Pitfall trap efficiency in sampling small vertebrates (Anura, Squamata, and Mammalia) in fragments of the Southeastern Atlantic Forest, Brazil

Eficiência de armadilhas *pitfall* na amostragem de pequenos vertebrados (Anura, Squamata e Mammalia) em fragmentos no sudeste da Floresta Atlântica, Brasil

Michel Varajão Garey[I] | Marcelo José Sturaro[II] |
Gabriel Spanghero Vicente Ferreira[III] | Vinicius Xavier da Silva[IV]

[I]Universidade Federal da Integração Latino-Americana. Instituto Latino-Americano de Ciências da Vida e da Natureza. Foz do Iguaçu, Paraná, Brasil

[II]Universidade Federal de São Paulo. Instituto de Ciências Ambientais. Diadema, São Paulo, Brasil

[III]Universidade Estadual de Campinas. Programa de Pós-Graduação em Ecologia. Campinas, São Paulo, Brasil

[IV]Universidade Federal de Alfenas. Instituto de Ciências da Natureza. Alfenas, Minas Gerais, Brasil

Abstract: Pitfall traps are a sampling method broadly used in studies with small terrestrial vertebrates. In this paper, we compared the efficiency of modified pitfall traps in sampling anurans, squamates, and mammals. In two forest fragments of the Seasonal Semi-deciduous Atlantic Forest, we set up 26 arrays of drift fences and pitfall traps, composed of four 30-liter buckets, each set up arranged in a 'Y' shape linked by a fence of 4 m in length and 0.5 m in height. We tested for the effect of an internal rim on the border of the buckets by comparing buckets with and without a rim on capture efficiency. In general, we did not observe any effect of the rims in capture efficiency, independently of the bucket position where the rim was present. Still, terminal buckets with rims were less efficient in capturing rodents. We hypothesized that the use of buckets with rims did not increase the capture of small vertebrates due to the animal's ability to perceive the rim due to substrate instability. However, the pitfall trap efficiently captures small vertebrates, and we do not recommend using the internal rims.

Keywords: Amphibians. Lizards. Mammals. Sampling method. Snakes.

Resumo: Armadilhas de interceptação e queda é um método de amostragem amplamente utilizado em estudos com pequenos vertebrados terrestres. Neste artigo, comparamos a eficiência de armadilhas de interceptação e queda modificadas na amostragem de anuros, squamatas e mamíferos. Em dois fragmentos de Floresta Estacional Semidecidual na Mata Atlântica, foram instalados 26 conjuntos de cercas e armadilhas de interceptação e queda, compostas por quatro baldes de 30 litros, cada conjunto disposto em forma de 'Y', ligados por uma cerca de 4 m de comprimento e 0,5 m de altura. Testamos o efeito da presença de um aro interno na borda dos baldes, comparando baldes com aro e sem aro na eficiência de captura. Em geral, não foi observado nenhum efeito dos aros na eficiência de captura, independentemente da posição dos baldes onde o aro estava presente. Ainda assim, baldes terminais com aros foram menos eficientes na captura de roedores. Hipotetizamos que o uso dos aros nos baldes não aumentou a captura de pequenos vertebrados devido à capacidade do animal de discernir o aro ao perceber instabilidade do substrato. Ainda que a armadilha de interceptação e queda seja um método eficiente para capturar pequenos vertebrados, não recomendamos o uso de bordas com aros.

Palavras-chave: Anfíbios. Lagartos. Mamíferos. Método de amostragem. Serpentes.

Garey, M. V., Sturaro, M. J., Vicente-Ferreira, G. S., & Silva, V. X. (2023). Pitfall trap efficiency in sampling small vertebrates (Anura, Squamata, and Mammalia) in fragments of the Southeastern Atlantic Forest, Brazil. *Boletim do Museu Paraense Emílio Goeldi. Ciências Naturais*, *18*(3), e2023-e893. http://doi.org/10.46357/bcnaturais.v18i3.893

Autor para correspondência: Michel Varajão Garey. Universidade Federal da Integração Latino-Americana. Tarquínio Joslin dos Santos, 1000. Foz do Iguaçu, PR, Brasil. CEP 85870-901 (michelgarey@gmail.com).

