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The usefulness of different methods for biodiversity surveys in the Amazonia/ Cerrado ecotone

A utilidade de diferentes métodos em inventários de biodiversidade no ecótono Amazônia/Cerrado

Rita G Rocha[1,2,3], Eduardo Ferreira[2,4,*], Andreia Serafini[5], Leonora P Costa[1], António JA Nogueira[2], Adriana Malvasio[4], Iracy CM Martins[3], Carlos Fonseca[2]

1. Departamento de Ciências Biológicas, Universidade Federal do Espírito Santo, Av. Fernando Ferrari 514 - Goiabeiras, 29075-910, Vitoria, ES, Brazil; 2. Departamento de Biologia & CESAM, Universidade de Aveiro, 3810-193, Aveiro, Portugal; 3. Laboratório de Impacto Ambiental, Universidade Federal do Tocantins, 77001-090, Palmas–TO, Brazil; 4. Laboratório de Ecologia e Zoologia, Universidade Federal do Tocantins, 77001-090, Palmas–TO, Brazil; 5. Dipartimento di Scienze Ambientali, Università degli Studi della Tuscia, 01100 Viterbo, Italy.
* Corresponding author: elferreira@ua.pt

Abstract Small mammals and herpetofauna were surveyed in the Amazonia/Cerrado ecotone and the capture effectiveness in terms of capture rates and species richness of live traps (Sherman and Tomahawk) and pitfalls (30 L and 60 L) was compared. We also evaluated if these methods alone could accurately estimate local species richness, by using additional methods. Sixty-five small vertebrate species were captured, 29 amphibian, 18 lizard and 18 small mammal species. Larger pitfalls captured significantly more individuals than the smaller ones, but did not capture more species of any taxonomic group. When comparing live traps, sherman traps captured significantly more cricetids, while Tomahawk traps captured more didelphids and teiids. Pitfalls captured significantly more small mammal species than live traps. Pitfalls were the less selective method and reveal to be very useful even in short-term biodiversity surveys. Additional sampling methods substantially increased the number of recorded species, mostly herpetofauna. A combination of pitfalls and live traps is adequate for sampling small mammals in the ecotone but is be insufficient for herpetofauna. Additionally, we present the relative costs and effort associated with each method and discuss their merits and drawbacks.

Keywords: active search; Brazil; capture effectiveness; live traps; pipe refuges; pitfalls.

Resumo A fauna de pequenos mamíferos e a herpetofauna do ecótono Amazônia/Cerrado foram amostradas e o sucesso de captura em termos de taxa de captura e de riqueza específica de armadilhas Sherman e Tomahawk, e armadilhas de queda (30 L e 60 L) foi comparada. Também avaliámos se estes métodos poderiam, por si só, estimar de forma adequada a riqueza específica local, utilizando métodos adicionais. Sessenta e cinco espécies de pequenos vertebrados foram capturadas, sendo 29 anfíbios, 18 répteis e 18 pequenos mamíferos. As armadilhas de queda maiores foram significativamente mais eficientes que as menores, em termos do número de indivíduos capturados por esforço medido como capturas-noite, mas não capturaram mais espécies de nenhum dos grupos taxonómicos. Quando compradas entre si, as armadilhas Sherman capturaram significativamente mais cricetídeos, enquanto as armadilhas Tomahawk capturaram significativamente mais didelfídeos e teídeos. As armadilhas de queda capturaram significativamente mais espécies de pequenos mamíferos do que as armadilhas Sherman e Tomahawk. As armadilhas de queda foram o método menos seletivo e podem revelar-se úteis mesmo em estudos de biodiversidade de curta duração. Os métodos de amostragem adicionais aumentaram substancialmente o número de espécies registradas, principalmente para a herpetofauna. Sugerimos que uma combinação de armadilhas de queda, Sherman e Tomahawk é adequada para amostrar a fauna de pequenos mamíferos no ecótono, mas será insuficiente para a amostragem da herpetofauna. No fim, apresentamos os custos e esforço associado a cada um dos métodos e discutimos os seus méritos e inconvenientes.

Palavras-chaves: Brasil; eficiência de captura; armadilhas Sherman e Tomahawk; armadilhas de queda.

Introduction

Brazilian Cerrado is the only tropical savanna included in the twenty-five biodiversity hotspots proposed by Myers *et al.* (2000), and

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Amazonian Rainforest is considered the largest and most diverse tropical wilderness area (Mittermeier *et al.* 1998). These are the two largest Brazilian biomes (Klink and Machado 2005) and converge along a large ecotone in central Brazil, which is considered a conservation priority area (Azevedo-Ramos and Gallati 2002, Cavalcanti and Joli 2002). Despite its perceived importance, there is a deficiency of biological sampling data in this area, as there is throughout the northern region of Cerrado (Marinho-Filho *et al.* 2002, Bini *et al.* 2006).

Biodiversity surveys with the objective of producing reasonably complete species lists depend on efficient capture techniques. Careful evaluation of various techniques by experienced wildlife biologists is the key for successful capture programs (Schemnitz 1996). When available, published data about the effectiveness of different methods could help to identify suitable techniques. Several studies on capture methodology have been conducted in Amazonian rainforest (Malcolm 1991, Voss and Emmons 1996, Woodman *et al.* 1996, Vieira 1998, Hice and Schmidly 2002, Lambert *et al.* 2005, Ribeiro-Júnior *et al.* 2008, Ribeiro-Júnior *et al.* 2011), but few have been undertaken in the Cerrado, and only for the southern region of this biome (Cechin and Martins 2000, Vieira *et al.* 2004, Caceres *et al.* 2011).

Some of the factors known to influence capture success are: incidence and amount of precipitation (Gibbons and Bennett 1974); closed *versus* mesh trap (O'Farrell *et al.* 1994); size of the trap and mass of captured individuals (Slade *et al.* 1993); trap-habituation and trap-avoidance (Sealander and James 1958); size of individuals and taxonomic group (Crosswhite *et al.* 1999) and ecological features across taxa (Malcolm 1991, Greenberg *et al.* 1994, Leite *et al.* 1996, Lambert *et al.* 2005). Generally, the simultaneous use of more than one method increases the number of species captured (Mengak and Guynn 1987, Greenberg *et al.* 1994, Voss and Emmons 1996, Crosswhite *et al.* 1999, Ribeiro-Júnior *et al.* 2008).

Studies comparing different capture methods are normally undertaken within a particular region with a characteristic species assemblage. When extrapolating capture efficiency results from one area to another, wildlife professionals are confronted with different, but sometimes close, taxonomic assemblages. Therefore, comparisons made at higher taxonomic level, rather than species level, might be more useful. The aims of this study were to survey the species richness of small mammals and herpetofauna in the Amazonia/Cerrado ecotone and compare the capture effectiveness of live traps (Sherman and Tomahawk traps) and pitfalls, in terms of capture rates and species richness. Additional methods (active search and pipe traps) were also used to evaluate if live traps and pitfalls alone accurately estimate local species richness.

