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# Subsidies for a poorly known endemic semiarid biome of Brazil: non-volant mammals of an eastern region of Caatinga

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## Abstract

**Background:** The mammalian fauna of the eastern Caatinga, a Brazilian semiarid biome, was surveyed in the dry and wet seasons aiming to contribute to the knowledge of this poorly known region. Complementary live-trap survey methods were employed for sampling small non-volant mammals and transects along roads for medium and large mammals.

**Results:** Seventeen mammalian species were recorded, with five new records for Sergipe state, two being endemic to Caatinga. More individuals were captured in the dry season, although species number was the same for both seasons. Medium- and large-sized mammalian species were not encountered in the region, which was also true for some small-sized species hunted for consumption.

**Conclusions:** These findings corroborate the importance of using complementary methods for sampling small non-volant mammals in the Caatinga and indicate that the mammalian fauna of this region, suffering a severe anthropogenic pressure, requires strong measures for its preservation.

**Keywords:** Conservation; Didelphimorphia; Inventory; Mammalia; Rodentia; Semiarid; Zoogeography

## Background

The Caatinga is the fourth largest biome of Brazil, covering approximately 800,000 km$^2$. Its largest portion extends across northeastern Brazil, from eastern Maranhão state to the south of Bahia state, as well as regions of northern Minas Gerais state, southeast of Brazil, along the São Francisco River (IBGE 2004a). This biome supports a poorly understood biodiversity but is presently endangered by several government developments (MIN 2013).

Carmignotto et al. (2012) and Paglia et al. (2012) recognized 153 mammal species for the Caatinga, an increase of 10 additional species to the previous compilation (Oliveira et al. 2003). Only 10 species (ca. 6%) were found to be endemic to this biome: the didelphimorph *Cryptonanus agricolai*, the primate *Callicebus barbarabrownae*, two bats *Chiroderma vizottoi* and *Xeronycteris vieirai*, five rodents, *Rhipidomys cariri*, *Phyllomys blainvillii*, *Trinomys minor*, *Trinomys yonenagae*, and *Thrichomys* cf. *laurentius* (Oliveira et al. 2003), and *Coendou baturitensis* (Feijó and Langguth 2013). Although taxonomic and ecologic studies on the mammalian fauna of Caatinga have increased over the past 10 years, small non-volant mammals still comprise the most speciose and least known group (Oliveira et al. 2003). Several taxa remain to be described, and the taxonomic boundaries of many species must be clearly determined (e.g., Basile 2003; Bezerra 2008).

The present study contributes to the knowledge of the poorly known mammalian fauna of the central-eastern region of the Caatinga. We provide karyotypic data for small mammals, with comments on their taxonomy and geographic distributions, including new records for Sergipe state. Implications for the conservation status of the mammalian fauna of the Caatinga are also discussed.

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## Methods

### Caatinga

The Caatinga biome is characterized by a semiarid climate, with very high temperatures and erratic rainfall, normally with two annual dry seasons: a long one followed by intermittent rains and another with short droughts followed by torrential rains and followed by a long dry period (IBGE 2004a). The severity of drought accounts for different types of Caatinga vegetation (Hueck 1972): (a) predominantly arboreal 'caatinga' or transition to this vegetation, in areas with six dry months; (b) predominantly shrub caatinga in areas with seven to eight dry months; (c) predominantly herbaceous caatinga, in areas with more than nine dry months; and (d) predominantly hyper-xerophilous caatinga, in areas with more than 11 dry months. The vegetation types of the Caatinga comprise (1) the caatinga itself; (2) gallery forests, 'carnaubais' (a concentration of endemic Arecaceae palms), agreste forests, and other dry forests; (3) dry fields (grasslands in the highlands - the 'brejos de altitude'); and (4) savanna enclaves (Hueck 1972).

### Study area

Two field studies were carried out, each for 18 days, in the dry and rainy seasons, November 2010 and April 2011, respectively, to assess the effect of seasonality on mammalian communities. These were sampled by capturing small non-volant mammals and by visual and auditory records and indirect evidence, like tracks, droppings, and interviews with local residents for other terrestrial mammals.

Due to the complexity of the different vegetation and geomorphologies across the study region that included the core of Caatinga and ecotones with the Atlantic Forest (IBGE 2004b), our survey took place in two sectors with the purpose of sampling the largest possible subset of regional diversity. These sectors were characterized as follows:

1. Southern sector (Figure 1), including the municipalities of Porto da Folha, Monte Alegre de Sergipe, and Nossa Senhora da Glória, in Sergipe state (Figure 2A,B,C,D,E,F), characterized as steppic savanna and ecotones of savanna/seasonal forest and savanna/steppic savanna (map of vegetation types of Brazil - IBGE 2004b), all affected by agricultural developments. This is an 'agreste' region, with average annual rainfall between 1,000 and 1,200 mm (SIRHSE 2011). The moisture is reflected in the existing vegetation, more verdant, and more litter covering the soil and by the presence of several species of stinging 'cansanção' (urticant plants of families Euphorbiaceae and Urticaceae) and 'macambiras' (*Bromelia laciniosa*). We sampled fragments of scrub and arboreal caatingas and partially degraded semideciduous forest, located in a private property and standing on sandy-latosol, gravel soil, and latosol.
2. Northern sector, including the municipality of Paulo Afonso, Bahia state, and municipalities of Canindé de São Francisco and Poço Redondo, Sergipe state (Figure 2G,H,I,J,K,L), characterized by as wooded steppic savanna, forested savanna, and steppic

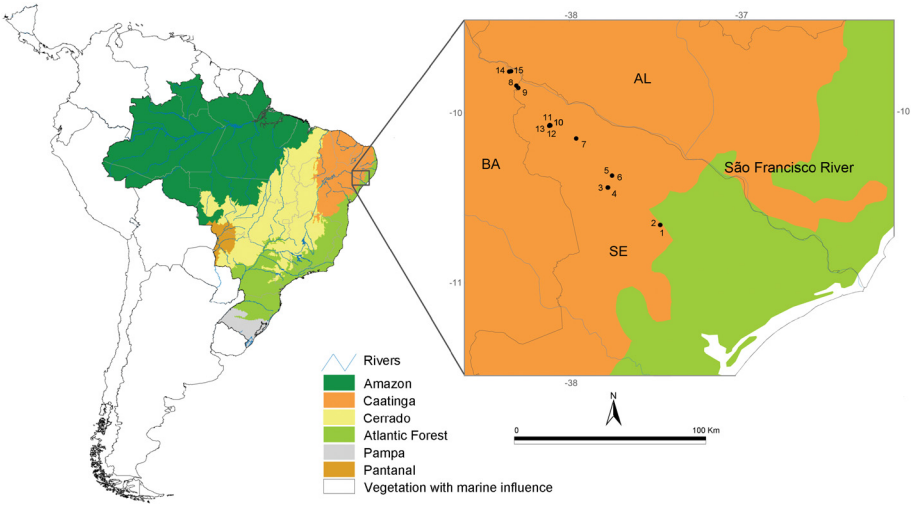


**Figure 1 Map of the surveyed localities.** Southern sector: 1. A and A I, Nossa Senhora da Glória; 2. A II, Nossa Senhora da Glória; 3. B and B I, Monte Alegre de Sergipe; 4. B II, Monte Alegre de Sergipe; 5. C and C I, Porto da Folha; 6. C II, Porto da Folha, Sergipe state. Northern sector: 7. D, Poço Redondo; 8. D I, Canindé de São Francisco; 9. D II, Canindé de São Francisco; 10. E I, Canindé de São Francisco; 11. E II, Canindé de São Francisco (in dry season); 12. E II, Canindé de São Francisco (in rainy season); 13. E, Canindé de São Francisco, Sergipe state; 14. F and F I, Paulo Afonso; 15. F II, Paulo Afonso, Bahia state. AL, Alagoas state; BA, Bahia state; SE, Sergipe state.