Recebido em 05/01/2023
Aprovado em 12/11/2023
Responsabilidade editorial: Adriano Oliveira Maciel

INTRODUCTION

Pitfall traps are frequently used in worldwide ecological studies to capture a variety of ground-dwelling animals, e.g., invertebrates and vertebrates, such as spiders (e.g., Privet et al., 2020), grasshoppers (e.g., Szinwelski et al., 2012), harvestmen and millipedes (e.g., Stašiov et al., 2021), amphibians (e.g., Fiorillo et al., 2018), squamates (e.g., Menezes et al., 2018), and mammals (e.g., Edwards & Jones, 2014; Palmeirim et al., 2019). Pitfall traps are buckets buried in the ground that can be linked by drift fences (Corn, 1994). Strait-line drift fences are usually used for terrestrial vertebrates and function as barriers that intercept and guide animals moving in the environment to fall into buckets (Cechin & Martins, 2000). This method is useful for long-term monitoring, as it can be left closed on the ground during non-sampling periods (Corn, 1994). Moreover, it has advantages in capturing seldom sampled animals (Campbell & Christman, 1982; Palmeirim et al., 2019), and many areas can be sampled simultaneously, reducing temporal-related variation activity (Bury & Corn, 1987). On the other hand, animals that are good climbers, jumpers, and/or relatively large to escape are not adequately sampled using this trap technique (Dodd Jr., 1991; Ali et al., 2018).

The capture success is influenced by species-specific factors, including morphology, home range, and diel activity period (Crosswhite et al., 1999; Ali et al., 2018), but also by environmental factors, such as climatic variables (e.g., temperature and precipitation – Bury & Corn, 1987; Enge, 2005; Todd et al., 2007; Spence-Bailey et al., 2010). In complex structural habitats, such as rainforests, these factors are often inflated due to high ecological and morphological diversity. The Atlantic Forest exhibits considerable structural heterogeneity, thus leading to noteworthy levels of species diversity and functional variety among terrestrial vertebrates. The Atlantic Forest contains approximately 320 species of mammals, 300 species of reptiles, and 600 anurans (there is no representative of Caudata) (Monteiro-Filho & Conte, 2017). Indeed, the highest richness and endemism of anurans from Brazil are also in the Atlantic Forest (Rossa-Feres et al., 2011). Where the highest species diversity and morphological and ecological characteristics are concentrated, there is a need to reinforce the design and evaluate different methods to capture vertebrates and improve our sampling capacity.

Some studies have provided information regarding the efficiency of pitfall traps in tropical forests (e.g., Ribeiro-Júnior et al., 2008; Santos-Filho et al., 2015); however, studies that propose alternative modifications to the traditional pitfall trap method are almost absent (Greenberg et al., 1994). Therefore, studies aiming to propose modifications to the traditional pitfall trap structure are important to maximize the sampling efficiency of capturing animals that can escape from the trap. We proposed to evaluate the efficiency of an additional obstacle adjacent to the edge of the buckets, focusing on the capture and trapping of anurans, squamates, and small mammals. We hypothesized that the use of an internal rim would increase the pitfall efficiency by preventing individuals from escaping.

MATERIALS AND METHODS

STUDY AREA

The study was conducted in the *Reserva Particular do Patrimônio Natural* (RPPN) *Fazenda Lagoa* (21° 23' S, 46° 15' W, 840 m.a.s.l.), located in the municipality of Monte Belo, southern State of Minas Gerais, southeastern Brazil (Figure 1). The region is inserted in the Atlantic Forest biome (Ab'Saber, 1977). According to the Köppen-Geiger climate classification (Peel et al., 2007), the climate of this region is Cwb (cold with day winter and temperate summer). The study site has been substantially modified by agriculture (Garey & Silva, 2010), with the reserve maintaining eight fragments of Seasonal Semi-deciduous Forest (*sensu* Morellato & Haddad, 2000). Seasonal Semi-deciduous Forests are characterized by two main seasons, one wet and warm from October to March and another dry and cold from April to September. Based on previous surveys at Fazenda Lagoa and in nearby areas, approximately

63 species of mammals (Laurindo et al., 2017), 16 reptiles (Sturaro & Silva, 2005), and 24 anurans (Garey & Silva, 2010) are recognized in the region.

