiquitous presence outside the park suggests their conservation may be furthered through conservation efforts in a network of private lands.

Remnant vegetation in the surveyed quadrats appeared to be associated with the presence of the wide-ranging mammals we studied. The privately owned network of woodland patches and riparian corridors may facilitate temperature buffering for giant anteaters (Mourão & Medri 2007) and stalking of prey by pumas (Logan & Sweanor 2001). Remnant vegetation may also provide undisturbed den sites that maned wolves need to establish breeding territories. Our results are consistent with results from other studies that show that natural grasslands are associated with presence of maned wolves and high densities of giant anteaters and giant armadillos (Jácomo et al. 2004; Silveira et al. 2009b). Natural grasslands currently comprise <10% of the native vegetation outside the park (derived in a geographic information system with data provided by Conservation International Brazil).

Robustness of Detection Method

The detection rates of our teams of scat-detection dogs were slightly higher than those of teams used to detect carnivore scat in a temperate forest in Vermont (U.S.A.) (Long et al. 2007a). Our daily detection rates were similar for jaguar and 5 to 20 times higher than those reported for the other species surveyed by camera traps and track plates in our study area (Silveira et al. 2003). Of seven teams working for 4 years with five species, only one team in 1 year had a different probability of detection for one species, which suggests that sampling by scat-detection dogs is not biased by identity of individual dogs, timing of visits, or weather. Our finding that probabilities of detection (when present) were equal for species associated with few and many vegetation types suggests that scat-detection dogs may be useful for detecting rare and cryptic species.

The percentage of surveys in which anteaters were detected declined annually. Our decreased rate of detection of anteaters may be associated with an observed reduced abundance of anteaters that followed large wildfires in Emas National Park in 2006 and 2007; earlier fires killed large numbers of giant anteaters in the park (Silveira et al. 1999). Throughout the study area the probability of site presence of anteaters, however, remained high; thus, the scat-detection dogs robustly detected the presence of anteaters even when their density varied annually.

Ensuring that dogs focus on detecting only study species is important for search efficiency and to avoid costly DNA analyses of samples from other species. Dogs will learn to search for scat that is not from study species if an inexperienced handler shows interest in scat that appears similar to scat of study species. Interest by the handler causes dogs to sit in apparent anticipation of a reward. The handler then believes the scat is from a study species, which increases the probability of repeating the mistake. Few or low-quality scat training samples can also reduce accuracy. In 2004 we had only six to eight training samples from study species, and these were stored with nontarget training samples, which potentially contaminated the scat samples of the study species.

Reliable methods of species determination, such as DNA analysis or sample-matching dogs (i.e., dogs trained with scent jars to match samples form the same species or individual) (Harrison 2006), are critical in studies in which scat from different species could be inadvertently confused by the handler. Species determination at the beginning of a field season allows incorrect scat identification to be caught early and retraining of the dog.

Study Design

In studies where repeated sampling of sites is required, quadrat size may affect scat-detection probabilities. Size is inversely correlated with the probability of detecting present scat because if a quadrat is relatively small the entire quadrat can be searched on each visit. Sampling different subareas of a quadrat on different visits (as we did with the 5 × 5 quadrats), however, appeared to increase the probability of detecting species with larger home ranges, presumably because that sampling method increased the total area and heterogeneity of the area sampled. Smaller quadrats may increase detection probabilities for species that are present and have high site fidelity or when quadrats are located in high-quality habitat for that species. In our study this was reflected by the higher detection probabilities for giant armadillos in the 3 × 3 quadrats because these grids were located in an area that included a high percentage of the grasslands with which the species often is associated.

Although the addition of two study species in 2006 did not affect the probability of detection of target species by dog teams or the teams' probability of detecting scat that were not from study species, each successful detection of scat stops the search and requires time to reward the dog. This can greatly reduce the amount of area searched, which might limit detections of rare or more dispersed species. Also, because dogs more often encounter scat of common animals and are thus more often rewarded for these detections, they may be less likely to follow a rare scent. We avoided this situation by continually training dogs with scats from target species detected at low rates.

