porosity. Precipitation of authigenic illite and mixed layer clay post-dates kaolinite and quartz overgrowths. These clay minerals reduce porosity and permeability by occurring as rims around detrital grains. Occurrence of bent mica and intragranular fractures on rigid framework grains indicates the effect of overburden pressure and tectonic compression at late stage of diagenesis.

Overall, the present study reveals the presence of both primary and secondary porosities in the sandstones. The primary porosity is mostly intergranular porosity. Secondary porosity is created by the dissolution of feldspars, quartz and other unstable minerals, and fracturing of comparatively rigid gains. However, the total porosity is destroyed to a large extent by both cementation and authigenic mineral growth. Occurrence of pyrite framboids suggests introduction of ferruginous solution at an early stage of diagenesis under anoxic condition. Oxidation of iron is superposed at a later stage. Coal seams and carbonaceous shales observed during field mapping in the upper part of the Barail Group suggest that these sediments were deposited in a lower delta plain environment. In such depositional setting, the sediments are influenced by tides as well as fluvial activities, and as a result they exhibit poorly sorted texture. So, the bottom and middle parts of the Barail sandstones show well-sorted texture and preserve higher porosity during burial, while sandstones of the upper part are poorly sorted and show low porosity. The sandstones are mostly angular to sub-angular in shape; therefore, they preserve good primary porosity. Secondary porosity is developed significantly in certain samples. The original pore morphology, as well as secondary porosity within the sandstones tends to be destroyed to a large extent by the diagenetic processes.

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Encounter rates and density of medium and large-sized mammals with nocturnal habits in southern Amazon, Brazil

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The aim of the present study is to calculate the encounter rate and estimate the density of medium and large-sized mammals with nocturnal habits in the Cristalino region of northern Mato Grosso, southern Amazon, Brazil, using distance sampling method. Eight species were detected with encounter rate varying from 0.09 at 1.68 encounters 10 km^{-1}, and three population densities were estimated: *Cuniculus paca* (7.75 individuals km^{-2}), *Potos flavus* (7.08 individuals km^{-2}) and *Mazama americana* (4.23 individuals km^{-2}). Our data help expand the information about density of nocturnal mammals in the southern Amazon region, in the transition between the Amazon and the Cerrado biomes, and can contribute to management and conservation of these species.

Keywords: Distance sampling, encounter rates, nocturnal mammals, population density, species abundance.

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UNDERSTANDING species distribution and abundance is important for ecological studies and for effective biodiversity conservation[1]. The estimation of population size or density is required to explain patterns in ecosystems or communities and make inferences about population trends. Besides, this is one of the most direct means of measuring the success of management and conservation strategies[2].

Mammalian studies require different sampling methods due to the great variation in body size, habit and habitat. Direct observation of nocturnal animals is more challenging because of the difficulty in spotting them at night, mainly to find species with low population density and in areas of closed forests. Therefore, indirect observation by tracks, faeces, marks and shelters is commonly used to estimate the presence and relative abundance of nocturnal species[3].

One methodology for estimating population density of medium and large mammals is based on a combination of line transects and distance sampling[4–6], mainly for animals that are relatively easy to observe in the wild, such as primates[7–10]. However, population density estimates using the currently available linear transect distance sampling are strongly focused on daytime surveys. On the other hand, estimates of mammalian population density by night surveys are scarce[11–14], because at night the detection and identification of animals is more difficult[3].

Estimating the size or population density of a species is essential to assess its conservation status, effects of habitat fragmentation, and its management and conservation plans. However, the line transects method is not commonly used for estimating population density of nocturnal mammal species. Thus, the present work expands the use of this method for nocturnal mammals, being able to contribute to their management and conservation.

In this study, we calculate the encounter rates and estimate the density of medium and large mammals with nocturnal habits in the Cristalino region of southern Amazon, northern Mato Grosso state, Brazil, using distance sampling method.

The study was conducted in the municipalities of Alta Floresta and Novo Mundo in the far north-central region of Mato Grosso state, Brazilian Midwest, near the border with the state of Pará (Figure 1). Five contiguous protected areas were sampled: Private Reserves of Natural Patrimony Natural (Reservas Particulares do Patrimônio Natural) Cristalino I, II, III (6476 ha), Lote Cristalino (670 ha) and the Cristalino State Park (Parque Estadual Cristalino – 184,900 ha).