Methods

Study area

This study was conducted in two conservation areas in the western region of the state of Tocantins, Central Brazil: Parque Estadual do Cantão (PEC) and the surrounding Área de Proteção Ambiental Bananal/Cantão (APABC). Fazenda Santa Fé (FSF) in the state of Pará – a nearby private ranch (65,000ha) without official conservation status – was also sampled. PEC (90,000 ha) is a state natural reserve and APABC (1,700,000 ha) is a conservation buffer area, where limited human activities (e.g. farming and forestry) are allowed. This buffer area surrounds PEC and the nearby Parque Nacional do Araguaia (PNA). A large river complex dominated by the Araguaia River, a natural border between the states of Tocantins and Pará, characterizes the area. The study area is located in the ecotone between the Cerrado of central Brazil and the Amazonian rainforest, and is mainly composed of alluvial forests and, in a lesser extent, well-drained areas with more open physiognomies typical of the Cerrado (Oliveira-Filho and Ratter 2002). Seasonally flooded areas occupy most of PEC, and permanently dry areas are mostly located outside the park, in APABC and in the western margin of Araguaia River, state of Pará. Climate in this region of Brazil is tropical, with a rainy season from October to April and a dry season from May to September (INMET 2011).

Sampling

Two trapping methods were used: pitfalls (buckets of approximately 30 L – diameter 32 cm/height 38 cm; and approximately 60 L – diameter 38 cm/height 54 cm) with plastic drift fences (50 cm height and 5m length between two consecutive pitfalls) and live traps (Tomahawk – 45 x 21 x 21 cm – and Sherman traps – 45 x 12.5 x 14.5 cm). Four smaller sub-areas within the study area were sampled, each with five sampling points established at least 2 Km apart. Fourteen sampling points were established inside PEC and six in the surrounding areas (geographic coordinates provided as supplementary data – Table S1), encompassing the diversity of phytophysiognomies present in the study area.

Sampling design at each point (Figure 1), consisted of: a line of sixteen 30 L pitfalls with drift fences (5 m between consecutive pitfalls); a line of ten 60 L pitfalls with drift fences (5 m between

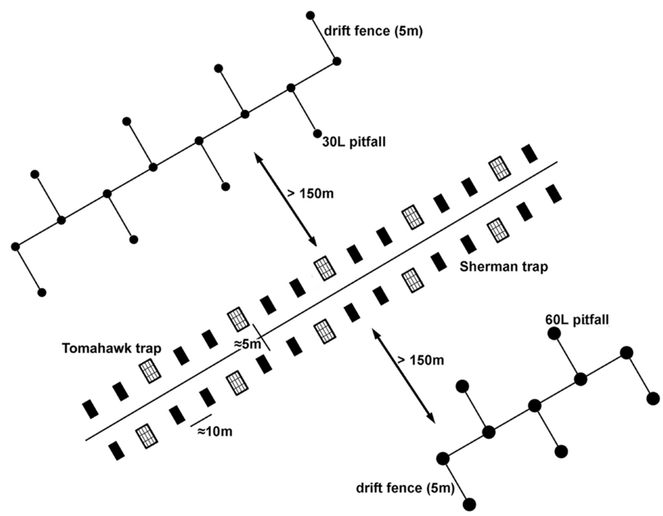

Figure 1 Sampling design used in each one of the 20 sampling points. Lines of pitfalls and live traps were placed at least 150m apart

consecutive pitalls); a mixed line with 22 Sherman traps (10/20 m between consecutive traps) and 10 Tomahawk traps (30 m between consecutive traps), placed in the ground. Lines were placed at least 150 m apart. Sampling design for pitfall lines was based on a model proposed by A.P. Carmignotto (pers. comm.). Traps were checked daily, at early morning, to avoid dehydration of captured individuals. In addition, traps or pitfalls exposed to direct sunlight were shaded using vegetation or its own lid, respectively. Water was added to pitfalls also to avoid desiccation, but not sufficient to drown small mammals, as reported earlier by Mengak and Guynn (1987). Excess water was removed after heavy rain. A small piece of wood or stone was placed inside the buckets to provide a dry surface for small mammals and lizards. Arthropods, mainly arachnids and ants, were removed from pitfalls, because they tend to prey on vertebrates inside the buckets. Adding water also helped reduce vertebrate mortality caused by arthropods. Live traps were baited with peanut butter and pineapple and the bait was replaced every two days. At the end of each sampling period, buckets were closed, to prevent accidental death or injury of animals in the area, and live traps were removed.

Sampling was carried out between June 2007 and November 2008. Three periods averaging seven nights (range 5–9 nights) were sampled in each area. One was at the end of the rainy season (June to July 2007; May to June 2008), the second during the dry season (August to September 2007 and 2008), and the third at the beginning of the following rainy season (October to November 2007 and 2008). Time intervals between consecutive samplings in the same area varied between six and eight weeks. We did not sample during the rainy season because most of the area remains flooded. Small inconsistencies in trap-night numbers across methods were due to damage to traps by wild animals or removal by local people. We also used active search and PVC pipe traps (tree pipe traps: 40 cm long, adapted from Jonhson 2005 – total 200 traps, 9 checking instances per trap; lake pipe traps: 80 cm long – total 80 traps, 6 checking instances per trap, see also Ferreira *et al.* 2012) as additional methods for surveying other species present in the area, but these methods were not used for statistical comparisons in this study.

Collecting and marking

All vertebrates captured in the traps (except snakes and some accidentally captured birds) were weighed with a digital scale (precision 0.1 g) or with a spring scale (precision 20 g), and identified to family and genus/species level, whenever possible. Individuals not identified in the field, as well as the first ones of each species caught, were collected as voucher specimens and deposited in "Coleção de Mamíferos da Universidade Federal do Espírito Santo" and "Coleção Herpetológica da Universidade de Brasília" (CHUNB). All other individuals were individually marked and released. Small mammals were marked with ear-tags and amphibians and lizards were marked with visible implant elastomer (VIE). All procedures were performed according to Brazilian national laws and guidelines. Fieldwork was carried out with permits from the federal (ICMBIO, permits: 200/2006; 036/2007; 13546-3 and 14307-1) and state (NATURATINS, permits: 019/2006; 009/2007 and 001/2008) conservation agencies.

Data analysis

Capture data from all sampling points and periods were pooled by type of trap (30 L or 60 L pitfall and Sherman or Tomahawk), family and species. Only first captures of each individual, for each method, were included in the analysis (except for estimation of recapture rates). If an individual was captured more than once by the same method, it was considered as a recapture. Capture and recapture rates (expressed as percentages) were calculated as the ratio of capture and recapture numbers over total trap-night numbers.

Captured individuals were classified by weight. Eight classes ranging from 0 to 2187 g were defined according to a geometric series of base 3: $[0–3^0:3^6–3^7]$. Species capture rates (capture/1000 trap-nights) per weight class were used to visually compare capture effectiveness by method, family and species.