SAMPLING DESIGN

We installed 26 arrays of pitfall traps in two fragments, one called Olaria Forest with 17 ha and the other as Lagoa Forest with 124 ha (Figure 1). An ecological corridor nearly entirely interconnects these forest fragments; jointly, they encompass an area of approximately 144 ha. In addition to variations in size and shape, the forest fragments exhibit distinctions arising from a lotic water body coursing through Lagoa Forest, whereas Olaria Forest lacks any lotic habitat.

We chose the areas to install the traps according to the natural conditions of the forest floor (presence of trees with a minimum of 15 m in height, slope lower than 30°, and at least 10 m apart from water bodies). The traps were installed in a 'Y' shape, with three terminal buckets and one central bucket (*n* = 104 plastic buckets) buried in the ground linked by plastic drift fences (Figure 2A). The plastic drift fence was 50 cm in height, and 4 m in length separating the terminal of the central bucket. The buckets were 30 L, with 40 cm in depth and 36 cm in diameter (Figures 2B and 2C). In every bucket, we made small orifices (1–2 mm in diameter) on the bottom to drain the water of rainfall (Cechin & Martins, 2000).

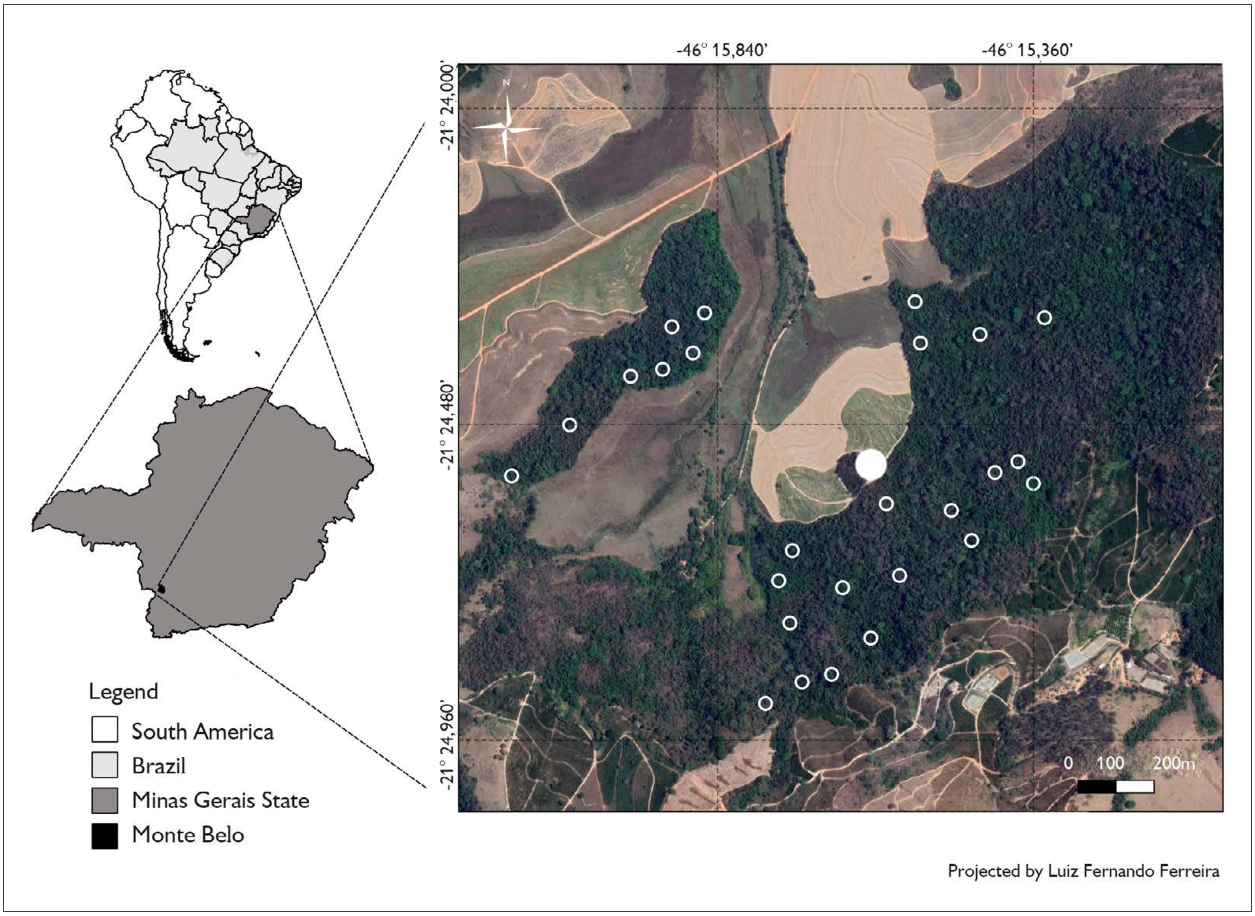

Figure 1. Map of the study area showing the South American countries and Brazilian states (light gray), State of Minas Gerais in dark gray. In detail, a satellite image displays the two forest fragments studied at Fazenda Lagoa, located in the municipality of Monte Belo. The circles on the map denote the positions of the pitfall traps.

