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Ecology of the Giant Armadillo (*Priodontes maximus*) in the Grasslands of Central Brazil

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Abstract

The giant armadillo (*Priodontes maximus*) is the largest armadillo and is considered at risk of extinction by IUCN. Due to its fossorial and highly cryptic nature, it is also one of the least-studied mammals. The Cerrado grassland-savannahs of central South America comprises approximately 25 percent of the species' range, and the 1320 km² Emas National Park (ENP) is considered to be a stronghold area for the species in this biome. In this study, we employed a combination of radio-tagging, burrow surveys, camera-trapping, and scat detection dogs, to gain insights into the ecology of the giant armadillo in the Central Brazilian grasslands. Biometrics of five males and four females captured showed sexual dimorphism. Mean home range of five radio-tracked individuals was 10 km², and minimum density was estimated at 3.36 animals/100 km². The species showed a nocturnal activity pattern. Overall, it preferred open habitat. For burrows, soil or termite mounds were the preferred over ant mounds. No prior information exists regarding how many giant armadillos inhabit the park, or how they are using the surrounding area.

Introduction

The giant armadillo (*Priodontes maximus*) is the largest extant species of the Magnaorder Xenarthra, family Dasypodidae. Classified as Vulnerable by the IUCN (IUCN, 2007; but see Fonseca and Aguiar, 2004 for detailed discussion of listing), listed on Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2007) and listed as endangered on the official list of the Brazilian fauna (IBAMA, 2003) the giant armadillo is at risk of extinction due to habitat loss, hunting for food, and capture for the black market (Fonseca and Aguiar, 2004). While rare everywhere it occurs, the giant armadillo tolerates a wide range of habitat types, from tropical evergreen forests to savannas, and it feeds almost exclusively on ants and termites (Redford, 1985; Eisenberg and Redford, 1999). The geographic distribution covers 12 countries of South America, from Colombia and Venezuela in the north, to Paraguay and northern Argentina and Brazil in the south (Wetzel, 1982).

Knowledge about giant armadillo ecology has traditionally been obtained mainly from indirect signs, sporadic sightings, or dead animals. Abundance and ranging behavior are largely unknown (Noss *et al.*, 2004). Activity patterns are highly nocturnal and the species is known to sometimes remain inside a burrow for more than three days (Anacleto, 1997). During our three year ecological study of *Priodontes maximus* in Emas National Park and its surroundings (Figure 1), data about biometry, home range, density, activity patterns, and habitat use of the species were obtained. Novel methods were tested and are evaluated in this article. This work represents the most comprehensive study of giant armadillo ecology to date.

Methods

Study area

Emas National Park (ENP), located in central western Brazil (18°19'S, 52°45'W), is 1320 km² in size and is one of the largest protected areas representing the Cerrado biome. ENP is primarily comprised of open grassland, with patches of shrubland (Cerrado *sensu stricto*), marshes and gallery forest (Jácomo *et al.*, 2004). The Park is located in one of Brazil's most productive agricultural areas; soy bean and corn plantations dominate the surrounding landscape. While comprising approximately 25% of the giant armadillo's range of distribution, the Cerrado has suffered from extensive conversion, and consequently fragmentation, of its natural habitat. Eighty percent of the biome is considered degraded to some extent (Cavalcanti and Joly, 2002). Emas National Park is, therefore, very likely one of the last refuges available for protecting the giant armadillo in this biodiversity hotspot (Mittermeier *et al.*, 2004). Our study area was concentrated on the open areas within Emas National Park. Scat detection dog surveys occurred in all Park habitat types, as well as on an additional 3300 km² of private lands outside the Park (Figure 1).

Live capture and biological data collection

The capture efforts were concentrated in Emas National Park during March 2004 through September 2005, and from December 2006 to February 2007. We monitored the internal roads of the park during the night and the early morning, with the objective of locating active animals and capturing them with a net. Additionally, we set a *jiqui* trap at the entrance of burrows that were thought to be active. The *jiqui* trap is a funnel-shaped cage closed at the narrow end and with a trap door at the wider end, which is placed at the borrow entrance and closes upon an animal entering the cage.