Differences in the species richness recorded in 30 L and 60 L pitfalls, Sherman and Tomahawk traps, and in pitfalls and live traps were analyzed using individual based rarefaction (Gotelli and Colwell 2001). Rarefaction curve and 95 % confidence intervals were calculated using EstimateS v.9 (Colwell 2013). Perceived species richness was considered significantly different whenever the lower bound of the 95% confidence interval of the curve with highest species richness did not overlap with the mean curve with the lowest species richness (Magurran 2004).

Odds ratio meta-analysis was performed on capture data pooled by family using the STATSDIRECT® statistical package, for each of the following pairs of methods: 60 L pitfall *versus* 30 L pitfall; Sherman traps *versus* Tomahawk trap; live traps *versus* pitfalls. For each comparison, only families recorded by both methods under comparison were included in the analysis. We excluded from this analysis the occasional captures of tree frogs (Hylidae), in comparison among pitfalls, since these individuals intentionally enter into these traps and could easily escape from buckets, and Iguanidae, Polychrotidae and Scincidae, in comparison among live traps and pitfalls since only one individual of each family was captured in live traps.

We estimated independent (family) and pooled odds-ratio, which weights the number of positive (capture) and negative cases (empty trap/pitfall), for both trap types. Thus, the calculation accounted for differences in trap-night numbers between different traps. Heterogeneity among independent odds-ratios was estimated in the analysis, using the inconsistency index I^2 (Higgins *et al.* 2003). A model accounting for random effects was chosen for estimating pooled odds-ratios (DerSimonian and Laird 1986). Confidence intervals (95%) for the independent and pooled estimates were also calculated in the analysis.

One-tailed *t*-tests for independent samples, corrected for unequal variances when needed – Welch's *t*-test (Welch 1947) – were used for comparing the average numbers of mammal recaptures per night in pitfalls, among the different sampling seasons: end of rainy season (28 nights), peak of dry season (28

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Table 1 Capture/recapture rates given by taxa and trap type, expressed as percentage of trap-nights number. When present, recapture rates are given after the dash. Numbers of trap arrays used in this study are also indicated.

		Sherman	Tomahawk	30 L pitfalls	60 L pitfalls
	Trap-nights	*8580*	*3900*	*6159*	*4079*
Taxa	*Arrays*	*20*	*20*	*20*	*20*
Amphibia					
	Bufonidae	-	-	0.08	0.42
	Hylidae	-	-	0.06	0.02
	Leiuperidae	-	-	6.61	9.19
	Leptodactylidae	-	-	3.20	5.10
	Microhylidae	-	-	2.45	3.97
	Class totals	-	-	*12.40*	*18.71*
Reptilia					
		-	-	-	
	Gekkonidae	-	-	0.10	0.07
	Gymnophtalmidae	-	-	0.42	0.25
	Iguanidae	0.01	-	0.02	-
	Polychrotidae	0.01	-	0.24	0.37
	Scincidae	0.01	-	0.06	0.07
	Teiidae	0.65/0.06	1.3/0.08	1.25/0.06	1.23/0.02
	Tropiduridae	-	-	0.05	0.05
	Class totals	*0.69/0.06*	*1.3/0.08*	*2.14/0.06*	*2.01/0.02*
Mammalia					
	Didelphidae	1.49/0.92	2.38/2.13	0.10	0.71/0.52
	Cricetidae	1.07/0.36	0.03	0.47	0.66/0.02
	Echimyidae	0.37/0.24	0.38/0.03	-	0.05/-
	Class totals	*2.94/1.53*	*2.79/2.15*	*0.57*	*1.42/0.54*
Totals		**3.62/1.59**	**4.10/2.23**	**15.12/0.06**	**22.14/0.56**

nights) and beginning of rainy season (28 nights). Our goal was to test the hypothesis that the average number of recaptures of mammals per night, in pitfalls, was higher during the drier periods.

Results

Capture rates and species richness

During this study 2,284 individuals were captured: 1,507 amphibians (five families), 323 lizards (nine families) and 454 small mammals (three families). Total numbers of trap-nights (Table 1) were as follows: Sherman traps (8,580 trap-nights); Tomahawk traps (3,900); 30 L pitfalls (6,159) and 60 L pitfalls (4,079). Overall capture rates were higher for 30 L (15.12%) and 60 L pitfalls (22.14%) than for Sherman (3.62%) and Tomahawk traps (4.10%) (Table 1). Capture rates for amphibians in 30 L and 60 L pitfalls were very high compared with other vertebrate groups. Recaptures in pitfalls and live traps only occurred for mammals and teiid lizards. A negligible number of amphibian recaptures was observed in pipe traps and during active search.

Sixty-five vertebrate species (Table 2) were captured: 29 amphibian, 18 lizard and 18 small mammal species. Pitfalls captured 15 amphibian, 11 lizard and 14 small mammal species. From all these species, six were unique to pitfalls (one amphibian, one lizard and four mammals). Live traps captured six lizard and 12 small mammal species. Only three small mammal species were unique to live traps. Additional methods accounted for the highest number of amphibian (active search – 26 spp.; pipe traps – eight spp.) and lizard species (active search – 14 spp.; pipe traps – one sp.), but captured only three small mammal species (active search – one sp.; pipe traps – two spp.). Additional methods also accounted for the highest number of unique species: eight amphibian and five lizard species by active search and three amphibian species in pipe traps.

Rarefaction analysis revealed that there were no significant differences, in terms of species richness, between 30 L and 60 L pitfalls, for each class in separate and for all vertebrate groups together (Figure 2). There were also no significant

Table 2 Species recorded by method, with reference to class/method totals. The numbers of species, per class and total, recorded by only one method are given between parentheses