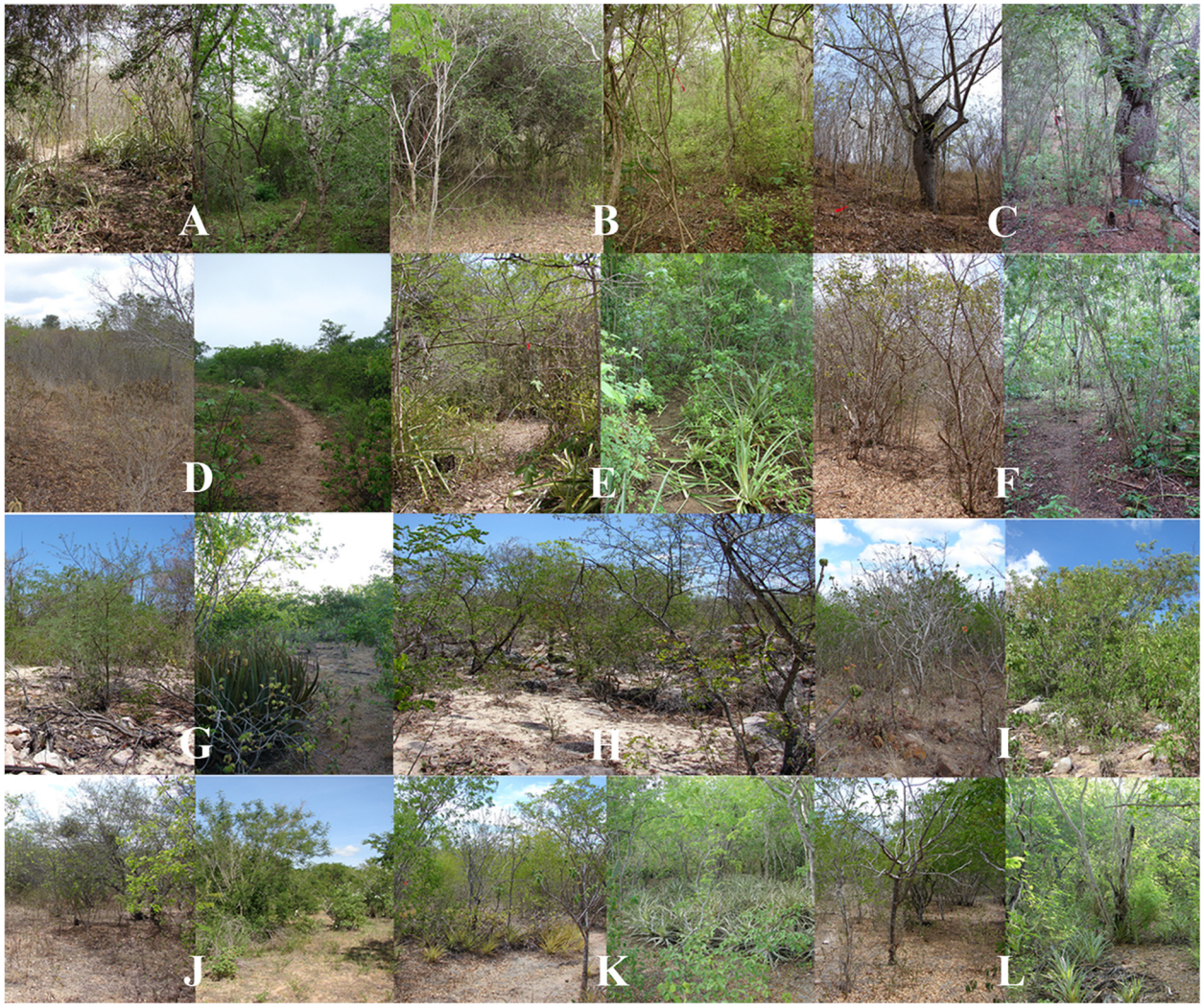


**Figure 2 Areas sampled in the dry season (left) and rainy season (right). (A)** A I, Nossa Senhora da Glória, arboreal caatinga and secondary semideciduous forest. **(B)** A II, Nossa Senhora da Glória, arboreal caatinga and semideciduous forest. **(C)** B I, Monte Alegre de Sergipe, semideciduous forest in a valley. **(D)** B II, Monte Alegre de Sergipe, arboreal caatinga with shrub along the edge of semideciduous forest. **(E)** C I, Porto da Folha, semideciduous forest. **(F)** C II, Porto da Folha, secondary semideciduous forest. **(G)** D I, Canindé de São Francisco, shrub caatinga along a river. **(H)** D II, Canindé de São Francisco, shrub caatinga along a river (sampling only in dry season due to complete filling of the river). **(I)** E I, Canindé de São Francisco, arboreal caatinga on a rocky outcrop. **(J)** E II, Canindé de São Francisco, arboreal and shrub caatingas on sandy soil. **(K)** F I, Paulo Afonso, arboreal caatinga on sandy soil. **(L)** F II, Paulo Afonso, arboreal caatinga on granular soil with gravels.

savanna (IBGE 2004b) and also affected by agricultural developments. This is a semiarid to agreste region, dryer than the southern sector, with average annual rainfall between below 700 mm and 1,000 mm in some localities (SIRHSE 2011). Samples were taken from fragments of preserved and anthropogenically modified steppic caatinga with sandy soil, gravel soil, and latosol. Extensive and well-preserved fragments are located in the area of the conservation unit 'Monumento Natural do Rio São Francisco,' in the northeastern corner of Paulo Afonso and the northwestern of Canindé de São Francisco.

Vegetation in this region included typical elements of semiarid biomes, with species of 'juremas' (*Mimosa* spp.), 'angicos' (*Anadenanthera* spp.), 'stinging favelas' (*Cnidoscolus* spp.), macambiras, and cactus 'rabo-de-raposa' (*Harrisia adscendens*), 'xique-xique' (*Pilosocereus gounellei*), and 'cabeça-de-frade' (*Melocactus zehntneri*).

Both sectors were sampled with six transects using 'Sherman' live traps, three transects with pitfall live traps, and random transects along the highways and back roads. Details on capture efforts with these methods and localities are summarized in Table 1.