Once captured, armadillos were immobilized with a tiletamine/zolazepam combination (Zoletil®, 50 mg of tiletamine and 50 mg of zolazepam per ml), given intramuscularly by a handheld syringe. The dose chosen for each animal was based on a visual assessment of the individual's size and weight and a dose of 4 mg/kg was estimated. After anesthetic induction, armadillos were weighed and measured. Blood, feces and ectoparasites were sampled. We compared body measurements for males and females using a factorial ANOVA to detect sexual dimorphism. In five out of nine cases, the animals were fitted with a radio transmitter. During the seasons of 2004 and 2005, the radio transmitters were attached by drilling through the posterior carapace at the height of the hind limbs. Placement was such that the transmitter did not interfere with the animal's ability to excavate and could not be removed with its claws. In 2006, we implanted a transmitter into the peritoneal cavity of one individual.

Radio Tracking and Home Range Estimates

Radio-tracking provides a useful technique for studying the movement of wildlife populations, permitting the determination of home ranges, activity patterns, habitat preference, social behavior, and migration patterns (White and Garrot, 1990; Millspaugh and Marzluff, 2001). To determine locations of our study animals outfitted with transmitters, two directional bearings of the transmitter's position were obtained from known locations. The radio-transmitter had a frequency of 151.000 MHZ.

We conducted radio-tracking surveys both at night and during the day, in equal proportions, using a 4 × 4 vehicle or an all terrain vehicle (ATV). We tracked individual armadillos at least once per week. From the two directional bearings taken in the field, we obtained the location of the individual using the computer program "Locate II" (Nams, 2000). We used locations of the same individual obtained on two consecutive days to calculate the minimum distance moved per night.

Home range analysis considered locations of the same animal taken 12 hours apart to minimize spatial autocorrelation. We used the computer program RANGES VI.211 (Kenward *et al.*, 2003) to estimate home range size for animals with more than 10 independent locations using the Minimum Convex Polygons (MCP) with 95 % of the locations. We further analyzed home range overlap using the MCP with 100% of the locations. While Kernel estimators are known to give better home range estimates, they suffer from small sample bias (Millspaugh and Marzluff, 2001). Due to our small sample size, we restricted our home range analysis to the MCP.

Density estimate

Camera trapping as a tool to determine a species' abundance and density has been developed for population studies of tigers (Karanth, 1995; Karanth and Nichols, 1998) and constitutes a methodology applicable to any species that can be individually identified by photographs. To survey giant armadillo density in Emas National Park, in 2002 we set 78 cameras in four Park areas, and in 2005, 45 camera traps in two areas. Camtrakker® cameras were set at every 1.5 km along animal trails and automatically recorded the day and hour on each photograph. Cameras were active continuously, and were checked every 15 days and reloaded with film or batteries when necessary.

Individual giant armadillos were identified according to the distinct scale patterns, particularly the dividing line between dark and light scales on the carapace and hind legs (Noss *et al.*, 2004). Lack of recaptures prohibited the use of mark-recapture models. We therefore calculated a minimum density, dividing the identified individuals by the sampled area. To account for the area covered by the outer camera traps beyond the outer trap polygon limit (Karanth and Nichols, 1998), we calculated the radius of mean giant armadillo home range, assuming home range to be circular, based on the findings from our telemetry study (see results below). We used the resulting value as radius of a circular buffer placed over every camera-trap, with the resulting area constituting the effective sampled area. This procedure was performed in ArcGIS 9.0© (ESRI, Redlands, CA, USA).

Activity pattern

Activity pattern was interpreted using time of registers of the species by camera-traps. All camera-trapping data accumulated between 2001 and 2006 in ENP and its surroundings were considered, including data from the two giant armadillo density surveys described above, but also from additional camera trapping events that targeted other species, but yielded giant armadillo records. By dividing the day into 12 time intervals, we grouped all activity registers into two-hour time intervals to identify hours of increased activity.