The study area spans a transition region between the Amazon and the Cerrado biomes. Although the vegetation shares characteristics of both biomes, floristically, it is almost exclusively Amazonian with tall, dense forests (varying from evergreen to completely deciduous), periodically flooded forests, open liana forests, various types of meadow (campinarana), vegetation associated with rocky outcrops (Amazonian rupestrian fields), and riparian and lacustrine vegetation[15]. One of the most important forest types in the study area is the dense ombrophilous forest, which is most prevalent in the south and west of Cristalino State Park[15]. A floristic inventory at Cristalino State Park found 1366 species of vascular plants and several taxa unknown to science[15]. Few fauna inventories have been carried out in the region and a study has registered 37 species of mammals, of which 33 are medium and large-sized[16].

The climate in the region is classified as Am (tropical monsoon), with high average temperatures (>26°C), heavy rainfall (approximately 3000 mm annually) and a dry season from May to September, when monthly rainfall averages less than 100 mm (ref. 17).

Data were collected between May 2008 and February 2010 along linear transects that were based on the distance sampling methodology[4,6]. Eight transects (mean length = 2.5 km, standard deviation = 0.67 km, variation: 1.6–3.25 km) were traversed in environments containing primary forests.

The transects were surveyed by either one or two researchers walking at an average rates of 1.02 km h^{-1} and using flashlights (Maglite LED 3 D-Cell) to detect animals and binoculars to assist in species identification. The researchers had their flashlights on for the entire period of the linear transects. To find the mammals, initially the light beam was projected along the trail in front of the researchers, starting at the substrate and moving up to the top of the trees. Then, the researchers shifted focus to the right and left sides, both on the substrate and in treetops, scanning with the light beam at an angle of approximately 180° in front of them. Animals were detected by visualizing the characteristic brightness of the retina of the eyes when in contact with the beam of light or by listening to the noise emitted by the animals, followed by a silent approach for better visualization and correct identification of the species.

Whenever an animal was viewed, the direction in which it moved was observed and noted, to avoid recounting. Most of the time, the animal distanced itself from the trail and was not seen again, but in cases where it remained close to the trail, this individual was not recounted to avoid replicating the records. The perpendicular distance between each animal sighted and the transect was determined by converting step counts to metres[18,19]. This conversion was based on the previously determined average stride length for each researcher. In addition to perpendicular distance, the following data were also recorded: transect identification, sampling time, detection time and weather conditions.

The surveys were conducted at night (18 h 30 min–05 h 30 min, local time), but mostly (75% of the distance walked) between 18 h 30 min and 22 h 40 min. Only one survey was conducted per night on each transect; the return paths in the transects were not considered in the sampling.