	Method					
Species	**Sherman trap**	**Tomahawk trap**	**30 L pitfalls**	**60 L pitfalls**	**Pipetrap**	**Active search**
Amphibia						
Bufonidae						
Rhaebo guttatus (Schneider, 1799)			X	X		X
Rhinella granulosa (Spix, 1824)						X
Rhinella ocellata (Günther, 1859 “1858”)			X	X		X
Rhinella schneideri (Werner, 1894)			X	X		X
Craugastoridae						
Haddadus sp.						X
Hylidae						
Dendropsophus melanargyreus (Cope, 1887)						X
Dendropsophus minutus (Peters, 1872)					X	
Dendropsophus nanus (Boulanger, 1889)					X	
Hypsiboas fasciatus (Günther, 1859 "1858")					X	X
Hypsiboas raniceps Cope, 1862					X	X
Osteocephalus taurinus Steindachner, 1862					X	X
Phyllomedusa azurea Cope, 1862						X
Scinax fuscomarginatus (A. Lutz, 1925)					X	X
Scinax fuscovarius (A. Lutz, 1925)			O	O		X
Scinax gr. *ruber* (Laurenti, 1768)			O		X	X
Trachycephalus venulosus (Laurenti, 1768)			O		X	X
Leiuperidae						
Physalaemus centralis Bokermann, 1962				X		X
Physalaemus cuvieri Fitzinger, 1826			X	X		X
Pseudopaludicola mystacalis (Cope, 1887)			X	X		X
Leptodactylidae						
Leptodactylus bokermanni Heyer, 1973			X	X		
Leptodactylus fuscus (Schneider, 1799)						X
Leptodactylus labyrinthicus (Spix, 1824)						X
Leptodactylus leptodactyloides (Andersson, 1945)			X	X		X
Leptodactylus mystaceus (Spix, 1824)			X	X		X
Leptodactylus latrans (Steffen, 1815)			X	X		X
Leptodactylus cf. *petersi* (Steindachner, 1864)						X
Leptodactylus pustulatus (Peters, 1870)			X			X
Microhylidae						
Chiasmocleis albopunctata (Boettger, 1885)						X
Elachistocleis ovalis (Schneider, 1799)			X	X		X
Class totals *29*	*0*	*0*	*14*	*12*	*8(2)*	*26(8)*
Reptilia						
Iguanidae						
Iguana iguana (Linnaeus, 1758)	O					X
Polychrotidae						
Anolis nitens (Wagler, 1830)	O		X	X		X
Anolis ortonii Cope, 1868				X		
Polychrus acutirostris Spix, 1825						X
Tropiduridae						
Tropidurus torquatus Wiegmann, 1834			X	X		X

X – Recorded species; O – Accidental capture of a single individual; a(b): a = total number of species; b = unique species. * – a single individual was captured in a preliminary sampling in a Sherman trap but was not captured again, during the study.

Table 2 cont. Species recorded by method, with reference to class/method totals. The numbers of species, per class and total, recorded by only one method are given between parentheses

Species	Method					
	Sherman trap	**Tomahawk trap**	**30 L pitfalls**	**60 L pitfalls**	**Pipetrap**	**Active search**
Reptilia						
Tropiduridae						
Tropidurus oreadicus Rodrigues, 1987			X	X		X
Gekkonidae						
Hemidactylus mabouia (Moreau de Jonnès, 1818)						X
Phyllodactylidae						
Gymnodactylus amarali Barbour,1825						X
Sphaerodactylidae						
Gonatodes humeralis (Guichenot, 1855)			X	X		X
Teiidae						
Ameiva ameiva (Linnaeus, 1758)	X	X	X	X		
Cnemidophorus ocellifer (Spix, 1825)						X
Kentropyx calcarata Spix, 1825	X		X	X		
Tupinambis teguixin (Linnaeus, 1758)	X	X		X		
Gymnophthalmidae						
Colobosaura modesta (Reinhardt & Luetken, 1862)			X	X		X
Micrablepharus atticolus Rodrigues, 1996			X	X		X
M. maximiliani (Reinhardt & Luetken, 1862)						X
Scincidae						
Mabuya frenata (Cope, 1862)					X	X
Mabuya nigropunctata (Spix, 1825)	O		X	X		X
Class totals *18*	*6*	*2*	*9*	*11(1)*	*1*	*14(5)*
Mammalia						
Didelphidae						
Caluromys philander (Linnaeus, 1758)		X	X		X	
Didelphis albiventris Lund, 1840	X	X		X		
Didelphis marsupialis Linnaeus, 1758	X	X	X	X		
Gracilinanus agilis (Burmeister, 1854)	X		X			
Marmosa murina (Linnaeus, 1758)	X	X	X	X		
Marmosa demerarae (Thomas, 1905)	X	X				
Metachirus nudicaudatus (É. Geoffroy, 1803)	X	X				
Philander opossum (Linnaeus, 1758)	X	X		X		X
Cricetidae						
Calomys tocantinsi Bonvicino, Lima & Almeida, 2003			X	X		
Holochilus sciureus Wagner 1842			X			
Hylaeamys megacephalus (Fischer, 1814)	X		X	X		
Oecomys sp.				X		
Oecomys roberti Thomas, 1904	X	X	X	X		
Oligoryzomys sp.			X	X		
Pseudoryzomys simplex Hershkovitz, 1962				X		
Rhipidomys ipukensis Rocha, Costa & Costa, 2011					X	

X – Recorded species; O – Accidental capture of a single individual; a(b): a = total number of species; b = unique species. * – a single individual was captured in a preliminary sampling in a Sherman trap but was not captured again, during the study.

Table 2 cont. Species recorded by method, with reference to class/method totals. The numbers of species, per class and total, recorded by only one method are given between parentheses

		Method					
Species		**Sherman trap**	**Tomahawk trap**	**30 L pitfalls**	**60 L pitfalls**	**Pipetrap**	**Active search**
Mammalia							
Echimyidae							
Makalata didelphoides (Desmarest, 1817)		X	X		X		
Proechimys roberti Thomas, 1901		X	X				
Class totals	*18*	*11*	*10*	*9(1)*	*11(2)*	*2(1)*	*1*
Total	**65**	**19**	**14**	**34(1)**	**36(3)**	**13(3)**	**43(13)**

X – Recorded species; O – Accidental capture of a single individual; a(b): a = total number of species; b = unique species. * – a single individual was captured in a preliminary sampling in a Sherman trap but was not captured again, during the study.

differences between Sherman and Tomahawk traps, in terms of small mammal species richness. However, pitfalls recorded a significantly higher value of species richness for small mammal, relatively to live traps. Perceived species richness (S = 9.8) for