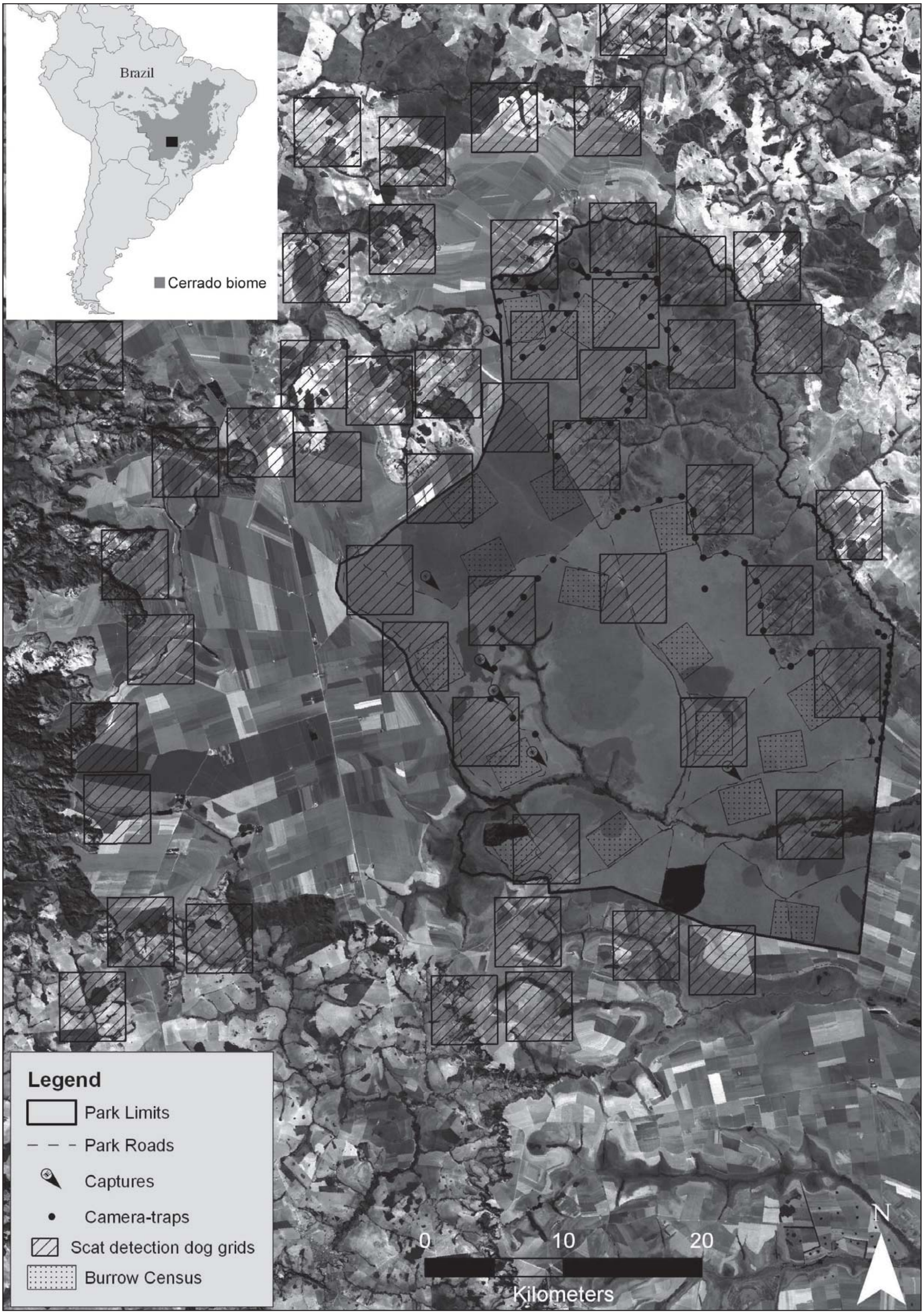

Figure 1. Location of Emas National Park within the Cerrado of Brazil, and locations within the park and its surroundings where each method was employed.

Scat Detection Dogs

Three scat detection dog teams were employed to locate scat of giant armadillos during May–July of 2006 (3 teams), April–June 2007 (2 teams), and November 2007–February 2008 (1 team). Detector dogs have been demonstrated to be highly efficient at surveying for presence of rare animals (Wasser *et al.*, 2004; Harrison, 2006; Long *et al.*, 2007) and they have demonstrated high accuracy at homing in on target animals even in the presence of sympatric species of the same family (Vynne *et al.*, submitted). To our knowledge, this study represents the first detection dog project outside of North America, as well as the first to employ the method for the giant armadillo (in addition to giant armadillo, dogs were trained to find scat of giant anteater *Myrmecophaga tridactyla*, maned wolf *Chrysocyon brachyurus*, puma *Puma concolor*, and jaguar *Panthera onca*). Surveys were conducted on foot and principally during the morning hours (6:30 – 12:30 hs).