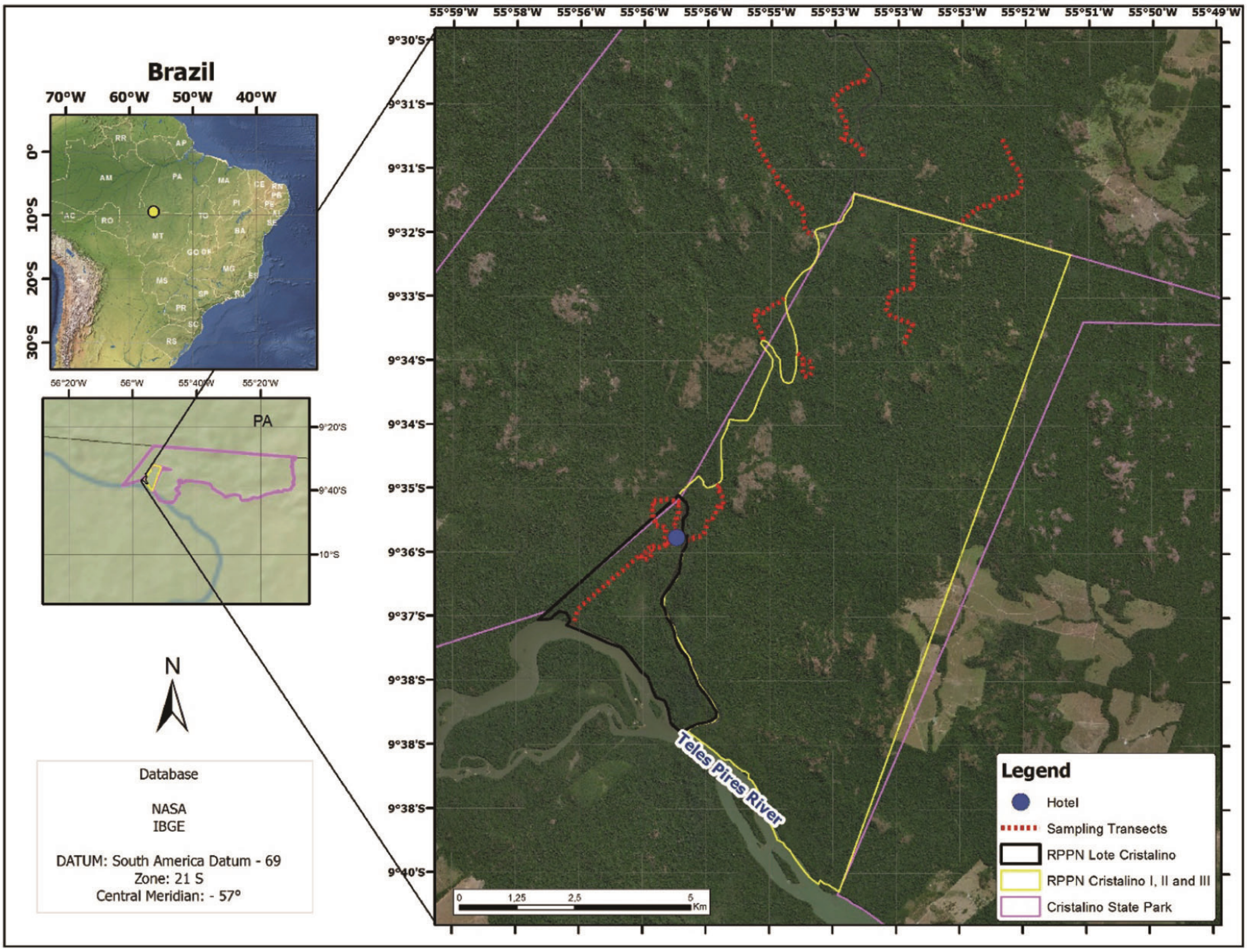

Figure 1. Location and delimitation of the study areas (Cristalino State Park, Private Reserves of Natural Patrimony Natural – RPPNs – Cristalino I, II, III and Lote Cristalino) in the state of Mato Grosso, Brazilian Midwest, with details of sampling transects (red lines).

The nocturnal mammal visualization records were used to calculate the encounter rate (ER) of each species using the following equation[19,20]: ER = Number of independent records of each species multiplied by 10 and divided by the total distance walked. Population density was estimated for species with the highest number of independent records, for which it was possible to adjust the model for density estimation[4]. For the remaining species, the number of records was not sufficient to generate population estimates and, therefore, only ER was determined.

Population density was determined using the Distance package[21] of R software[22], without truncating the data. The analysis is based on finding a model, or detection function, that best reflects the behaviour of the distances measured in the field. This function is used to estimate the ratio of undetected individuals in the surveys and then estimate population density for a given species[4,6,23]. The best-fit model was chosen using the minimum AIC (Akaike information criterion)[6,19,23]. AIC was computed for each model and used to identify the best-fit model (lowest AIC)[4]. In this study, the selected models used the half-normal function and cosine adjustment term.