**Table 1 Surveyed localities, including coordinates, sampling effort, and habitat description for each locality**

| Locality | Coordinates | Sampling effort | Habitat |
|---|---|---|---|
| A I - Nossa Senhora da Glória/SE | 10° 12′ 17.1″ S, 37° 21′ 12.2″ W | 33 Shermans × 14 = 462 | Savanna/seasonal forest - arboreal caatinga and secondary semidecidual forest patch. Sandy-latosol |
| A II[a] - Nossa Senhora da Glória/SE | 10° 12′ 14.3″ S, 37° 21′ 10.4″ W | 31 Shermans × 2 + 32 Shermans × 1 + 33 Shermans × 10 = 424 | Savanna/seasonal forest - very degraded scrub caatinga and secondary semidecidual forest patch. Sandy-latosol |
| A - Nossa Senhora da Glória/SE | 10° 12′ 15″ S, 37° 21′ 12″ W | 20 pitfalls × 26 = 520 | Savanna/seasonal forest - arboreal caatinga patch and secondary semidecidual forest patch. Sandy-latosol |
| 'A' sampling effort subtotal | | Shermans = 886 trap-nights; pitfalls = 520 trap-nights | |
| B I - Monte Alegre de Sergipe/SE | 10° 01′ 46.1″ S, 37° 35′ 58.7″ W | 33 Shermans × 14 = 462 | Steppic savanna under agricultural activities - semideciduous forest in deep valley with arboreal caatinga at the edge. Latosol covered with litter |
| B II - Monte Alegre de Sergipe/SE | 10° 1′ 46.6″ S, 37° 36′ 03.7″ W | 33 Shermans × 13 + 32 Shermans × 1 = 461 | Steppic savanna under agricultural activities - degraded arboreal caatinga bordering a semidecidual forest. Sandy-latosol |
| B - Monte Alegre/SE | 10° 1′ 49.5″ S, 37° 36′ 2.9″ W | 20 pitfalls × 26 = 520 | Steppic savanna under agricultural activities - semideciduous forest in deep valley with arboreal caatinga at the edge. Latosol covered with litter |
| 'B' sampling effort subtotal | | Shermans = 923 trap-nights; pitfalls = 520 trap-nights | |
| C I - Porto da Folha/SE | 9° 58′ 25″ S, 37° 34′ 49.8″ W | 33 Shermans × 14 = 462 | Steppic savanna under agricultural activities - semidecidual forest. Sandy-latosol covered with litter |
| C II - Porto da Folha/SE | 9° 58′ 25″ S, 37° 34′ 50.8″ W | 33 Shermans × 14 = 462 | Steppic savanna under agricultural activities - secondary semidecidual forest. Gravel soil and latosol with litter |
| C - Porto da Folha/SE | 9° 58′ 37.4″ S, 37° 34′ 47″ W | 20 pitfalls × 26 = 520 | Steppic savanna under agricultural activities - semidecidual forest. Sandy-latosol covered with litter |
| 'C' sampling effort subtotal | | Shermans = 924 trap-nights; pitfalls = 520 trap-nights | |
| Porto da Folha, Monte Alegre de Sergipe e Nossa Senhora da Glória/SE | 10° 3′ 45″ S, 37° 21′ 10″ W to 10° 2′ 22″ S, 37° 36′ 22″ W; 9° 59′ 1″ S, 37° 25′ 54″ W to 10° 3′ 55″ S, 37° 36′ 27″ W | Morning (57 h and 20 min) and evening random transects (25 h and 4 min) | Steppic savanna under agricultural activities, savanna/seasonal forest - highways and back roads |
| 'A,' 'B,' and 'C' = southern sector sampling effort | | Shermans = 2.733 trap-nights; pitfalls = 1.560 trap-nights; random transects = 82 h and 24 min | |
| D I - border BA/SE | 9° 33′ 04″ S, 38° 01′ 46″ W | 38 Shermans × 6 + 37 Shermans × 1 + 33 Shermans × 7 = 496 | Wooded steppic savanna - shrub caatinga in sandy and rocky soils along a river |
| D II[b] - Xingozinho River/SE | 9° 33′ 41″ S, 38° 01′ 14″ W | 38 Shermans × 7 = 266 | Wooded steppic savanna - shrub caatinga in sandy and rocky soils along a river |
| D - Poço Redondo/SE | 9° 47′ 59″ S, 37° 44′ 56″ W | 20 pitfalls × 22 = 440 | Wooded steppic savanna - arboreal caatinga. Sandy soil |
| 'D' sampling effort subtotal | | Shermans = 762 trap-nights; pitfalls = 440 trap-nights | |
| E I - Canindé de São Francisco/SE | 9° 44′ 23.4″ S, 37° 52′ 30.2″ W | 38 Shermans × 7 + 33 Shermans × 7 = 497 | Forested steppic savanna - arboreal caatinga on a small hill with outcrops. Sandy-latosol in its higher elevation |

**Table 1 Surveyed localities, including coordinates, sampling effort, and habitat description for each locality** *(Continued)*

| | | | |
|---|---|---|---|
| E II[c] - Canindé de São Francisco/SE (in dry season) | 9° 44′ 16.9″ S, 37° 52′ 11.8″ W | 38 Shermans × 4 = 152 | Forested steppic savanna - arboreal caatinga. Sandy soil covered with litter |
| E II[d] - Canindé de São Francisco/SE (in rainy season) | 9° 44′ 10″ S, 37° 52′ 22″ W | 33 Shermans × 7 = 231 | Forested steppic savanna - shrub caatinga with caatinga in regeneration process (capoeira). Sandy soil covered with bushes |
| E - Canindé de São Francisco/SE | 9° 44′ 23″ S, 37° 52′ 30″ W | 20 pitfalls × 22 = 440 | Forested steppic savanna - arboreal caatinga on a small hill with outcrops. Sandy-latosol in its higher elevation |
| 'E' sampling effort subtotal | | Shermans = 880 trap-nights; pitfalls = 440 trap-nights | |
| F I - Paulo Afonso/BA | 9° 29′ 00″ S, 38° 03′ 46″ W | 38 Shermans × 7 + 33 Shermans × 7 = 497 | Wooded steppic savanna - arboreal caatinga. Sandy soil, with patches covered with short herbs |
| F II - Paulo Afonso/BA | 9° 28′ 54″ S, 38° 03′ 14″ W | 38 Shermans × 7 + 33 Shermans × 7 = 497 | Wooded steppic savanna - arboreal caatinga. Sandy and gravel soil. Terrain declining to a drained area with many rocks |
| F - Paulo Afonso/BA | 9° 29′ 00″ S, 38° 03′ 46″ W | 20 pitfalls × 22 = 440 | Wooded steppic savanna - arboreal caatinga. Sandy soil, with patches covered with short herbs |
| 'F' sampling effort subtotal | | Shermans = 994 trap-nights; pitfalls = 440 trap-nights | |
| Paulo Afonso/BA, Canindé de São Francisco, Poço Redondo/SE | 9° 57′ 40″ S, 37° 36′ 21″ W to 10° 32′ 46″ S, 37° 47′ 05″ W to 9° 24′ 31″ S, 38° 14′ 13″ W | Morning (76 h and 51 min) and evening random transects (31 h and 20 min) | Wooded steppic savanna, forested steppic savanna - highways and back roads |
| 'D,' 'E,' and 'F' = northern sector sampling effort | | Shermans = 2,636 trap-nights; pitfalls = 1,320 trap-nights; random transects = 108 h and 11 min | |
| Total sampling effort | | Shermans = 5,369 trap-nights, pitfalls = 2,880 trap-nights; random transects = 190 h and 35 min | |