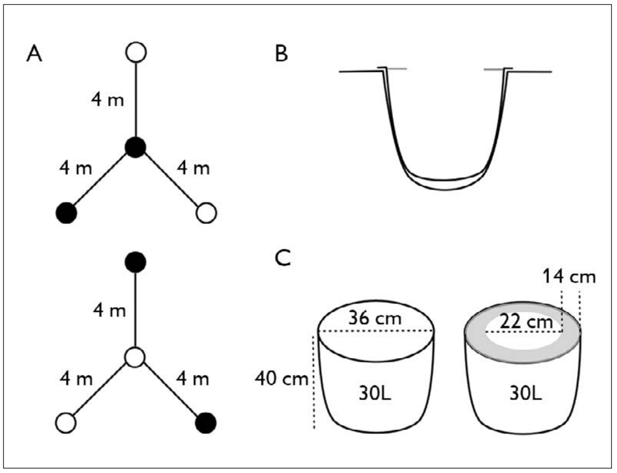

Figure 2. Representation of the pitfall trap used in the present study design. A) Scheme of the two sets of pitfall trap array ('Y' structure) - black circles represent the buckets with rims and the white circles, the buckets without rims, B) Lateral view of a bucket with rim, and C) perspective view of a bucket without rim and with rim and the dimensions comparing both types of buckets.

We installed rims on the bucket border to evaluate the effect on the abundance of anurans, squamates, and small mammals trapped. The internal rims were composed of plastic, fourteen centimeters in width, and were fixed with wire on the internal borders of buckets, reducing their diameter to 22 cm (Figures 2B and 2C). The pitfall arrays were divided into two groups with 13 traps each: in the first group, the internal rim was installed on the central and in one terminal bucket; in the second group, the internal rims were installed on two-terminal buckets (the black circles in Figure 2A represent rim). This design totalized 13 central buckets with rim, 13 central buckets without rim, 39 terminal buckets with rim, and 39 without rim. We chose this sampling design to exclude the possible effects of the variation in environmental heterogeneity among the areas where pitfalls were installed and to reduce the effects of species with aggregated distribution in capture rates.