Night sampling involved 41 surveys and 105.3 sampling hours, covering 107 km of sampling. Eight medium and large-sized mammal species were recorded during night surveys with a total of 69 records (Table 1). The least frequent species and therefore with least ER were: nine-banded armadillo – *Dasypus novemcinctus* (F_i [absolute frequency] = 5; ER = 0.47 encounters 10 km^{-1}), feline night monkey – *Aotus infulatus* (F_i = 3; ER = 0.28 encounters 10 km^{-1}), common opossum – *Didelphis marsupialis* (F_i = 2; ER = 0.19 encounters 10 km^{-1}) and southern tamandua – *Tamandua tetradactyla* (F_i = 1; ER = 0.09 encounters 10 km^{-1}) (Table 1). The most frequent mammal species were: kinkajou – *Potos flavus* (F_i = 18; ER = 1.68 encounters 10 km^{-1}), followed by the spotted paca – *Cuniculus paca* (F_i = 16; ER = 1.50 encounters 10 km^{-1}), red brocket deer – *Mazama americana*

Table 1. List of recorded medium and large-sized mammals with nocturnal habits in the Cristalino region of northern Mato Grosso state, Brazilian Midwest, and their respective absolute (F_i) and relative frequencies (FR_i) and encounter rates (encounters 10 km^{-1} walked)

Taxon	Common name	F_i	FR_i (%)	Encounter rate
Order Didelphimorphia				
Family Didelphidae				
Didelphis marsupialis Linnaeus, 1758	Common opossum	2	2.9	0.19
Order Pilosa				
Family Myrmecophagidae				
Tamandua tetradactyla (Linnaeus, 1758)	Southern tamandua	1	1.4	0.09
Order Cingulata				
Family Dasypodidae				
Dasypus beniensis Krauss, 1862	Greater long-nose armadillo	11	15.9	1.03
Dasypus novemcinctus Linnaeus, 1758	Nine-banded armadillo	5	7.2	0.47
Order Primates				
Family Aotidae				
Aotus infulatus (Kühl, 1820)	Feline night monkey	3	4.3	0.28
Order Carnivora				
Family Procyonidae				
Potos flavus (Schreber, 1774)	Kinkajou	18	26.1	1.68
Order Artiodactyla				
Family Cervidae				
Mazama americana (Erxleben, 1777)	Red brocket deer	13	18.8	1.21
Order Rodentia				
Family Cuniculidae				
Cuniculus paca (Linnaeus, 1766)	Spotted paca	16	23.2	1.50

($F_i = 13$; ER = 1.21 encounters 10 km^{-1}) and the greater long-nosed armadillo – *Dasypus beniensis* ($F_i = 11$; ER = 1.03 encounters 10 km^{-1}) (Table 1).

Population density was estimated for the following three species: *C. paca* (density – $D = 7.75$ individuals km^{-2}; CI [confidence interval] = 3.89–15.44); *P. flavus* ($D = 7.08$ individuals km^{-2}; CI = 3.99–12.58); and *M. americana* ($D = 4.23$ individuals km^{-2}; IC = 2.19–8.18) (Figure 2).

The distance covered in the transects in the present study, although less than the 320 km recommended by other researchers[4,23], was one of the most extensive nocturnal sampling efforts ever employed to estimate mammal abundance. Other night-time surveys have been conducted by Beck-King *et al.*[11] covering 67.2 km in areas of primary and secondary forests in Costa Rica; Pontes and Chivers[12] covering 98.7 km in Roraima Brazil; Rocha *et al.*[19] covering 129.8 and 62 km in *campo sujo* (dry, open shrub Cerrado) and pasture respectively, in the Brazilian Cerrado, and Svensson *et al.*[13] covering 75 km over three areas in Panama. This is because sampling distances at night is more difficult to perform and is more expensive than during the day.

Differences in frequency and consequent encounter rate of species can be attributed to individual characteristics, distribution within the study area and animal habits. In this sense, the low encounter rates of *D. novemcinctus*, *A. infulatus*, *T. tetradactyla* and *D. marsupialis* obtained in this study indicate that they are not abundant in pristine areas of the sampled region. Rocha *et al.*[16] registered the occurrence of *D. novemcinctus e D. beniensis* (species with intermediate encounter rate in this study) living in sympathy in the Cristalino region, the second species being more abundant in protected areas. A study with small mammals carried out in 23 forest fragments of the Amazon in Mato Grosso state reported only four *D. marsupialis* individuals[24].