The table also includes total effort per sector. Southern sector: municipalities of Nossa Senhora da Glória, Monte Alegre de Sergipe, and Porto da Folha, Sergipe state; northern sector: municipalities of Poço Redondo, Canindé de São Francisco, Sergipe state, and the municipality of Paulo Afonso, Bahia state. BA, Bahia state; SE, Sergipe state. Effort = number of traps multiplied by number of nights. [a]Transect removed due to stolen three traps during the third sampling day; [b]sampling only during the dry season due to filling of the river and edges in the rainy season; [c]almost all traps of the E II transect were stolen during the fieldwork in the dry season; [d]E II transect was placed in different but near areas, because it was stolen during the first sampling season.

### Sampling small non-volant mammals

Sampling of small non-volant mammals was carried out using Sherman-like and pitfall live traps (Figure 3A,B, C) in view of their complementary effectiveness for capturing different sets of species (Voss and Emmons 1996). Isolated transects were established in each sector (Smith et al. 1975) with folding Sherman traps (30.5 × 8 × 9 cm). This method was based on 66 to 76 traps (variation in number due to robbery of several traps) in each of the six sampled areas (A, B, C, D, E, and F), with two transects, each with 33 to 38 traps, spaced ca. 10 between them, placed in selected microhabitats for optimizing capture (Table 1). These traps were baited with a mixture of peanut butter, canned sardines, banana, bacon, and cornmeal to attract a broad spectrum of species (carnivores, frugivores, granivores, and omnivores).

Simultaneously, system interception and fall traps, herein called 'pitfall traps,' were arranged in transects (Heyer et al. 1994). In all six areas, named areas A, B, C, D, E, and F, twenty 20-l buckets were arranged in five sites, each containing four buckets, connected by plastic fences and arranged on a Y-shaped setting.

Voucher specimens were weighed, measured, tagged, and prepared as skins, skulls, and skeletons or fixed in formalin and preserved in 70% ethanol.

### Sampling of medium-sized and large mammals

Medium-sized and large mammals were sampled in a complementary way, and evidence were carried out directly (sightings and calls) and/or indirectly (by tracks, feces, and burrows). Transects along roads were toured in mornings (between 0530 and 1030 hours - sometimes until 1300 hours) and evenings (between 1700 and 2030 hours). During the morning, census were made along roads and trails where the traps were laid by persons walking at ca. 1 km/h. Evening transects were toured by car at 20 to 30 km/h along highways and back roads with spotlights and flashlights. The total area

sampled by the transect method was calculated using the georeferenced points. Interviews were also conducted with local residents to obtain information on species. Species were only considered when based on reliable descriptions.

### Species identification

Identification in the field was based on external characteristics following Emmons and Feer (1997) and Eisenberg and Redford (1999). Nomenclature and classification followed Wilson and Reeder (2005a, b) and Zhou et al. (2011). Specific classification of Didelphimorphia and Chiroptera followed Gardner (2008), while *Oligoryzomys* was classified according to Weksler and Bonvicino (2005), *Thrichomys* according to Nascimento et al. (2013b), and *Galea* according to Bezerra (2008). Footprints were identified following Becker and Dalponte (1991). As complementary evidence for species identification, specimens were karyotyped, with chromosome preparations obtained in the field from the bone marrow following injection of 0.1% colchicine *in vivo* and incubation for 2 h (Ford and Hamerton 1956). All specimens collected as vouchers will be deposited in the Mammal Collection of the Universidade Federal da Paraíba, Campus of João Pessoa. The acronym ARB refers to Alexandra M. R. Bezerra. The research was carried with the approval and license of IBAMA (no. 189/2010-CGFAP), CR6/ICMBio (no. 186/2010-CR6/ICMBio), and fellow appropriate ethics committee and followed internationally recognized guidelines.

Geographic coordinates, using the GPS GARMIN® Etrex Legend H (Olathe, KS, USA); vegetation; and record type (e.g., capture, sighting) were registered for each specimen/record (with sightings). Sampling efficiency was evaluated by accumulation and rarefaction species curves (Gotelli and Colwell 2001) for each sector (southern and northern) and for the whole area. Species accumulation curves and Jackknife were estimated with EstimateS 8.2.0 (Colwell 2004). The second-order Jackknife estimator (Jackknife 2) was used due to its efficiency in conditions of low equability (Brose et al. 2003).

We applied the 'sequence-determines-credit' approach (SDC) for the sequence of authors (Tscharntke et al. 2007).

## Results

A total of 17 species was recorded, including one exotic species (*Rattus rattus*): 10 were captured and seven sighted (including four also captured), one found in its shelter, one identified by tracks (also sighted), one by vocalization (also sighted and captured), and nine by interviews with 10 local dwellers (two species were recorded exclusively by this method) (Table 2). Five captured species represent new records for Sergipe state: *C. agricolai*, *Gracilinanus agilis*, *Monodelphis domestica*, *Calomys expulsus*, and *T.* cf. *laurentius*. Data obtained in the fieldwork, including orders, families, species, and localities, are summarized in Table 2 and Additional file 1.

Total effort was 5,369 trap-nights with Sherman traps (1.54% capture success) and 2,880 trap-nights with pitfall traps (0.27% capture success), totaling 8,249 trap-nights (the summary of capture effort by location sampled is in Table 1). Together, these two methods sampled eight species, six in the southern sector and four in the northern sector, while two, *G. agilis* and *Wiedomys pyrrhorhinus*, were sampled in both sectors (Table 2). More individuals were captured during dry season ($n = 52$) than during rainy season ($n = 20$), but the species richness was the same for both seasons (eight).