While giant armadillo scat samples have yet to be DNA-confirmed, the same three dogs employed on this study have a combined accuracy of 95% based on DNA-confirmed sampling of 300 putative maned wolf scat samples from the same study, as well as a 91% DNA-proven accuracy for more than 1,000 caribou and wolf samples they identified on a study conducted in Canada in 2006 and 2007 (Vynne *et al.*, submitted; Wasser *et al.*, submitted). To ensure the highest accuracy of species ID possible without DNA proof, we are only including for the purpose of this study samples that received a "high" confidence ranking in at least two of the five categories: handler gestalt, dog response, presence of tracks, size/shape, and smell. We collected and preserved scats for future DNA, diet, and hormone analyses.

Burrow census

Due to their large size in comparison with those of other sympatric Dasypodidae, the burrows of the giant armadillo are readily identifiable in the field. We employed two burrow survey methods to better understand habitat selection by this species and the preferred substrate for digging burrows. We used the burrow census walked by scat detection dog teams to investigate habitat selection by giant armadillos. These teams walked daily ~10 km loops within pre-designated survey grids both inside and outside of ENP (Figure 1). We conducted our surveys on foot and GPS-recorded locations of all encountered burrows. For the habitat use results, we include only burrows that were at least 10 m in distance from one another as an independent burrow.

To better understand substrate selection for digging burrows, we conducted systematic transect searches inside ENP. Throughout the park, we walked transect groups consisting of four parallel lines, each 2 km in length and 1 km in distance from each other, starting at interior Park roads. These transects were realized on foot, by car, and by ATV by two or more observers. Burrows within 5–25 m of each side of the transect line, depending on visibility due to different vegetation, were marked with a GPS location, and it was noted whether the burrow occurred in the soil, or at the base of an anthill or termite mound. We estimated sampled area as transect length multiplied with twice the maximum distance of burrow visibility. We calculated mean burrow density for all transects and compared number of burrows found in the soil, at the base of termite mounds, and in anthills.

Results

Biometry

Between March 2004 and September 2005, and between December 2006 and February 2007, five male and two female giant armadillos were captured in Emas National Park, and an additional two females in the Park's surroundings. Four males were fitted with a radio transmitter on their carapace. The fifth male was the only individual captured with the *jiqui* trap and also the only one in which we implanted a radio transmitter. In one instance, the *jiqui* was armed at an active burrow, but the animal escaped digging a second exit, a behaviour not previously observed.

All animals were adults, with mean body weight of 44.40 kg (SD = 4.1) for males and 28.00 kg (SD = 2.71) for females, and a mean total body length of 155.90 cm (SD = 4.46) for males and 137.74 cm (SD = 4.01) for females (Table 1). Both parameters' means differed significantly between sexes (F = 46.904, df = 8, p ≤ 0.001; F = 40.050, df = 8, p ≤ 0.001). We found significant gender differences in mean body measurements in seven out of the 14 parameters recorded.

All animals appeared to be in good health and physical condition. The mean of the anesthetic (tiletamine/zolazepam combination) dose was 3.8 ± 0.58 mg/kg.

Home range

A total of 115 independent localizations of the five individuals fitted with radio transmitters were obtained through radio-telemetry in a mean period of 27.25 days of monitoring. Three of the four external transmitters fell off after a mean period of 45 days and were found after that period.

We obtained 18 pairs of locations for the same individual on consecutive days. Mean minimum distance moved per night was 1800 m (SD = 1356). This value does not include consecutive registers of an animal at the same location, as we cannot distinguish whether the animal remained in its burrow or returned to the same burrow.

For four of the five monitored individuals, we obtained more than 10 independent locations. When analyzed using the 95% MCP, the estimated home range was 10.05 km² (SD = 4.64). Home range overlap for two individuals using 100% of the localizations was 1.56%.

The armadillos were observed spending up to three consecutive days inside their burrows.

Density

Throughout 2002 we sampled four areas of the park, with an average of 19.5 cameras per area for a total of 4447 trap days. We obtained 40 photo records of giant armadillos. From February to June 2005, we re-sampled two of the areas with a mean of 22.5 cameras per area, accumulating 439 trap days and obtaining four records of giant armadillos. We estimated a mean home range of 10 km², which, if assumed to be circular, has a radius of 1.8 km. Placing circular buffer areas with this radius over the camera traps resulted in a total sampled area of

TABLE 1. Mean body measurements for five male and four female adult giant armadillos captured in Emas National Park between 2004 and 2006, with standard deviation (SD) and p-values for comparison of means between sexes using an ANOVA (p ANOVA); measurements that presented significantly different means between sexes are indicated with an asterisk (*).