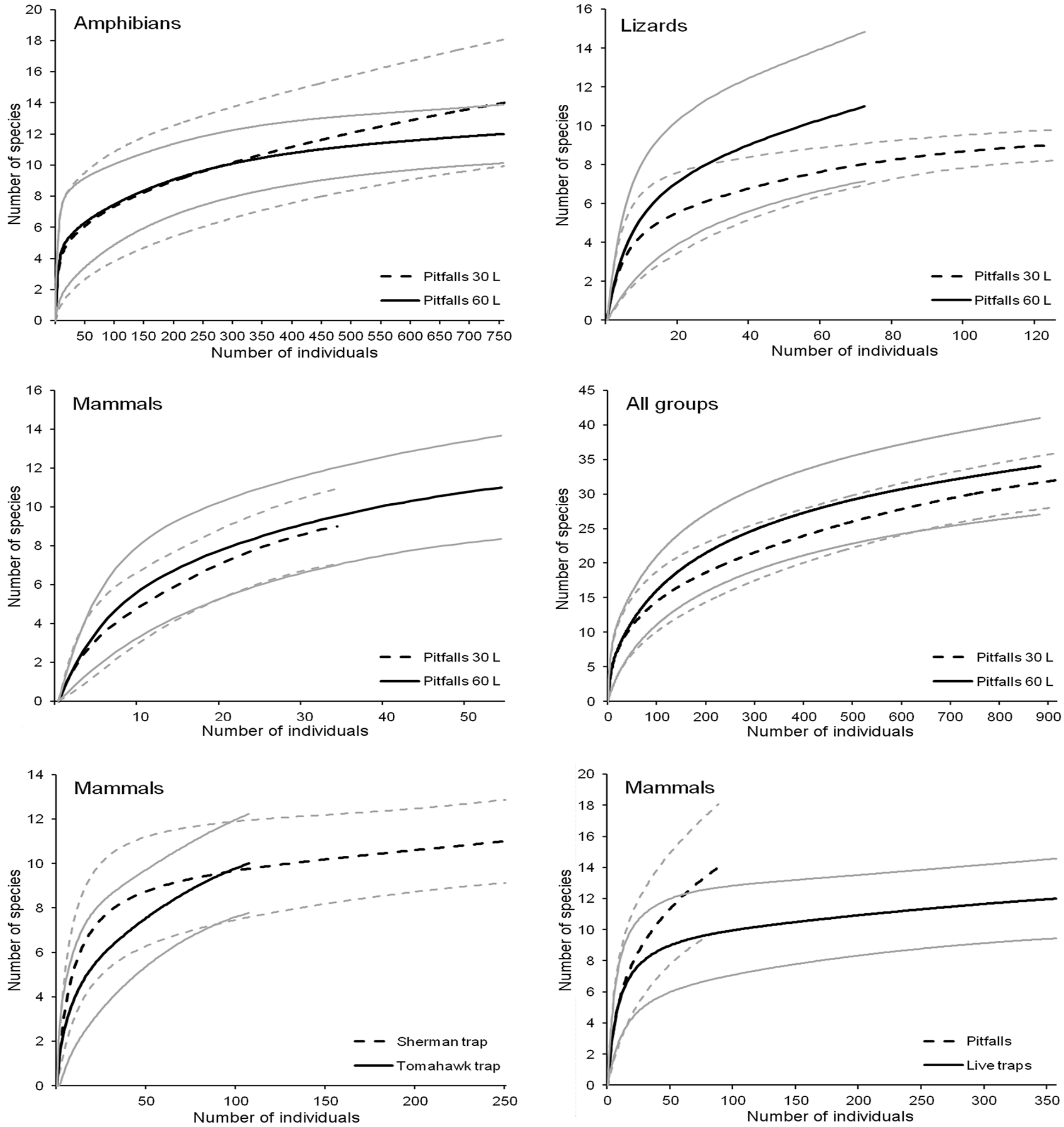

Figure 2 Individual based rarefaction curves for amphibians, lizards and mammals captured in 30 L and 60 L pitfalls, and for mammals captured in Sherman and Tomahawk traps. Gray lines represent 95% confidence intervals.

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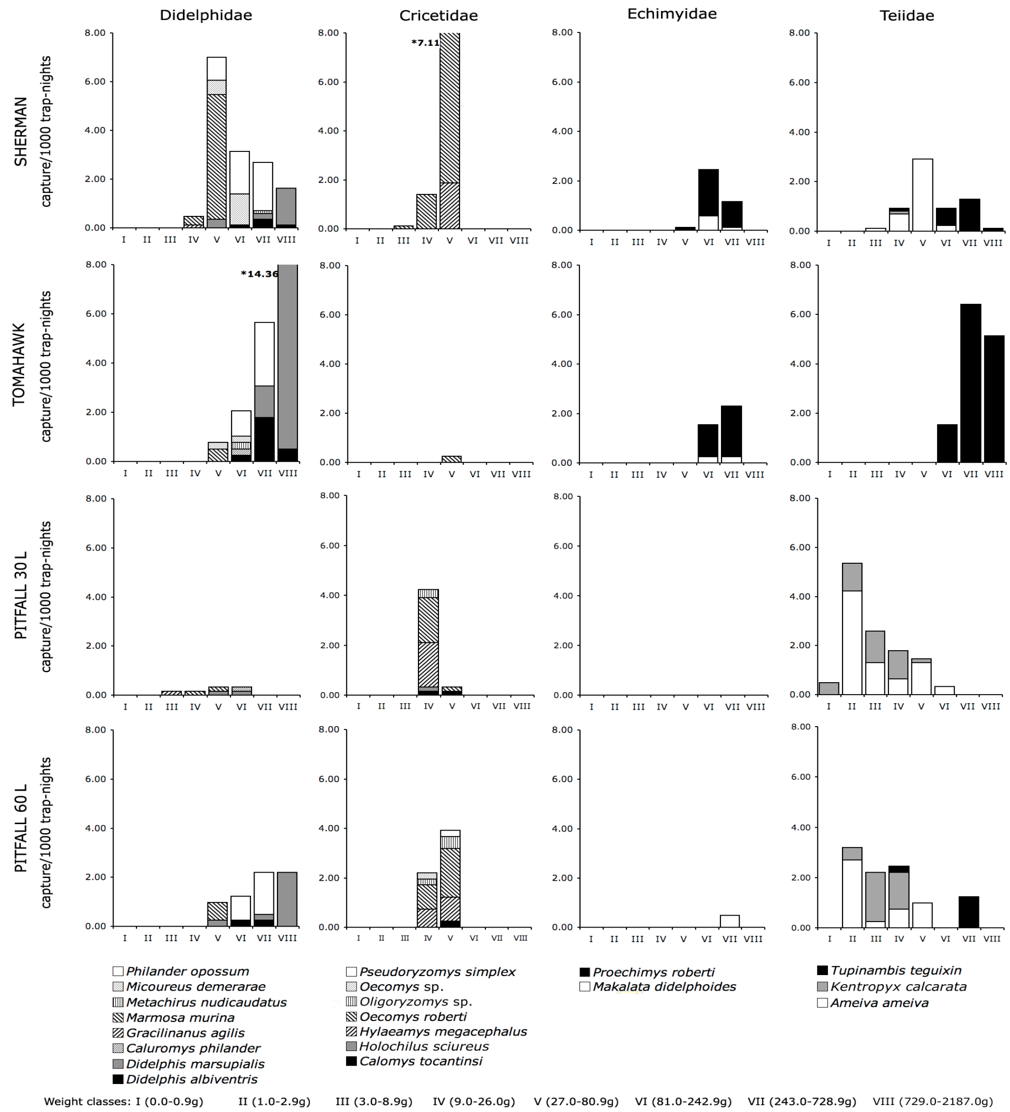

Figure 3 Capture rates (captures/1000 trap-nights) for all families recorded by all methods under comparison, presented by weight class. Species are identified by shades of grey and black and white patterns. Asterisks stand for off-scale values – actual capture rates for these two species are shown at the side of the bar.

live traps (n = 88), was below the lower bound of the 95% confidence interval (9.94) for pitfalls.