Efforts for active search totaled 190 h and 35 min (Table 1), covering an area of 1,463 km$^2$. The complementary methods used for sampling specimens and the interviews resulted in records of 11 species, including small non-volant mammals like the opossums *M. domestica* and *Didelphis albiventris*, the echimid rodent *T.* cf. *laurentius*, and the common marmoset *Callithrix jacchus* (Additional file 1). Fifty-three individuals of nine species were sighted

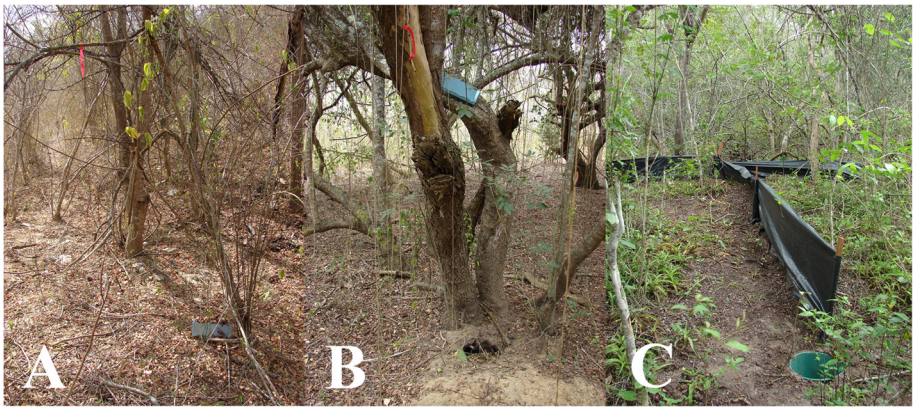


**Figure 3 Trap type used for sampling small non-volant mammals. (A)** Sherman-like trap on the ground in an arboreal caatinga. **(B)** Sherman-like trap on the trunk of an arboreal caatinga of semideciduous forest. **(C)** Pitfall traps in semideciduous forest.

**Table 2 Mammal species recorded in the six areas surveyed in northern and southern sectors per municipality**

| Taxa | Southern sector | | | Northern sector | | |
|---|---|---|---|---|---|---|
| | Nossa Senhora da Glória | Monte Alegre de Sergipe | Porto da Folha | Poço Redondo | Canindé de São Francisco | Paulo Afonso |
| Didelphimorphia | | | | | | |
| Didelphidae | | | | | | |
| *Didelphis albiventris* | X | X | X | X | X | X |
| *Cryptonanus agricolai*[a] | | X | X | | | |
| *Gracilinanus agilis*[a] | X | X | | | | X |
| *Monodelphis domestica*[a] | X | | | | | X |
| Chiroptera | | | | | | |
| Molossidae | | | | | | |
| *Molossus molossus* | | | | | X | |
| Primates | | | | | | |
| Callithrichidae | | | | | | |
| *Callithrix jacchus* | X | X | | X | X | X |
| Carnivora | | | | | | |
| Canidae | | | | | | |
| *Cerdocyon thous* | X | X | X | X | X | |
| Mustelidae | | | | | | |
| *Galictis cuja* | X | | | | | |
| Procyonidae | | | | | | |
| *Procyon cancrivorus* | | X | | | X | X |
| Artiodacytla | | | | | | |
| Cervidae | | | | | | |
| *Mazama* sp.[b] | | | | | X | |
| Rodentia | | | | | | |
| Muridae | | | | | | |
| *Rattus rattus*[c] | | | | | X | |
| Cricetidae | | | | | | |
| *Calomys expulsus*[a] | | X | | | | |
| *Oligoryzomys stramineus* | | | | | X | X |
| *Wiedomys pyrrhorhinus* | X | | X | | X | |
| Caviidae | | | | | | |
| *Kerodon rupestris*[b] | | | | X | X | |
| *Galea spixii* | X | | | X | X | X |
| Echimyidae | | | | | | |
| *Thrichomys* cf. *laurentius*[a] | | | | X | X | X |
| Total 17 (100%) | 8 (47) | 7 (41) | 4 (23.5) | 6 (35.3) | 13 (76.4) | 8 (47) |
| Total per sector | | 11 (64.7) | | | 15 (88.2) | |

Values in brackets are the relative percentage to total species in the sampling areas. [a]New records for the Sergipe state; [b]species recorded only during interviews, but with distribution known for the region; [c]aloctone species.

from highways and secondary roads and 26 roadkills were recorded. The species sighted or run over are listed in Additional file 1. Species accumulation curves by sampling day showed a tendency to stability (Figure 4), with one or more species added after 6 days of sampling, but this trend is not true for the northern sector. This result can be due to the lower number of individuals sampled in the northern sector.

The following account comments on small non-volant mammal species and collected in the study areas, including

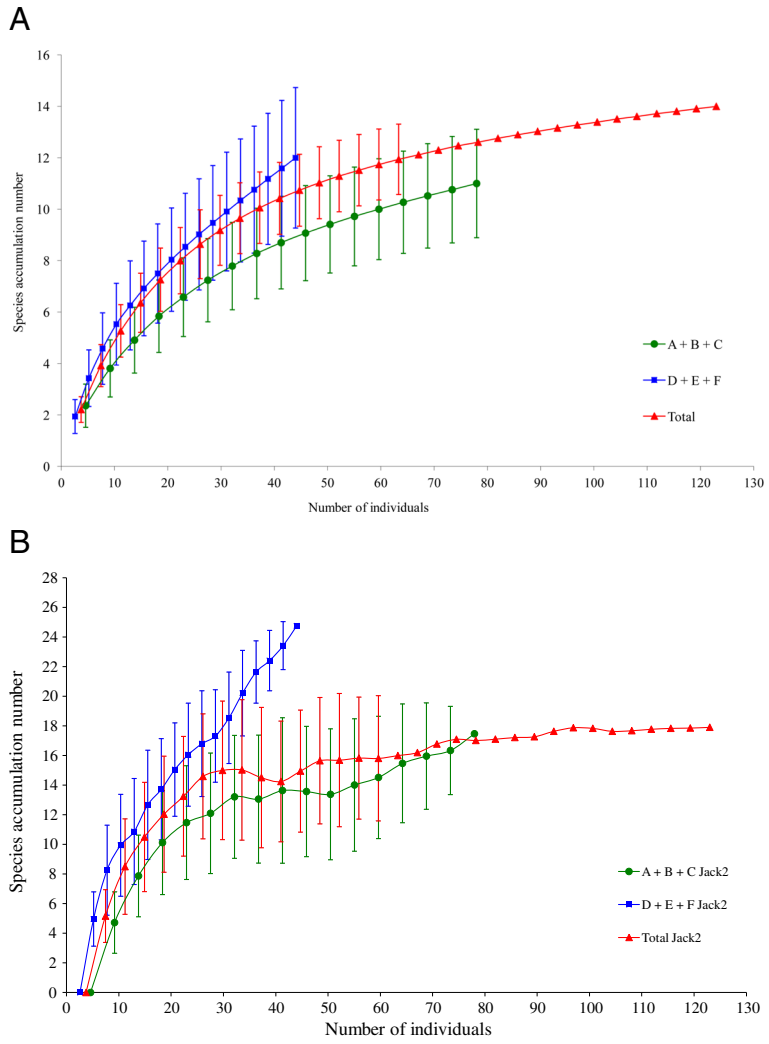


**Figure 4 Species accumulation curves. (A)** Mean curve of the increased number of species registered with the increase in sampling effort and in the number of individuals surveyed in the southern sector (A + B + C areas), in the northern sector (D + E + F areas), and total estimates for the study region (Total). **(B)** Mean rarefaction curve of increased number of estimated species (Jackknife 2) with the increase of sampling effort and in the number of individuals surveyed in the southern sector (A + B + C areas), in the northern sector (D + E + F areas), and in the total period of study in the region (Total). Bars are the standard deviation from each mean value.

karyotypic data (2*n*, diploid number and FNa, fundamental autosomal number) when available. A bat species hand-captured is also included in this section. Voucher specimens are listed in Additional file 2.