The desired balance among potentially competing objectives, such as maximizing detections of a target species or sampling all land-use and land-cover types across a study area equally, affects how studies are designed. The jaguars in our study area provide an illustration. Although the dogs detected only 33 jaguar scats, the probability of detecting jaguar scat in quadrats where jaguars were present was 57%. Dogs detected a jaguar scat on 88% of visits to a quadrat where jaguars were previously shown to be most likely to occur (Silveira 2004). Had our entire sampling effort been confined to this area, we would have expected the dogs to detect 363 jaguar scats, more than 10 times the number encountered. When conditional and joint detection probabilities of scat detection have been tested, the required number of survey sites and visits for a given application can be estimated directly from our effort model.

Dogs have been used successfully to find scats of a variety of carnivores in temperate regions of North America (Smith et al. 2003; Wasser et al. 2004; Long et al. 2007a), of Spotted Owls (*Strix occidentalis*) in California (S.K.W., unpublished data), and of tigers (*Panthera tigris*) in Cambodia (S.K.W., unpublished data), and they were used in the study of right whales (*Eubalaena glacialis*) in the Atlantic (Rolland et al. 2006). To the best of our knowledge, we are the first to document the effectiveness of scat-detection dogs for spatially extensive surveys of multiple species in the tropics. Not only can dogs be used for repeated presence-absence surveys, but DNA and hormone analysis of the scats they detect can be used to estimate animal abundance and physiological response to some forms of disturbance (e.g., Wasser et al. 2004; Rolland et al. 2006).

Acknowledgments

We thank G. Fonseca and T. Lacher for supporting inception of this project and the working dogs and their trainers, project assistants, laboratory staff, and volunteers for their tireless efforts. Thanks to the staff of Emas National Park, private landowners in the region, and the Brazilian Institute of Renewable Natural Resources and the National Counsel of Technological and Scientific Development for project licensing. Funding was provided by the TEAM Network of Conservation International, funded by the Gordon and Betty Moore Foundation, the Morris Animal Foundation, Conservation International of Brazil, and National Security Education Program, and National Science Foundation graduate fellowships to C.V. The Smithsonian Conservation and Research Center, Woodland Park Zoo, and Parque Zoológico de Goiânia supplied training and control samples. Two anonymous reviewers and M. Hunter helped improve the manuscript.

Supporting Information

The number of visits to quadrats, number of quadrats, and distance surveyed by year (Appendix S1) and the number of carnivore scats collected and DNA results by species (Appendix S2) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than the absence of the material) should be directed to the corresponding author.

Literature Cited

Brannstrom, C., W. Jepson, A. M. Filippi, D. Redo, Z. Xu, and S. Ganesh. 2008. Land change in the Brazilian Savanna (Cerrado), 1986–2002: comparative analysis and implication for land-use policy. Land Use Policy **25:**579–595.

Chame, M. 2003. Terrestrial mammal feces: a morphometric summary and description. Memórias do Instituto Oswaldo Cruz **98:**71–94.

Frantzen, M., J. Silk, J. Ferguson, R. Wayne, and M. Kohn. 1998. Empirical evaluation of the preservation methods for faecal DNA. Molecular Ecology **7:**1423–1428.

Gobush, K. S., B. M. Mutayoba, and S. K. Wasser. 2008. Long-term impacts of poaching on relatedness, stress physiology, and reproductive output of adult female African elephants. Conservation Biology **22:**1590–1599.

Harrison, R. L. 2006. A comparison of survey methods for detecting bobcats. Wildlife Society Bulletin **34:**548–552.

Jácomo, A. T. d. A., L. Silveira, J. A. F. Diniz-Filho. 2004. Niche separation between the maned-wolf (*Chrysocyon brachyurus*), crab-eating fox (*Dusicyon thous*) and the hoary-fox (*Dusicyon vetulus*) in the cerrado of Central Brazil. Journal of Zoology London **262:**99–106.

Klink, C., and R. B. Machado. 2005. Conservation of the Brazilian cerrado. Conservation Biology **19:**707–713.

Logan, K. A., and L. L. Sweanor. 2001. Desert puma: evolutionary ecology and conservation of an enduring carnivore. Island Press, Washington, D.C.

Long, R.A., T. M. Donovan, P. Mackay, W. J. Zielinski, and J. S. Buzas. 2007a. Effectiveness of scat detection dogs for detecting forest carnivores. Journal of Wildlife Management **71:**2007–2017.

Long, R.A., T. M. Donovan, P. Mackay, W. J. Zielinski, and J. S. Buzas. 2007b. Comparing scat detection dogs, cameras, and hair snares for surveying carnivores. Journal of Wildlife Management **71:**2018–2025.