Measure	Sex	Mean	SD	p (ANOVA)
Weight* (kg)	Males	44 .40	4 .10	0 .000
	Females	28 .00	2 .71	
Head circumference* (cm)	Males	31 .70	0 .45	0 .000
	Females	28 .75	0 .87	
Neck circumference* (cm)	Males	35 .10	1 .02	0 .001
	Females	31 .75	0 .50	
Thorax circumference* (cm)	Males	86 .60	5 .94	0 .006
	Females	73 .13	3 .92	
Head length (cm)	Males	20 .90	0 .74	0 .625
	Females	20 .70	0 .24	
Body length w/o tail* (cm)	Males	100 .20	3 .85	0 .004
	Females	89 .88	3 .33	
Tail length* (cm)	Males	55 .30	1 .75	0 .001
	Females	47 .88	2 .25	
Total length head to tail* (cm)	Males	155 .90	4 .46	0 .000
	Females	137 .75	4 .01	
Ear length (cm)	Males	5 .60	0 .42	0 .101
	Females	6 .00	0 .00	
Ear width (cm)	Males	2 .64	0 .59	0 .745
	Females	2 .75	0 .29	
Shoulder height (cm)	Males	49 .00	5 .67	0 .490
	Females	46 .50	0 .87	
Hindleg length (cm)	Males	18 .50	1 .32	0 .083
	Females	17 .13	0 .25	
Carapace length (cm)	Males	80 .40	3 .45	0 .216
	Females	76 .00	6 .20	
Carapace width (cm)	Males	63 .75	2 .63	0 .376
	Females	69 .83	12 .55	

359 km² in 2002 and 204 km² in 2005. In each area, we identified two to five giant armadillos. Resulting local minimum densities ranged from 1.27 to 5.55 individuals/100 km², with a mean minimum density of 3.36 individuals/100 km² (SD = 1.63). As this is a minimum value, we estimate 50 adult individuals to inhabit the 1320 km² of ENP.

Activity Pattern

From 2001 to 2006, we accumulated 9051 camera-trap days and obtained a total of 65 temporally independent photographic registers of giant armadillos. Due to technical problems, time of day was recorded only in 50 of them. These records suggested a highly nocturnal activity pattern for the giant armadillos. The peak of activity was observed from 2:01 to 4:00 hs (24% of the photos), and there were no registers during the daytime, from 10:01 to 18:00 hs (Figure 2). Direct observations by CV, who conducted scat detection dog surveys on foot between 7:00 and 13:00 hs in 2006–2008, yielded two registers of giant armadillos that were day active. One was found walking on a Park road at 10:15 hs (April 2007) and another digging a burrow at the base of an anthill at 12:30 hs (June 2007).

Habitat use

Habitat use for the giant armadillo was determined based on our scat detection dog teams' identification of burrows and giant armadillo scats. Scat detection dog teams (canine, dog handler, and, when available, field assistant) logged 281 field days, 2343 km of trails (human distance covered), and 794 hours of direct search (excludes time collecting samples or resting in field) between May 2006 and February 2008. Forty percent of our effort was dedicated to inside the Park and sixty percent to a 3300 km² area of private land surrounding the Park.

Of 67 putative scats encountered, 54 received a "high" confidence score in at least two of five categories and thus are included in these results and related analyses. Scats were encountered an average of one in five search days, requiring an average of 13 direct search hours per scat encounter. Burrows were found on average during every two hours of search effort.

The habitat breakdown of where scats and burrows were found relative to amount of search time is shown in Figure 3. In this region, the giant armadillo shows a clear preference for open habitats, with open cerrado, grasslands, and marsh edges being the most commonly used areas. While there is some evidence of individuals using altered landscapes (pastures and agricultural edges), we found no evidence of burrow digging or scat samples of armadillos in croplands or pasture further than 100 m from a natural habitat edge.

While only 40% of our dog teams' effort was dedicated to searching within the Park, 57% of the giant armadillo localities were within Park borders. Twenty-two of the 54 scats (41%), and 169 of 394 burrows (43%), were located within Park boundaries. The number of locations outside of ENP decreased with distance. There was only one location of an armadillo found outside ENP in an area not connected by habitat corridors. This location, also the sole location further than 18 km from the Park boundary (it was 30 km from ENP), occurred at the border of a state protected area. Finally, whereas the majority of locations inside the Park were in predominantly open habitat types, most beyond-Park occurrences were in closed cerrado.