### Didelphimorphia

*Cryptonanus agricolai* (Moojen 1943) (Figure 5A) - The specimen karyotyped showed $2n = 14$ and FNa = 24 (Figure 6A) as reported by Voss et al. (2005). Four specimens were collected in the southern sector (Table 1, Additional file 2) with pitfall traps. This taxon was described as endemic to Brazil and widely distributed throughout the Cerrado, including transitional regions between Caatinga and Amazon (Voss et al. 2005), and later restricted to Caatinga (Carmignotto et al. 2012) based on molecular phylogenetic analyses (AP Carmignotto, unpublished data). *C. agricolai* is similar in size and external characters to *G. agilis*, a sympatric species in Monte Alegre de Sergipe, Sergipe state, but differs from it mainly by lacking a secondary foramen ovale and the absence of maxillary palatal fenestrae (Voss et al. 2005). Other differences tentatively identified by Voss et al. (2005), including smaller ears, shorter mystacial vibrissae, and a proportionally shorter tail with respect to the body, in *Cryptonanus* compared to *Gracilinanus* were clearly verifiable in this study and also during additional captures of *Cryptonanus* spp. specimens (AMRB, personal observation).

*Didelphis albiventris* Lund, 1840 (Figure 5B) is characterized by $2n = 22$ and FNa = 20 (Carvalho et al. 2002). Eleven individuals were captured and/or visualized in both

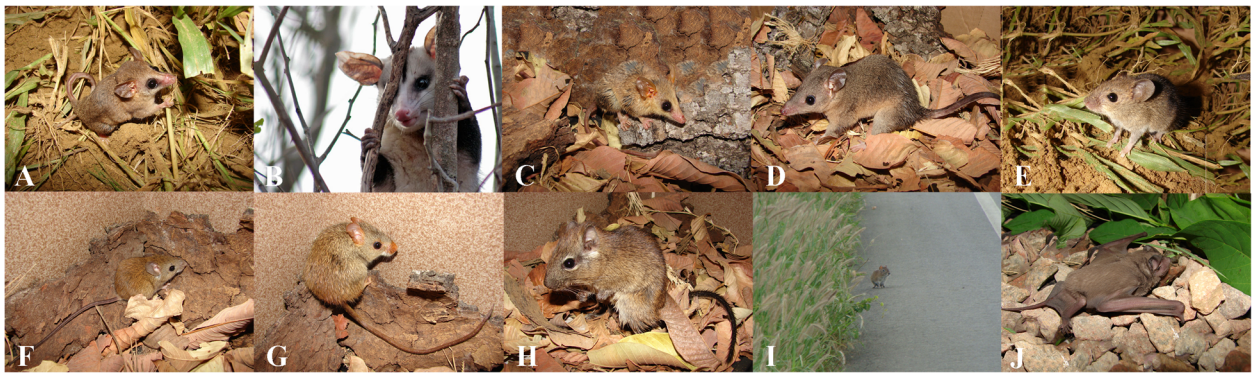


**Figure 5 Small mammals species recorded in the region. (A)** *Cryptonanus agricolai* ARB 832, from Porto da Folha. **(B)** *Didelphis albiventris*, in Monte Alegre de Sergipe/SE (Photo: courtesy of André Oliveira). **(C)** *Gracilinanus agilis*, ARB 804, Porto da Folha/SE. **(D)** *Monodelphis domestica* ARB 810, from Nossa Senhora da Glória. **(E)** *Calomys expulsus* ARB 831, from Monte Alegre de Sergipe. **(F)** *Oligoryzomys stramineus* ARB 791, from Canindé de São Francisco. **(G)** *Wiedomys pyrrhorhinus* ARB 788, from Canindé de São Francisco. **(H)** *Thrichomys* cf. *laurentius* ARB 799, from Canindé de São Francisco. **(I)** *Galea spixii*, individual along a road in Nossa Senhora da Glória. **(J)** *Molossus molossus* ARB 826, from Canindé de São Francisco.

southern and northern sectors (Table 1), and two specimens were collected. This species was visualized in both seasons, but most records (eight specimens, including a female with offspring) occurred during the dry season. This widespread species occurs in domains of Caatinga, Cerrado, Pantanal, Pampa, and the western limit of the Atlantic Forest. Its white ears easily differentiate it from *Didelphis marsupialis* and *Didelphis aurita*, which have distribution limits in the western and eastern Cerrado, respectively (Carmignotto 2005).

*Gracilinanus agilis* (Burmeister, 1854) (Figure 5C) is characterized by $2n = 14$ and FNa = 24 (Carvalho et al.

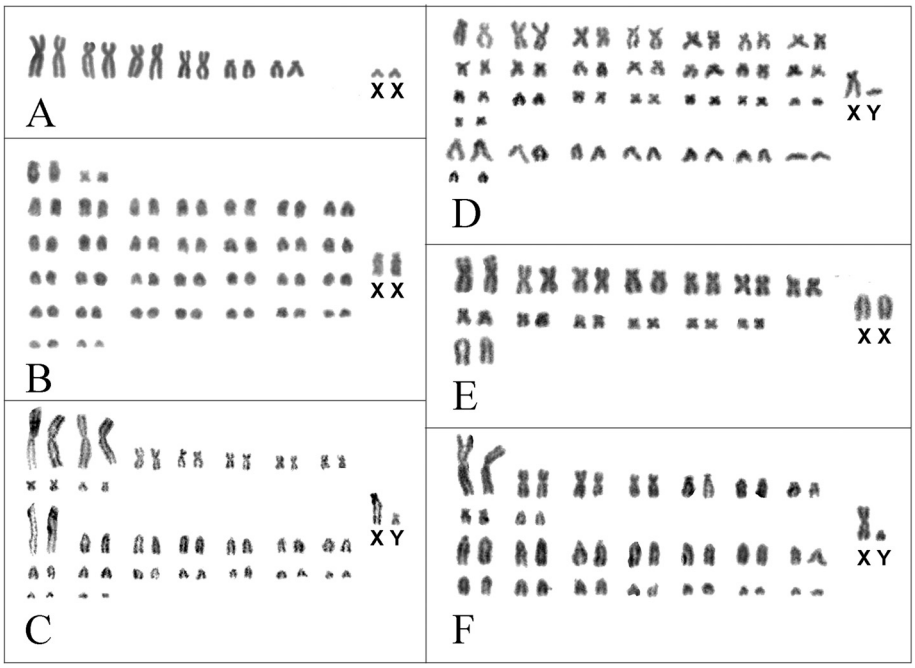


**Figure 6 Conventional Giemsa staining of chromosome complement. (A)** *Cryptonanus agricolai* (female ARB 832) with $2n = 14$ and FNa = 24. **(B)** *Calomys expulsus* (female ARB 831) with $2n = 66$ and FNa = 68. **(C)** *Oligoryzomys stramineus* (male ARB 791) with $2n = 52$ and FNa = 68. **(D)** *Wiedomys pyrrhorhinus* (male ARB 788) with $2n = 62$ and FNa = 104. **(E)** *Thrichomys* cf. *laurentius* (female ARB 824) with $2n = 30$ and FNa = 54. **(F)** *Molossus molossus* (male ARB 826) with $2n = 48$ and FNa = 64.