Manly, B., and M. J. Parr. 1968. A new method of estimating population size, survivorship, and birth rate from capture-recapture data. Transactions of the Society of British Entomology **18:**81–89.

Morrison, J.C., W. Sechrest, E. Dinerstein, D. S. Wilcove, and J. F. Lamoreaux. 2007. Persistence of large mammal faunas as indicators of global human impacts. Journal of Mammalogy **88:**1363–1380.

Mourão, G., and M. I. Medri. 2007. Activity of a specialized insectivorous mammal (*Myrmecophaga tridactyla*) in the Pantanal of Brazil. Journal of Zoology **271:**187–192.

Rolland, R. M., P. K. Hamilton, S. D. Kraus, B. Davenport, R. M. Gillett, and S. K. Wasser. 2006. Faecal sampling using detection dogs to study reproduction and health in North Atlantic right whales *(Eubalaena glacialis)*. Journal of Cetacean Research and Management **8:**121–125.

Silva, J. M., and J. M. Bates. 2002. Biogeographic patterns and conservation in the South American Cerrado: a tropical savanna hotspot. BioScience **52:**225–233.

Silveira, L., 2004. Ecologia comparada e conservação da onça-pintada (*Panthera onca*) e onça-parda (*Puma concolor*), no Cerrado e Pantanal. PhD dissertation. University of Brasilia, Brasilia.

Silveira, L., M. M. Furtado, N. M. Tôrres, R. Sollmann, G. Uhl, and A. T. A. Jácomo. 2009a. Maned wolf density in a central Brazilian grassland. Journal of Wildlife Management **73:**68–71.

Silveira, L., A. T. A. Jácomo, and J. A. F. Diniz-Filho. 2003. Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation **114:**351–355.

Silveira, L., A. T. A. Jácomo, M. M. Furtado, N. M. Torres, R. Sollmann, and C. Vynne. 2009b. Ecology of the giant armadillo (*Priodontes maximus*) in the grasslands of central Brazil. Edentata **8–10:** 25–34.

Silveira, L., F. H. G. Rodrigues, A. T. A. Jácomo, and J. A. F. Diniz-Filho. 1999. Impact of wildfire on the megafauna of Emas National Park, central Brazil. Oryx **33:**108–114.

Skalski, J. R. and Robson, D. S. 1992. Techniques for wildlife investigations: design and analysis of capture data. Academic Press, San Diego, California.

Smith, D. A., K. Ralls, A. Hurt, B. Adams, M. Parker, B. Davenport, M. C. Smith, and J. E. Maldonado. 2003. Detection and accuracy rates of dogs trained to find scats of San Joaquin kit foxes (*Vulpes macrotis mutica*). Animal Conservation **6:**339–346.

Vynne, C. 2010. Landscape use by wide-ranging mammals of the Brazilian Cerrado. PhD dissertation. Department of Biology, University of Washington, Seattle.

Vynne, C., R. B. Machado, J. Marinho-Filho, and S. K. Wasser. 2009. Scat-detection dogs seek out new locations of *Priodontes maximus* and *Myrmecophaga tridactyla* in Central Brazil. Edentata **8–10:** 13–14.

Wasser, S. K., B. Davenport, E. R. Ramage, K. E. Hunt, M. Parker, C. Clarke, and G. Stenhouse. 2004. Scat detection dogs in wildlife research and management: applications to grizzly and black bears in the Yellowhead Ecosystem, Alberta, Canada. Canadian Journal of Zoology **82:**475–492.

Wasser, S. K., C. S. Houston, G. M. Koehler, G. G. Cadd, and S. R. Fain. 1997. Techniques for application of fecal DNA methods to field studies of ursids. Molecular Ecology **6:**1091–1097.

Wolf, M., and S. Ale. 2009. Signs at the top: habitat features influencing snow leopard *Uncia Uncia* activity in Sagarmatha National Park, Nepal. Journal of Mammalogy **90:**604–611.

Woodroffe, R. 2001. Strategies for carnivore conservation: lessons from contemporary extinctions. Pages 61–92 in J. L. Gittleman, S. M. Funk, D. Macdonald, and R. K. Wayne, editors. Carnivore conservation. Cambridge University Press, Cambridge, United Kingdom.