Of the 54 scat samples found, a minimum of 22 are expected to be from a different individual. These 22 samples are exclusive to a radius of 1.8 km around each sample, which comprises the giant armadillo's presumed home range (this study). 59% of burrow locations had a scat encountered within the presumed home range area of 10 km^2. Since giant armadillo scats are unlikely to persist in the landscape beyond a matter of days, these areas can thus be considered as active home ranges.

Burrow census

A total of 943 ha were sampled, walking 183 km of transects. We identified 723 giant armadillo burrows. Mean burrow density for all transects was 1.47/ha (SD = 1.07). Forty-five percent of the burrows were dug in the soil, 40% at the base of termite mounds, and 15% in ant hills. This distribution differed significantly from an equal distribution ($\chi = 15.50$, $df = 2$, $p < 0.001$). Pairwise comparison showed significant preference of both soil and termite mounds over anthills ($\chi \geq 11.364$, $df = 1$, $p \leq 0.001$), but no significant difference between soil and ant hills.

Discussion

The giant armadillo has not been extensively studied in the wild and little is known about its ecology. With nine animals captured, and five of them monitored for a mean period of 27 days each, the present study comprises the highest number of captures of giant armadillos until today. To our knowledge, the studies at Serra da Canastra (MG), where two individuals were captured (Carter and Encarnação, 1983) and at Fazenda São Miguel (MG), where one individual was captured (Anacleto, 1997), serve as the only previously published references about attempts to capture the species. Besides the nine captures and subsequent radio-telemetry locations, we collected more than 700 additional observations through camera-trap photos, scats, and burrows, all of which provided further insight in this species' ecology in the Brazilian grasslands (Table 2).

Average weight of the females captured at Emas National Park was lower than that observed by Encarnação (1986), while the average weight of the males was higher than that found by Anacleto (1997). The body weights observed in this study corroborate the literature in that adult individuals weigh more than 30 kg (Emmons and Feer, 1990) but no more than 60 kg (Nowak, 1991). Body and tail measurements from this study are within the range of measures given by Emmons and Feer (1990), but higher than the average described by Nowak (1991) and Anacleto (1997). The significant gender differences in 7 out of 14 body measurements indicates some degree of sexual dimorphism exists in this species; however, a larger number of individuals would need to be measured to confirm this conclusion.

Giant armadillos are difficult to equip with radio transmitters due to their morphology and digging behavior. We tested the acrylic resin used by Carter and Encarnação (1983) and Anacleto (1997) without success. The method we used of drilling into the edge of the carapace improved the time the device stayed on the animal, but was still limited to an average of 45 days. Recapture of the animal showed no complications caused by the way the transmitter was attached to the carapace. In contrast to external transmitters, implants hold potential for monitoring giant armadillos over longer time periods. In the present study, we did not observe any

TABLE 2. Sampling effort and observations of giant armadillos in Emas National Park and surroundings, listed by method.

Study Method	Number of Observations	Effort*
Capture	9	Not recorded
Telemetry	115	Not recorded
Camera-traps	65	9051 trap days
Scats: high confidence	54	794 hrs / 2343 km
All putative scats	67	794 hrs / 2343 km
Burrows – scat survey	394	794 hrs / 2343 km
Burrows – line census	723	183 km

*Includes only time spent doing direct survey using the respective method; not preparation, travel, or set-up time.