Our study was conducted monthly between March 2004 and May 2005, except for June 2004, August 2004, and February 2005, when no sampling was performed due to logistical difficulties. The buckets remained closed all the time when we were not sampling. In each sampling month, buckets remained open up to six days in a row, totaling 32 days of sampling (2.5 ± 1.2 days per month). All pitfall traps were checked once a day (between 8 AM and 2 PM) to reduce the mortality rate. The captured anuran individuals were individually marked using a pelvic ring, constructed using a black polyester thread, adorned with a combination of one to three colored beads (Narvaes & Rodrigues, 2005), and released three meters away from the traps. This marking configuration allowed the individualized identification of the specimens. All captured mammals and some reptiles were released into the environment without individual marking. Thus, the same individual may have been captured more than one time. The recapture of the same individual only biases our results if the individual consistently has fallen into the same bucket within the same trap. However, since our sampling design encompassed buckets both with and without rims within the same trap and considering an equal probability of an individual moving to the right or left upon encountering the drift fence, we believe that specimen recaptures did not influence the capture rates between buckets with and without rims. Some trapped specimens of amphibians and reptiles were collected as voucher specimens of the study area. These specimens were anesthetized and euthanized with a solution of 5% benzocaine, fixed (formalin 10%), preserved (ethanol 70%), and deposited in the collection of the *Coleção Herpetólogica Alfred Russel Wallace* (CHARW), *Universidade Federal de Alfenas*, municipality of Alfenas, in the state of Minas Gerais, Brazil.

STATISTICAL ANALYSIS

All analyzes were performed in R software with RStudio (R Development Core Team, 2017), while the graphics were made in the Windows version of GraphPad Prism (version 9.0.0, GraphPad, n. d.). Before evaluating the effect of the rims on the pitfalls, we verified the normality of the data using the Shapiro-Wilk test and data homoscedasticity by Levene's test, assuming a significance level of 0.05. We square rooted data with non-normal distribution to better fit. To evaluate the efficiency of the rims, we compared the average abundance of individuals captured in the pitfall buckets with and without rims.

Analyses were conducted using two approaches. First, we adopted the General Linear Model (GLM) in the two-factor repeated measures ANOVA design using the *ez* package (v4.4; Lawrence & Lawrence, 2016). We evaluated the effect of different combinations of predictors on the overall abundance sampled, thus checking the effects of months evaluated, rim presence, and the interactions between months and rims on individuals captured (dependent variables). Following our sampling design, our measurements were not temporally independent (i.e., pseudo-temporal replicate). Therefore, we incorporated time (i.e., month) as a factor that could account for the variation in capture rates between buckets with and without rims. Afterward, we implemented a *t-test* or Wilcox test (if data was not homoscedastic) to compare the number of individuals captured between buckets with and without internal rims in two separate analyses: one with only the terminal buckets and only central buckets. Additionally, we evaluated the efficiency of the buckets with rims by individualized taxa order: Anura, Squamata, Rodentia, and Didelphimorphia. Moreover, we conducted separate analyses for the frog *Physalaemus cuvieri* Fitzinger, 1826 because of its high abundance among the trapped Anura species. We assumed an alpha of 5% in all hypothesis tests.

We assumed an equal probability for the animal to go to the right or left after encountering the drift fence (Enge, 2001). Hence, the probability of capturing with radial buckets was three times greater than the central buckets. For that reason, we did not compare the radial and central buckets' efficiency, thus focusing strictly on the effects of the rims. Animals that died inside the traps were not included in the analyses to avoid sampling bias, i.e., animals with climbing abilities could have escaped if they had not died.

RESULTS

The trapping effort totalized 13,056 hours by trap, and the average days of operation of pitfalls were 21 (range: 12–32 days). In total, we captured 676 individuals, consisting of 171 from the Anura order (13 species, six families), 11 from Squamata (five lizard species and one snake species, from five families), and 494 mammals from Rodentia and Didelphimorphia orders (unidentified species) (Table 1). The capture rate was 0.211 specimens/bucket/day overall, 0.16 for mammals, 0.05 for amphibians and 0.003 for squamates. Representatives of mammals, order Didelphimorphia and Rodentia together, were the most abundant (Rodentia = 71.4% of the total captured, Didelphimorphia = 1.6%). Anura was the second order of most captured animals (25.2%), and *Physalaemus cuvieri* was the most captured species (10.6% of the total and 42.1% of the anurans captured). Squamata was the least captured group (1.6%), with *Enyalius perditus* (45.4 % of Squamata) the most captured species.