2002). Eleven specimens were collected in both southern and northern sectors (Table 1), two in pitfall traps and the others in Sherman traps; nine specimens were captured during the dry season. This widely distributed species is found in Caatinga, Cerrado, and Pantanal. Compared to other species presently found in the study region, *G. agilis* differs from *Thylamys karimii* by its relatively longer tail and body (Gardner 2008) and from *C. agricolai* by the presence of a secondary foramen ovale and maxillary palatal fenestrae (Voss et al. 2005).

*Monodelphis domestica* (Wagner, 1842) (Figure 5D) is characterized by $2n = 14$ and FNa = 24 (Carvalho et al. 2002). This species is widely distributed in Brazil, mainly in open areas east from the southern Amazon basin, through central, eastern, and southern Brazil (Gardner 2008). *Monodelphis domestica* varies widely in body size and color pattern with geography, and it likely represents a species complex (Caramaschi et al. 2011). Thirty-four individuals were captured in two sectors, 33 in Nossa Senhora da Glória and 1 road-killed in Canindé de São Francisco, Sergipe state; we prepared six specimens.

#### Rodentia: Cricetidae: Sigmodontinae

*Calomys expulsus* (Lund, 1841) (Figure 5E) - The specimen karyotyped showed $2n = 66$ and FNa = 68 (Figure 6B) as reported by Bonvicino and Almeida (2000). This is a widespread species from the Cerrado and Caatinga (Bonvicino et al. 2008). Only one specimen was captured with a pitfall trap during the rainy season in a semideciduous forest of Monte Alegre de Sergipe (Table 1). This species can be sympatric with *Calomys tener*, a smaller *Calomys* species with $2n = 66$ and FNa = 66 (Bonvicino and Almeida 2000).

*Oligoryzomys stramineus* Bonvicino and Weksler, 1998 (Figure 5F) - Six karyotyped specimens showed $2n = 52$ and FNa = 68 (Figure 6C) as reported by Weksler and Bonvicino (2005). This large-sized *Oligoryzomys* species, endemic to Brazil, is distributed from the Cerrado of northern Goiás state to the Caatinga of Ceará state in the northeast region (Weksler and Bonvicino 2005; Fernandes et al. 2012). Eleven specimens were captured and nine were collected (Additional file 2). Most specimens were captured in the dry season, except a single individual. This species was found only in the northern sector, mainly in Paulo Afonso municipality, in Bahia state. It is sympatric with *Oligoryzomys nigripes* (a species similar in body size and pelage pattern with $2n = 62$ and FNa = 82) and *Oligoryzomys fornesi* (a small-sized *Oligoryzomys* species with $2n = 62$ and FNa = 64) (Weksler and Bonvicino 2005).

*Wiedomys pyrrhorhinus* (Wied-Neuwied, 1821) (Figure 5G) - Two karyotyped specimens showed $2n = 62$ and FNa = 104 (Figure 6D) as reported by Souza et al. (2011). Three specimens were captured in the northern and southern sectors, all in arboreal caatinga and during the dry season. This species is widely distributed in Caatinga, at the right bank of the São Francisco River (AL, unpublished data). It differs from *Wiedomys cerradensis* by a set of characters including a larger body size, molar rows, and karyotype ($2n = 60$ to 62 and FNa = 88 in *W. cerradensis* against $2n = 62$ and FNa = 86, 90, or 104 in *W. pyrrhorhinus*) (Gonçalves et al. 2005; Souza et al. 2011; AL, unpublished data). This was the second report of the species for Sergipe state (first report by Bocchiglieri et al. 2012) and the first report with karyotypic data for this region.

#### Rodentia: Echimyidae: Eumysopinae

*Thrichomys* cf. *laurentius* (Lund, 1839) (Figure 5H) - Four karyotyped specimens showed $2n = 30$ and FNa = 54 (Figure 6E). *T. laurentius* was recently recognized based on karyologic, morphologic, and molecular data (Bonvicino et al. 2002b; Basile 2003; Braggio and Bonvicino 2004). It is endemic to the Caatinga, from eastern Piauí state to the interior of Bahia state (Bonvicino et al. 2008). Recently, Nascimento et al. (2013b), based on molecular analysis, suggested that the *Thrichomys* specimens with karyotype $2n = 30$ and FNa = 54 (*T.* cf. *laurentius*) found in the right bank of the São Francisco River, in Bahia state, belongs to a different lineage compared to the specimens from the left bank of the São Francisco River (*T. laurentius*). Seven individuals were collected in the northern sector. A lactating female and a juvenile specimen were captured in the rainy season.

#### Rodentia: Caviidae: Caviinae

*Galea spixii* (Wagler, 1831) (Figure 5I) has $2n = 64$ and FNa = 118 or 120 (Bonvicino et al. 2013). Both collected specimens had been killed along roads of the northern sector (Table 1) in the dry season. This species is restricted to the southwestern Caatinga and eastern Cerrado and differs from other congeneric species by a suite of morphometric characters (Bezerra 2008).

#### Chiroptera: Molossidae

One insectivorous bat *Molossus molossus* (Figure 5J) was captured in a roost in Canindé de São Francisco, Sergipe state (Additional file 1). This species, whose karyotype was described in Morielle-Versute et al. (1996) as $2n = 48$ and FNa = 64 (Figure 6F), was the second reported specimen for Sergipe state (first reported by Rocha et al. 2010) and the first report with karyotypic data for this region. This species is widely distributed in Brazil (Gardner 2008).

## Discussion

### The mammalian fauna of Caatinga

The postulation that the mammalian fauna of the Caatinga was a subset of the fauna of the Cerrado, with relatively few

endemic species (Oliveira et al. 2003), is changing after the recent mammal surveys and taxonomic studies. It is now known that the Caatinga exclusively shares only 15/153 (9.8%) species with the Cerrado, 10 other species with the Atlantic Rainforest, and six others with the Amazon. Furthermore, the number of species is not so poor when compared to its area, where the Caatinga has 1.92 species/10,000 $km^2$ and the Cerrado 1.14 species/10,000 $km^2$ (Carmignotto et al. 2012). Precise estimates on the expected species richness of Caatinga are unavailable. Sixty mammalian species were considered an approximate plateau, roughly 50% of them being bat species (Oliveira et al. 2003), meaning that the expected diversity of non-volant mammals stays around 30 species. We recorded 16 autochthonous species of non-volant mammals, 5 of them being newly recorded for Sergipe state. All new records were of small non-volant mammal species, most of which are widely distributed in Brazil, two being endemic to Caatinga (*C. agricolai* and *T.* cf. *laurentius*). As patterns of population fluctuations of small non-volant mammals of the Caatinga are poorly understood, additional records are likely to be reported in surveys carried out in different climatic periods when sampling has not yet taken place, as the end of the rainy season (when large number of individuals were captured in an area of the Caatinga of Pernambuco state; Streilein 1982b). Interestingly, two newly recorded species (*C. agricolai* and *C. expulsus*) were only captured with pitfall traps, corroborating the importance of using complementary sampling methods for capturing small non-volant mammals (e.g., Patterson et al. 1989; Voss and Emmons 1996).