Graphical analysis

All small mammal families (Didelphidae, Cricetidae and Echimyidae) and one lizard family (Teiidae) were consistently recorded in live traps and pitfalls (Figure 3). With exception to some infrequent captures in live traps, other lizard or amphibian families were only captured in pitfalls (Figure 4). Small teiid species were mainly captured in pitfalls. *Ameiva ameiva* was also frequently captured in Sherman traps. *Tupinambis teguixin,* the largest species of the family occurring in the area, was almost exclusively captured in Tomahawk traps. Large didelphids were mainly captured in Tomahawk traps and, to a lesser extent, in Sherman traps and 60L pitfalls. Small didelphid species, such as *Marmosa murina,* were mainly captured in Sherman traps. Large cricetids were captured more frequently in Sherman traps and 60 L pitfalls. Small cricetids were mainly captured in pitfalls, particularly in the larger ones. Echimyids were almost only captured in live traps.

Capture rates for amphibian taxa were consistently higher for 60 L pitfalls, but both pitfalls captured individuals within the same weight-range. Families Leiuperidae, Leptodactylidae and Microhylidae were the major contributors to the observed capture rates. One or two species per family – *Pseudopaludicola mystacalis* (Leiuperidae) and *Physalaemus cuvieri* (Leiuperidae), *Leptodactylus leptodactyloides* (Leptodactylidae) and *Elachistocleis ovalis* (Microhylidae) – accounted for most of the captures, with a large proportion of juveniles in the latter three species. For lizard taxa, 30L and 60 L also captured individuals within the same weight-range.

Odds-ratio comparisons among traps

Heterogeneity estimates for odds-ratio analysis, using the inconsistency index (I^2) were: 67.0% (among pitfalls), 90.0% (among live-traps) and 97.0% (between pitfalls and live-traps). Heterogeneity among independent estimates (families) was generally high. Therefore, we used a random model to estimate the pooled odds-ratios. For overall comparisons (Figure 5), combined odds-ratio was only significantly different from 1 in the pair 60 L/30 L pitfalls

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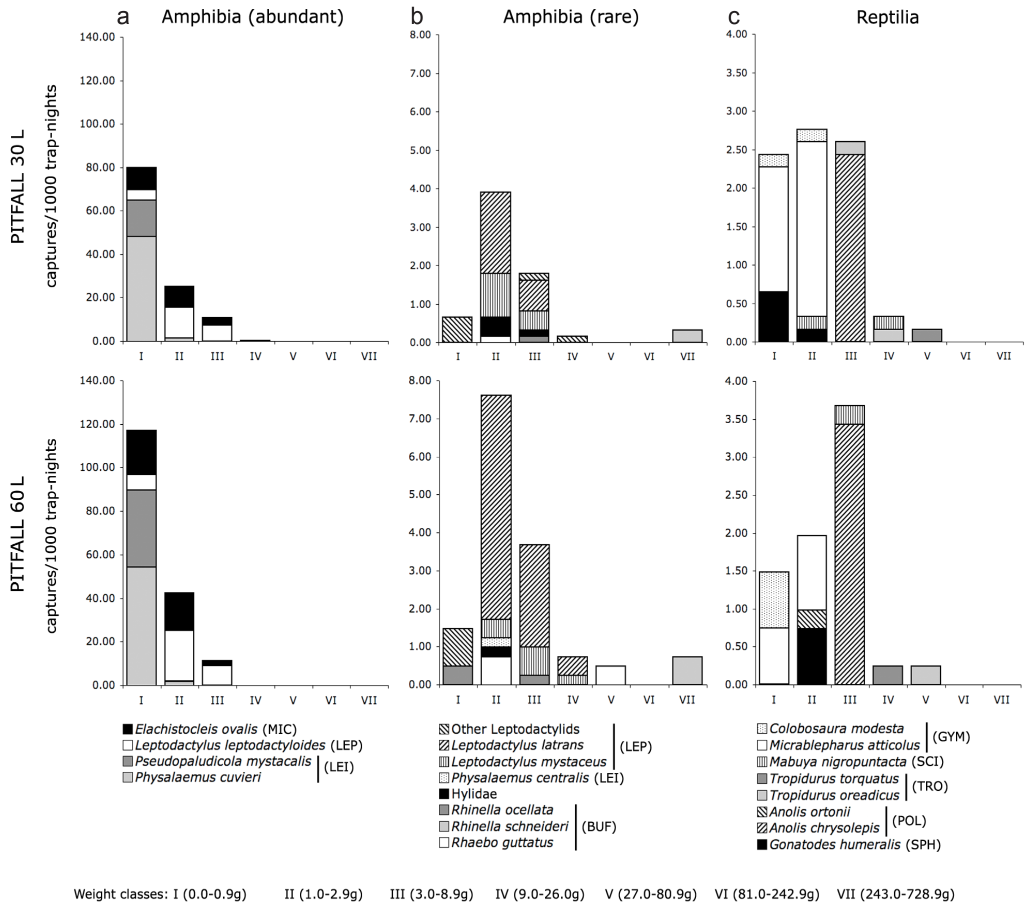

Figure 4 Capture rates (captures/1000 trap-nights) for families recorded only in pitfalls, presented by weight class: **a**) abundant amphibian species; **b**) rare amphibian species; **c**) lizard species. Species are identified by shades of grey and black and white patterns. BUF – Bufonidae; SPH – Sphaerodactylidae; GYM – Gymnophthalmidae; LEI – Leiuperidae; LEP – Leptodactylidae; MIC – Microhylidae; POL – Polychrotidae; SCI – Scincidae; TRO – Tropiduridae.

(odds-ratio = 1.50, 95% CI = 1.19–1.88), where we can state that capture odds for 60 L pitfalls were about one and a half times greater than the odds for 30 L pitfalls. In familial comparisons between pitfalls of different size, capture odds were significantly greater in 60 L than in 30 L pitfalls for the families Bufonidae (5.15, 1.82–17.87), Leiuperidae (1.43, 1.23–1.66), Leptodactylidae (1.62, 1.32–1.99), Microhylidae (1.65, 1.31–2.08) and Didelphidae (7.34, 2.99–21.65). Capture odds were significantly greater in Sherman traps than in Tomahawk traps for Cricetidae (42.27, 7.39–1687.94), and significantly greater in Tomahawk traps than in Sherman traps for Teiidae (0.50, 0.33–0.74). Capture odds were significantly greater in live traps for Didelphidae (4.43, 3.09–6.54) and Echimyidae (16.33, 4.27–138.85); and significantly greater in pitfall traps for Teiidae (0.59, 0.45–0.76).

Trap-habit behaviour in pitfalls

Small mammals were recaptured in pitfalls, on average, more often during the dry season (0.71 ± 0.90, n = 21) than in the end of the rainy season (0.46 ± 0.64, n = 21) or in the beginning of the following rainy season (0.04 ± 0.19, n = 21). We tested for the significance of these differences and found that the average number of recaptures was significantly higher in the dry season relatively to the end of rainy season (Welch's *t*-test, t = -3.9179, df = 29.4, p = 0.0002) but not relatively to the beginning of the following dry season (t = 1.2025, df = 54, p =0.1172). However, the average number of recaptures during the beginning of rainy season was also significantly higher than during the end of the rainy season (Welch's *t*-test, t = -3.4118, df = 31.7, p = 0.0009).