The use of rims did not improve efficiency in sampling medium-sized animals (Figure 3). Buckets with rims, independently from the position of the rims and taxonomic group, did not increase the number of individuals trapped (Table 2, Figure 3). Abundance varied accordingly to month as expected due to seasonality, but it was independent of rim being present or absent. However, the interaction between the month and the presence of the rim did not explain the difference in the number of individuals trapped (Table 2). Moreover, when comparing only the central buckets, the abundance of total animals trapped was not different accordingly to the presence of rims (t-test; $P = 0.89$). The same pattern was observed for each separated taxonomic group (See Table 3 for the results of individualized groups). On the other hand, when comparing only the terminal buckets, we found that the presence of rims reduced the efficiency by 34.3% (Figure 3) in capturing individuals of Rodentia (t-test; $P = 0.01$). For all other taxonomic groups and all groups together, the presence of rims did not relate to the abundance of individuals trapped on central buckets (Table 3).

Table 1. Individuals of the orders Anura, Squamata, Rodentia and Didelphimorphia collected in pitfall traps at the RPPN Fazenda Lagoa, municipality of Monte Belo, Minas Gerais, Brazil. Legendas: CR = central bucket with rim, CNR = central bucket without rim, TR = terminal bucket with rim, TNR = terminal bucket without rim.

Taxon	Family	Species	N (total)	CR	CNR	TR	TNR
Anura	Brachycephalidae	*Ischnocnema juipoca* (Sazima & Cardoso, 1978)	2	0	0	2	0
	Bufonidae	*Rhinella icterica* (Spix, 1824)	18	6	1	7	4
		Rhinella crucifer (Wied-Neuwied, 1821)	23	2	4	6	11
		Rhinella diptycha (Cope, 1862)	13	4	4	2	3
	Craugastoridae	*Haddadus binotatus* (Spix, 1824)	4	0	1	1	2
	Cycloramphidae	*Odontophrynus asper* (Philippi, 1902)	2	0	1	0	1
		Odontophrynus cultripes Reinhardt & Lütken, 1862	22	3	5	6	8
		Proceratophrys boiei (Wied-Neuwied, 1824)	1	0	1	0	0
	Leiuperidae	*Physalaemus cuvieri* Fitzinger, 1826	72	15	19	22	16
	Leptodactylidae	*Adenomera bokermanni* (Heyer, 1973)	3	0	2	1	0
		Leptodactylus fuscus (Schneider, 1799)	1	0	1	0	0
		Leptodactylus mystacinus (Burmeister, 1861)	2	1	0	0	1
	Microhylidae	*Elachistocleis cesarii* (Miranda-Ribeiro, 1920)	4	1	0	2	1
Subtotal			171	35	39	50	47
Squamata	Colubridae	*Elapomorphus quinquelineatus* (Raddi, 1820)	1	0	0	0	1
	Leiosauridae	*Enyalius perditus* Jackson, 1978	5	1	0	3	1
		Urostrophus vautieri Dúmeril & Bibron, 1837	1	0	0	1	0
	Gymnophthalmidae	*Heterodactylus imbricatus* Spix, 1825	1	1	0	1	0
	Scincidae	*Notomabuya frenata* (Cope, 1862)	1	0	0	1	0
	Teiidae	*Salvator merianae* Duméril & Bibron, 1839	1	0	0	0	1
Subtotal			11	2	0	6	3
Rodentia			483	83	86	116	198
Didelphimorphia			11	4	0	3	4
Total			676	158	164	230	302