The mammalian fauna of these two sectors was very similar, only one species, *T.* cf. *laurentius*, was restricted to the northern sector and two species, *C. expulsus* and *C. agricolai*, to the southern sector. All these species, however, are widely distributed, a reason why these differences are irrelevant.

### Comparison of sampling efforts and species richness

The number of small non-volant mammal species from different localities in the Cerrado, with a minimal effort of 1,000 trap-nights, may vary from 6 to 27 (Carmignotto 2005). Very few studies on population parameters and community structure of small mammals have been reported for the Caatinga (e.g., Streilein 1982a, b), explaining why estimates of the expected richness and minimal effort to achieve satisfactory values are not possible. In a 1-year study in the municipality of Exu, Pernambuco state, with an effort of approximately 25,000 trap-nights (Streilein 1982a), 12 species (9 rodents and 3 marsupials) were found in addition to the exotic species *Mus musculus* and *Rattus* spp. *T. karimii*, *Cerradomys* sp., *Necromys lasiurus*, *Dasyprocta prymnolopha*, and *Kerodon rupestris* were recorded by Streilein (1982a) (although *K. rupestris* was cited in an interview), but were not sampled in our study; vice versa, the herein recorded *C. agricolai* was not sampled by him.

Capture success with Sherman traps was 1.54%, almost twice the capture success of 0.87% recorded in another area of the Caatinga (Streilein 1982b) with an effort of 25,000 trap-nights, but lower than that in the Cerrado, where it can reach 5% (Carmignotto 2005). Capture success with pitfall traps was 0.27%, lower than 6.6% recorded in a 1-year field study in Pernambuco's caatinga (Nascimento et al. 2013a). There is no more record on capture success of small non-volant mammals of the Caatinga with pitfall traps.

Fluctuations of species richness and abundance of small non-volant mammals in environments under strong climatic seasonality have been extensively discussed (e.g., Mares et al. 1989; Ribeiro et al. 2011). In fact, this climatic variable must be taken into consideration, especially in environments with unpredictable and erratic rainfalls, where months or even years of drought may occur (Nimer 1972). During the rainy season, few individuals were collected, a result similar to that found in a caatinga of Bahia state, where twice more individuals were captured during the dry season (Freitas et al. 2005). It is probably due to the availability of abundant resources like fruits and leaves (Lima 2007), which facilitated foraging in smaller areas, with consequent fewer encounters with traps, and/or making baits less appealing.

Species accumulation curves per sampling day showed a tendency to stability, mainly in the southern sector. Although the sampling effort employed in this study was high and carried out with complementary methods, a few further considerations are relevant. The environmental heterogeneity of a given region directly contributes to mammalian species richness (Carmignotto 2005), as does the degree of habitat preservation (Bonvicino et al. 2002a). In fact, in a fieldwork season of 6 days only, carried out in a conservation area of Catimbau National Park, Pernambuco state, nine species from orders Didelphimorphia and Rodentia (the same species number captured by us for these orders) were sampled within a capture success of only 0.14% (Geise et al. 2010). It is clear that the whole study area was under intense anthropic pressure, and it is likely that several species (Carmignotto et al. 2012; Paglia et al. 2012) have become locally extinct. This was the case of medium and large mammals, like the puma (*Puma concolor*), the peccaries *Pecari tajacu* and *Tayssu pecari*, and armadillo species, which could not be found in the study region, but are only cited. Hunting pressure may result in drastic population declines (Thoisy et al. 2000), leading to the local extinction of species prized for consumption like the South American brown brocket deer *Mazama gouazoubira* and the rock cavy *K. rupestris*, which

are presently rare and restricted to farms with large protected areas. Other species of the study area which are also prized by hunters include the non-extinct yellow-toothed cavy *G. spixii* and the punaré *T.* cf. *laurentius*, which are not locally extinct probably due to their larger litter size than that of *K. rupestris* (Streilein 1982b).

## Conclusions

Two highly adverse activities are currently affecting the mammalian community in the region: (1) deforestation for lumber, open pastures, and cultivation (except for the less fragmented areas of the Monumento Natural do Rio São Francisco), also observed by Silva et al. (2013), and (2) subsistence hunting (a very common activity in the study region). Government-sponsored settlement projects (MDA 2004) have increased the population density in several areas, accelerating hunting and deforestation. A higher human population density also attracts commensal species, such as the domestic cat (*Felis catus*), the domestic dog (*Canis lupus familiaris*), the house mouse (*M. musculus*), and the house rat (*R. rattus*) (recorded in the region along highways and relatively far from towns).

The Caatinga has been deeply altered, with 50% of its vegetation already changed by human activities, with approximately 15% degraded by desertification (Leal et al. 2005). New protected areas are necessary for preserving the species richness of the Caatinga, considering that, even in a degraded region, five new records of small non-volant mammal species can be documented. In addition, intensively orientated programs of conservation must be urgently implemented in schools for eradicating the strongly rooted habit of consuming hunted animals. These measures, in the long term, will be essential for a sustainable regional development.

## Additional files

**Additional file 1: Mammal species recorded in the municipalities of Paulo Afonso, Bahia state (BA), and Canindé de São Francisco, Poço Redondo, Porto da Folha, Monte Alegre de Sergipe, and Nossa Senhora da Glória, Sergipe state (SE).** FU = Federative Units. RT = Record type are 1 = Sighting, 2 = Run over, 3 = Tracks, 4 = Faeces, 5 = Vocalization, 6 = Searching in roost, and 7 = Interview.

**Additional file 2: Voucher specimens collected in the study areas.** The acronym ARB refers to Alexandra M. R. Bezerra field number. All specimens will be deposited in the Mammal Collection of the Universidade Federal da Paraíba, Campus João Pessoa, Brazil. Municipalities are underlined.

#### Competing interests

The authors declare that they have no competing interests.

#### Authors' contributions

AMRB participated in the design, coordination, and drafting of the manuscript, carried out the karyological and statistical analyses, and edited the figures and tables. AL carried out part of the karyological analysis, edited some of the figures, and provided assistance with interpretation and redrafting of the manuscript. CRB provided assistance with interpretation and redrafting of the manuscript. ASC conceived and participated in the design of the study. All authors read and approved the final manuscript.

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