Discussion

Trap effectiveness

In terms of capture rates, the only significant difference at the global level is between 30 L and 60 L, with the latter capturing significantly more individuals from all groups. The difference in capture rates between pitfalls was strongly influenced by the captures of three amphibian families (Leiuperidae, Leptodactylidae and Microhylidae) which collectively represent more than 80% of the captures in both pitfall sizes. Species from genus *Physalaemus*, *Leptodactylus* and *Elachistocleis* are known to present explosive breeding behaviour and tend to be gregarious in early stages of life (Barreto and Andrade 1995, Rodrigues *et al.* 2003, Brasileiro *et al.* 2005), and this is probably the reason for the observed high capture rate for juveniles of these species that influenced these result. Moreover, this difference between pitfalls is probably due to the ability to escape from smaller buckets. The fact that some amphibians are able to escape from buckets was

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Table 3 Costs and effort associated with pitfalls and live traps (based on authors' data) and some advantages and disadvantages related with the use of each method.

Trap type	N traps /array	Cost (USD)			Installation Effort (person.day)		Checking Effort (person.minute)		Habitat perturbation during installation	Some advantages	Some disadvantages
		Trap	Drift-fence (5m)	Array	Trap	Array	Trap	Array			
Sherman trap	22	44.9	-	988	0.012	0.264	1.00	22.0	minimal	• installation not physically very demanding; • Easy to change trap location.	• need to be baited every 2 or 3 days; • advisable to remove traps at the end of each sampling period.
Tomahawk trap	10	40.4	-	404	0.012	0.120	1.00	10.0			
Pitfall 30 L	16	7.2	1.7	141	0.078	1.25	0.75	12.0	substantial	• no need for bait; • can be left in the field between sampling periods.	• installation is physically very demanding; • possible need to remove water after heavy rain (rainy season) or to carry water to put in the buckets (dry season); • many non-target captures.
Pitfall 60 L	10	9.2	1.7	107	0.125	1.25	0.75	7.5			

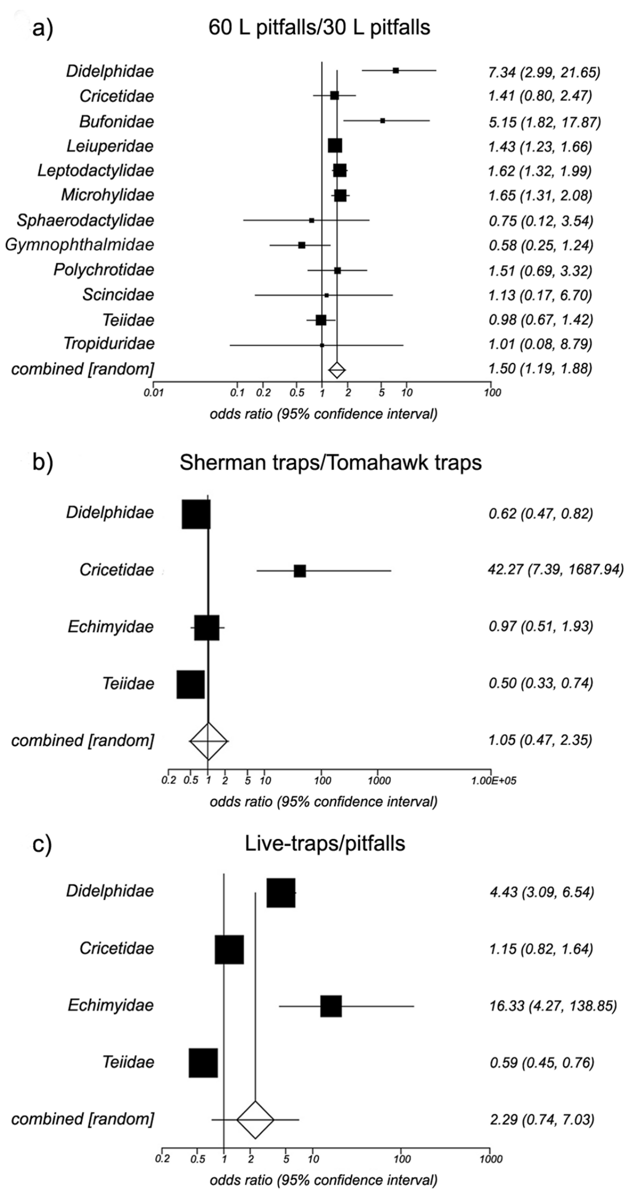

Figure 5 Results from odds-ratio pairwise meta-analysis: 60 L pitfalls versus 30 L pitfalls (a); Sherman traps versus Tomahawk traps (b); live-traps versus pitfall traps (c). Black solid squares represent ratios for each family; open rhombuses represent combined ratios and horizontal lines indicate 95% confidence intervals. Values are presented in the right side of the graphs. Size of squares is proportional to contribution of each family to combined ratios

reported in a recent study on the efficiency of different types of pitfalls (Ribeiro-Júnior *et al.* 2011).

Live traps were significantly more successful in capturing individuals of two families (Didelphidae and Echimyidae). The difference in capture rates between pitfalls and live traps for didelphids and echimyids is probably related with the large size and ability to jump of several species, which allow them to escape from pitfalls. Cricetids, on the other hand, are smaller and cannot escape so easily. This suggestion as been made several times by other authors (Lyra-Jorge and Pivello 2001, Hice and Schmidly 2002, Thompson *et al.* 2005, Umetsu *et al.* 2006) and is supported , in this study, by the fact that the largest didelphids and echimyids were rarely caught on pitfalls, and when it occurred it was only on 60 L pitfalls.

In what refers to species richness, there were no significant differences between 30 L and 60 L pitfalls, for any of the vertebrate groups. Ribeiro-Júnior and collaborators (2011) found significant differences in species richness for small mammal species (but not herpetofauna) in comparisons between 35 L, 62 L and 100 L pitfall, but only for 100 L pitfalls. Despite the lack of differences between 30 L and 60 L pitfalls, when pooled together and compared against live traps, pitfalls recorded significantly more mammal species, which is in agreement with the results from previous studies (Umetsu *et al.* 2006, Caceres *et al.* 2011). Considered separately, Sherman and Tomahawk traps recorded 15 and 19 species of all groups, respectively. Also considered separately, pitfalls appear to have done better by recording between 34 (30 L) and 36 species (60 L). This is not a surprising result because pitfalls are much less selective than live traps, which were design for capturing small mammals, and also revealed to be suitable for teiid lizards. Teiids are active foragers that use mainly chemical signals for prey capture and discrimination (Cooper 2007), and it is likely that they were attracted to bait in live traps, like mammals.