The species with the highest encounter rate (*C. paca*, *M. americana* and *P. flavus*) were widely distributed throughout the study area and were relatively easy to detect, due to their larger size, greater retina brightness when in contact with light, or greater movement during foraging or displacement (e.g. *D. beniensis*). Conversely, species that were smaller, stealthier and more discreet tended to have lower observation frequencies or not be registered (e.g. small feline species). These observations suggest that encounter rates should be examined with a degree of caution, because several factors can affect species registration, such as the animal activity period, climate conditions and transect location[25]. Thus, whenever possible, the methods used to estimate species abundance should consider the probabilities of detecting individuals.

The estimated density of *C. paca* was lower than that recorded in other studies with this species. Relative to the present study, using the distance sampling method, Rocha *et al.*[26] estimated higher densities of spotted paca in the Juruena National Park, in the southern Amazon of Brazil (14.35 individuals km^{-2}, CI = 6.90–29.88) and Ferreguetti *et al.*[14] estimated 35 ± 3.2 individuals km^{-2} of the spotted paca in Ilha Grande State Park, located in the southwestern

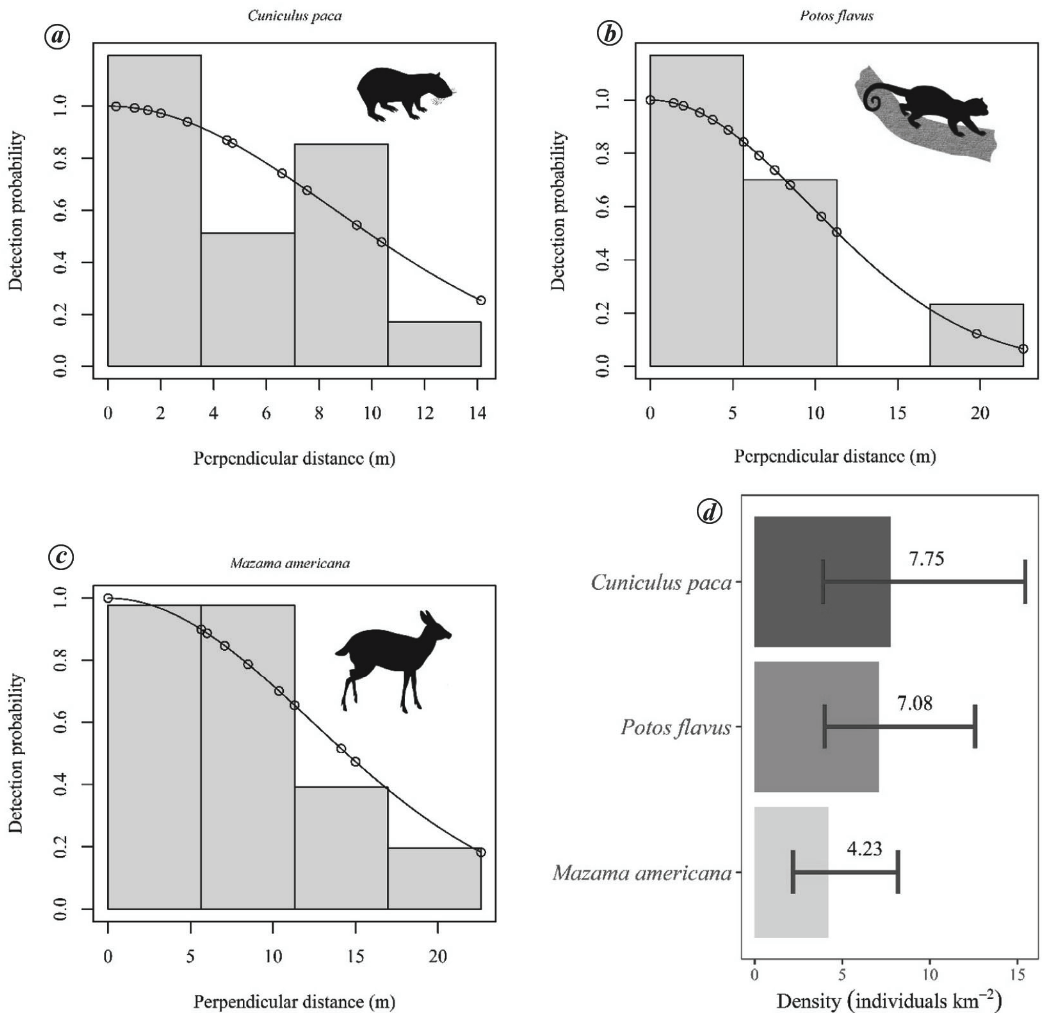

Figure 2. Detection probability, by perpendicular distance to the transect, of (***a***) *Cuniculus paca*, (***b***) *Potos flavus* and (***c***) *Mazama americana* and (***d***) estimated population density (the respective confidence intervals are highlighted in blue), in the Cristalino region of northern Mato Grosso state, Brazilian Midwest.

coast of Rio de Janeiro state, Brazil. Higher densities of spotted paca (67–93 individuals km^{-2}) were also reported in a small area (200 ha) of primary and secondary forests in Costa Rica, using the counting methods of King and Kelker[11]. Factors that were not evaluated in the present study, such as location of trails, food availability and predators, may have contributed to lower detection rates.

Only two (12.5%) of the 16 *C. paca* observations were due to the reflection of moonlight, even though 28.2 km (26.4% of the total) of the transects was covered during moonlit periods. In these cases, observations were made in the early evening when lunar luminosity was low. Some studies indicate that lunar illumination influences *C. paca* activity, and these animals tend to be more active in the absence of moonlight[27]. This 'lunar phobia'[20] may be a strategy to reduce predation[28]. Thus, various factors may be linked to the infrequent observations of this species, such as habitat and predation; however, none of these variables was evaluated in the present study.