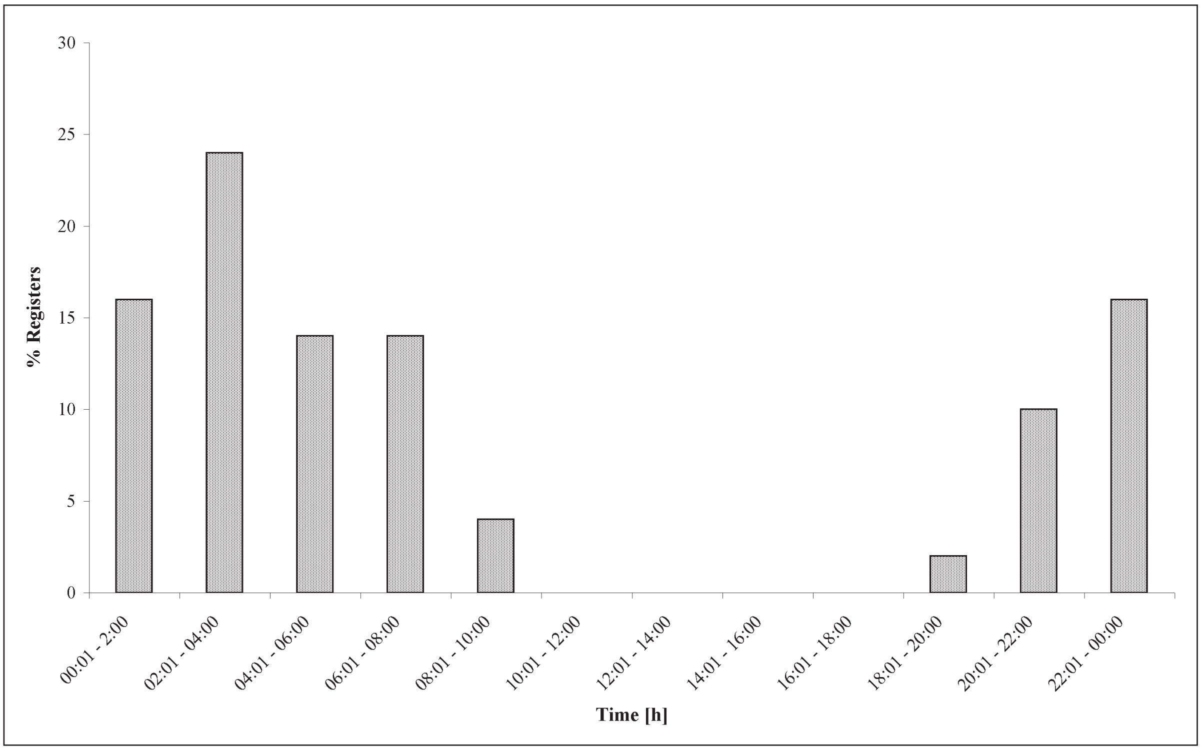

Figure 2. Activity pattern of the giant armadillo in Emas National Park, expressed as percentage of photographic records (N = 50) per two-hour time interval.

complications caused by the surgery or the implant itself. This method merits further testing, perhaps on other more common members of the family, to determine its effectiveness and safety. Radio telemetry is an important technique to acquire detailed data about a species of interest, and we recommend further study into how to safely monitor giant armadillos via telemetry in the wild.

Although relatively few locations could be accumulated using radio telemetry, home range estimates reached a reasonable stability and are thus reliable. Our estimate of 10.05 km² falls within the 3 to 15 km² estimated from three camera-trap locations in Bolivia by Noss *et al.* (2004). Medium home range size was larger than that found by Carter (1985, cited in Nowak, 1991) of 4.52 km².

We confirmed the nocturnal activity of the giant armadillo cited in literature (Nowak, 1991; Anacleto, 1997; Emmons and Feer, 1999; Noss *et al.,* 2004). Most of the time, the animals were inactive during the day and presumably remained inside their burrows. The distance of 1800 m we observed giant armadillos to cover per night was larger than that found by Encarnação (1986, cited in Nowak, 1991) of 300 m daily and smaller than the 2765 m per night found by Carter (1985, as cited in Nowak, 1991).

The preference for open habitats determined in this study differs from the results found by Anacleto (1997), who states cerrado and forest as the habitats most used by giant armadillos. For the first time, we report the occurrence of this species in the Park's surroundings and clearly show that it persists in this fragmented landscape by using remaining patches of native habitat set aside on private lands. The fact that the armadillos use more closed habitats outside of ENP than inside probably indicates a lack of open habitat types conserved outside of the Park.

The low number of scats found per unit effort is due in part to our study design, which was based on a multi-species approach and emphasized landscape matrix use by each of the species. A large part of the search therefore occurred outside of preferred habitat of the giant armadillo and outside of the protected area. This heavy search effort outside of areas typically considered by the armadillo, however, did allow us to locate occurrences not previously known for the species. Because use of scat detection dogs allows relatively rapid sampling over a large area, this method allowed us to cover a much larger area than with any