Our results suggest that despite the low number of species uniquely recorded by pitfalls (six species) and live traps (three species) these methods complement each other. However, the number of species recorded by pitfalls and live traps is only about

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two thirds of the total number of species that we recorded during this study. Altogether, additional methods (active search and pipe traps) increased by 21 the number of recorded species. A large portion of this increase results from the capture of tree frogs, which are not expected to be captured in pitfalls and live traps. Other species would be suitable candidates to be recorded in pitfalls or live traps, and were not. An example is the climbing rat *Rhipidomys ipukensis*, which turned out to be a new species (Rocha *et al.* 2011), and was recorded only in a pipe trap, during this study. Other species not captured by pitfalls were habitat specialists like *Gymnodactylus amarali*, which lives in close association with termite mounds and rarely leaving them (Vitt *et al.* 2007). Pitfalls also failed to capture several leaf-litter or ground-dwelling anurans from several families such as *Chiasmocleis albopunctata*, *Haddadus* sp., *Rhinella granulosa*, *Leptdactylus fuscus* or *L. labyrinthicus*. Therefore, despite a combination of live traps and pitfalls could adequately sample the small mammal assemblage, it is not suitable for integrated studies that also target herpetofauna. Based on these findings, we suggest that the use of several methods is critical for adequately sampling herpetofauna, concurring with the conclusions from previous studies (Greenberg *et al.* 1994, Crosswhite *et al.* 1999, Ribeiro-Júnior *et al.* 2008, Hutchens and DePerno 2009).

Trap-habituation in pitfalls

During this study, didelphids almost systematically presented the highest recapture rates, suggesting the existence of trap-habituation behaviour. While this behaviour is frequently referred in literature for live traps (Sealander and James 1958, Woodman *et al.* 1996, Umetsu *et al.* 2006), we found no references in literature that related trap-happy behaviour to pitfalls.

Moreover, we observed differences in the recapture rates of mammals (73% of which were didelphids) between the sampling seasons. The recaptures were significantly higher in the driest sampling period, when compared with the wettest one. Despite not all differences being significant, there is a clear increase in recapture rates with increasing drought. The rate is lower (0.04 ± 0.19) in the end of the rain season (when there are still some rainy days), intermediate (0.46 ± 0.64) in the beginning of the following rainy season (when rain is just beginning to pour) and higher (0.71 ± 0.90) during the peak of the dry season.

Two possible explanations for this trap-habituation behaviour include: either the animals were entering the pitfalls because of the water that we placed there (see methods section) or they were researching for food, i.e. the animals trapped inside the pitfalls. The most commonly recaptured species were *Didelphis marsupialis* and *Philander opossum*, and both species commonly include arthropods in their diet (Emmons and Feer 1997). It is possible that, in response to the seasonal scarcity of fruits, seeds and arthropods in this region (Vieira 2003), these individuals found a suitable source of food inside the pitfalls. However, because food is still scarce in the beginning of the rainy season, it would be expected that recapture rates should remain high in this period, which they don't. The difference between this period and the dry season was not significant but it was conspicuous. This suggests that the most likely explanation is that it was water, not food, which was attracting mammals into the pitfalls. It is also worth to refer that several captures recorded in the beginning of the rainy season did occur prior to the first rains.

Effort, cost and efficiency

This study addresses the issue of the effectiveness of different capture methods. This means that the aim was to check how many species would be captured and how frequently it would occur. Despite the relevance of these results for planning biodiversity surveys, monitoring programs or rapid assessment studies, researchers are frequently concerned with the efficiency of methods. The efficiency might be based in criteria different from captures per sampling effort. These criteria can be, for example, monetary cost, time consumed, physical effort or the level of expertise (Ribeiro-Júnior *et al.* 2008, Hutchens and DePerno, 2009).

Many of these criteria will be given different weight by different authors and their values will certainly vary from one region to another. However, we here present (Table 3) the estimated costs, installation and checking effort (based on personal experience), and refer some advantages and disadvantages related with the use of pitfalls and live traps. We will not combine this analysis with the effectiveness of each method, but we provide it to allow the reader to weight the costs and benefits of each method and thus obtain an estimate of efficiency. As an example, we could refer the much higher cost of live traps relatively to pitfalls, or the greater physical effort of installation of the latter, relatively to live traps. We did not quantify the effort or the costs of active search or pipe-traps, because they were not central in this paper. However, we would say that active search would present low monetary cost. On the other hand, this method would demand a greater level of experience (Ribeiro-Júnior *et al* 2008). Pipe traps will demand an initial investment in raw materials but, after installation, the maintenance effort is minimal and monitoring of pipes does not request expertise. These traps can be placed in the field, combining a set of environmental or micro-habitat conditions and be used in ecological studies (e.g. Johnson *et al.* 2008, Pittman *et al.* 2008, Ferreira *et al.* 2012).

There is a growing need for conducting integrated biodiversity surveys at a large geographical scale, to serve as basis for land-use and conservation planning (Costa and Magnusson 2010). In fact, ultimately, the aim of all biodiversity surveys is to produce datasets that can be used for such planning and this must be achieved in a coordinate way. Because of that, weighting the relation between costs and benefits becomes even more important, as well as other issues related with sampling effort or the scale, size or distribution of sampling units. In this sense, the results here presented will certainly be useful in the planning or validation of integrated approaches to biodiversity research, in this ecotonal region.

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Supplementary material - **Table S1** - Location and geographical coordinates of the sampling points

Sampling Point	Conservation Unit	Municipality	State	Latitude	Longitude
NA	PEC	Pium	TO	09°23'37.7"S	50°00'08.1"W
NB	PEC	Pium	TO	09°22'28.9"S	49°59'05.5"W
NC	APA	Caseara	TO	09°23'03.5"S	49°58'31.8"W
ND	PEC	Pium	TO	09°20'31.2"S	49°58'24.1"W
NE	PEC	Caseara	TO	09°18'13.0"S	49°57'31.1"W
CA	FSF	Santana do Araguaia	PA	09°37'35.0"S	50°09'11.5"W
CB	FSF	Santana do Araguaia	PA	09°37'48.7"S	50°08'38.9"W
CC	PEC	Pium	TO	09°30'08.3"S	50°05'35.0"W
CD	PEC	Pium	TO	09°28'09.5"S	50°05'54.6"W
CE	PEC	Pium	TO	09°28'24.8"S	50°05'32.3"W
SA	APA	Pium	TO	09°58'38.0"S	50°02'00.0'W
SB	PEC	Pium	TO	09°58'43.6"S	50°02'33.9"W
SC	PEC	Pium	TO	09°58'11.2"S	50°04'07.2"W
SD	PEC	Pium	TO	09°58'17.1"S	50°05'43.6"W
SE	PEC	Pium	TO	09°57'40.5"S	50°06'56.1"W
CP1	FSF	Santana do Araguaia	PA	09°43'37.7"S	50°10'52.8"W
CP2	FSF	Santana do Araguaia	PA	09°40'52.3"S	50°09'29.1"W
CT1	PEC	Pium	TO	09°44'36.2"S	50°10'30.4"W
CT2	PEC	Pium	TO	09°39'14.3"S	50°08'09.8"W
CI	PEC	Pium	TO	09°42'36.5"S	50°08'42.2"W

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