The population size and distribution of *P. flavus* is still poorly understood, while the population density of this species within the Amazon is entirely unknown[29]. However, population density may reach 59 individuals km^{-2} in preserved habits of tropical dry forest in Guatemala[30]. According to Sampaio *et al.*[29], the abundance of *P. flavus* is highest in the Amazon but varies by the level of threats present within a given biome. Miranda *et al.*[31] confirmed the occurrence of this species in the Cerrado; however, estimates of species abundance in this biome are not yet available. The population density of kinkajou obtained in the present study (7.08 individuals km^{-2}; CI = 3.99–12.58) was lower than that reported by Pontes and Chivers[12] (20.4 individuals km^{-2}) for olingo density (*Bassaricyon* sp.) – a species that is morphologically similar and occupies a relatively similar trophic niche to that of *P. flavus*.

The density of *M. americana* was similar to that found in other studies. For example, Ferreguetti *et al.*[32] estimated 3.67 individuals km^{-2} (CI = 2.99–4.60) in a reserve of Atlantic Forest (23,711 ha) in the Brazilian state of Espírito Santo. Rivero *et al.*[33] used faeces counts to find an average *M. americana* density of 5.08 individuals km^{-2} within four protected areas in Bolivia. Thus, the population density of *M. americana* estimated in the present study is within the range expected for forest preserves. Furthermore, our logged detections of *M. americana* agree with those of Ferreguetti *et al.*[32], who showed that this species is more active at night.

Our results confirm that distance sampling along linear transects can be effectively used to detect species and estimate the relative abundance of mammals with nocturnal habits[14], especially species that are difficult to detect with other sampling methodologies, such as camera trap and footprint identification (e.g. *P. flavus* and *A. infulatus*). Moreover, the encounter rate and density estimates expand on our understanding of nocturnal mammals in a region of southern Amazon that is still poorly studied, but is of great interest for biodiversity conservation. Such knowledge can be applied to various situations that require an understanding of species abundance, such as management and conservation, occupancy patterns and population trends.

Night surveys along linear transects identified eight species of medium and large mammals, including those that have been rarely recorded by other sampling methods (e.g. *P. flavus* and *A. infulatus*).

This study expands our knowledge about nocturnal mammals of a region of great interest for conservation, in the transition between the Amazon and the Cerrado biomes.

The encounter rates of eight species of mammals were determined and for three of them (*C. paca*, *P. flavus* and *M. americana*) population densities were also estimated.

The information presented here may help establish appropriate strategies for the management and conservation of these species of nocturnal mammals in the study region and similar locations.

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