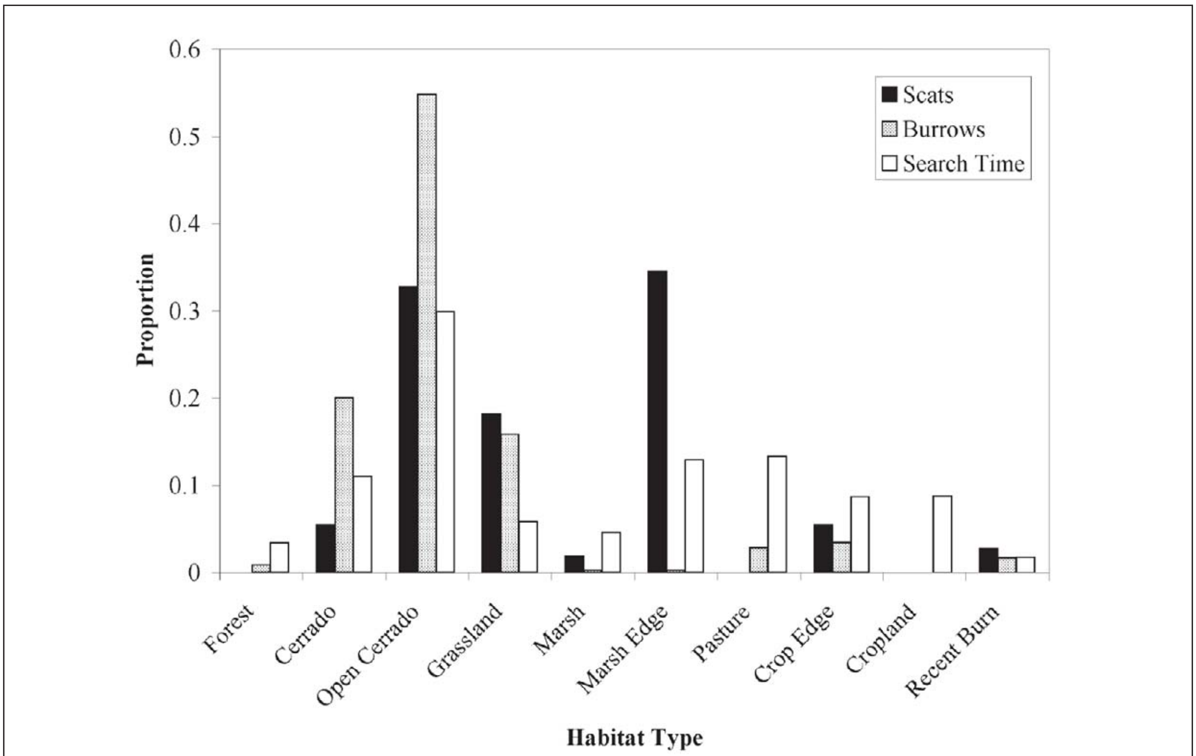

Figure 3. Habitat use of the giant armadillo in Emas National Park and surroundings, expressed as proportion of total scats and burrows found per habitat type, and proportion of search time spent in each habitat type.

of the other methods thus far tested for studying giant armadillos. In spite of the low scat encounter rates for giant armadillos, we likely found scats from a minimum of 22 individuals.

Forty-one percent of burrows did not have a scat associated within the presumed home range of the giant armadillo. Possibly, our dogs failed to detect the presence of an individual within the range of these burrows. Because we marked all burrows, however, and some of them were many months, if not years, old, it is possible that these areas represent locations where the animals are not currently present. Since our home range estimates were derived from a relatively short period of time, it is possible that the armadillos move into different parts of a larger home range while searching for food throughout the year. The areas where burrows were found but not scats, thus, could represent areas where giant armadillos are currently absent.

The preferred substrate for digging burrows in our study area was soil. This differs from the results obtained by Anacleto (1997), who found that ant mounds were the substrate most preferred by the armadillos, while Carter and Encarnação (1986) found termite mounds to be preferred. Choice of the substrate for burrows appears to vary with food availability and the effort necessary to acquire it (Anacleto, 1997). In our study, the repeated use of a burrow was observed only once, while Carter and Encarnação (1983) observed repeated use of burrows in three cases. Anacleto (1997) states that mainly burrows dug in termite mounds are used repeatedly, while recently used burrows are never reused by the animal. Every individual seems to dig various burrows within its home range (Eisenberg, 1989). It would be worthwhile to study if substrate preference varies in human-altered landscapes.

Due to the cryptic nature of the giant armadillo, few studies have yielded even basic ecological information on this enigmatic species. By applying a combination of standard and novel techniques in this first study of the giant armadillo in the grasslands of Central Brazil, we have acquired a base of knowledge on the animal's ecology, as well as laid the groundwork for refining the most useful methods for further investigation of this species.

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