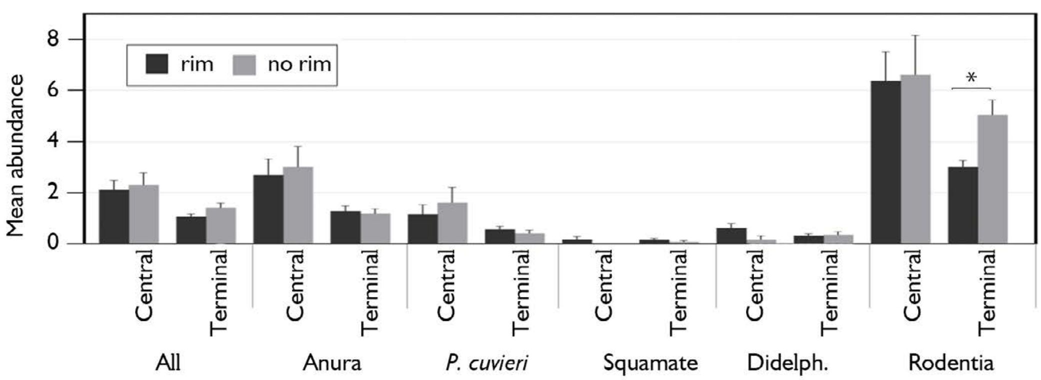

Figure 3. Mean abundance ± standard error (SE; vertical lines) of the animals sampled in the central and terminal buckets, with and without the internal rims for all individuals trapped and by taxonomic group. Black bars = buckets with rims; gray bars = buckets without rims.

Table 2. Data of Repeated Measures ANOVA expressed in degrees of freedom, the sum of squares in the numerator, F ratio, and P-value of the total abundance of individuals captured by month and the type of bucket used (with and without internal rims). Asterisk indicate interaction term. Bold values highlight statistical significance.

	df	SSn	*F*	*P*
Month	8	41.75	11.06	**0.01**
Rim	1	0.63	0.93	0.34
Month* Rim	8	3.40	1.30	0.24

Table 3. T-test results comparing the presence and absence of rims on the abundance of specimens captured depending on bucket position and taxonomic group. Bold values highlight statistical significance.

Group	df	*t*	*P*
Central			
All	121.43	-0.12	0.89
Anura	22.45	-0.29	0.76
Physalaemus cuvieri	20.18	-0.65	0.51
Squamatas	11	1.48	0.16
Didelphimorphia	23	1.94	0.06
Rodentia	21.99	-0.12	0.90
Terminal			
All	307.76	-1.68	0.09
Anura	75.97	0.37	0.71
Physalaemus cuvieri	75.87	0.88	0.38
Squamatas	69.94	1.05	0.29
Didelphimorphia	69.87	-0.36	0.71
Rodentia	58.59	-2.51	**0.01**

DISCUSSION

Pitfall traps are frequently used to sample mammals (Pardini & Umetsu, 2006), squamates (Ribeiro-Júnior et al., 2008), and amphibians (Gascon, 1996; C. Rocha et al., 2001) in several forest environments around the globe, e.g., Amazon Forest in Brazil (Santos-Filho et al., 2015; Ardente et al., 2017; Palmeirim et al., 2019), Atlantic Forest in Brazil (Bovendorp et al., 2017), Uzungwa forest in Tanzania (Lyakurwa et al., 2019), Wologizi in Liberia (Mamba et al., 2020). Still, this is the first study to evaluate the efficiency of pitfall traps with internal rims on the bucket border for sampling terrestrial vertebrates. Our results indicate that modifications implemented in the pitfall traps (rims) did not affect their capture efficiency in sampling ground-dwelling and semi-arboreal species of anurans, lizards, and mammals in the Seasonal Semi-deciduous Forest.

The pitfall traps exhibited efficiency in sampling amphibians, notably more efficient for the ground-dwelling species. Specifically, they recorded 46.4% (n = 13) of the potential species known to inhabit the area, while capturing 76.9% of the ground-dwelling species (Sierra Ramírez, 1998; Garey & Silva, 2010). The efficiency of pitfall traps in sampling ground-dwelling anurans is congruent with other studies (e.g., C. Rocha et al., 2001; Ribeiro-Júnior et al., 2008; R. Rocha et al., 2015) but there are exceptions (see C. Rocha et al., 2004; Hutchens & DePerno, 2009). The capture of terrestrial frogs is expected because these animals inhabit the forest leaf litter; hence, they are pruned to be oriented by the drift fences when moving on the ground (Ali et al., 2018). As ground-dweller anuran species are poor climbers, we did not expect that the rims would affect the smaller species, like the microhylid *Elachistocleis cesarii*. However, large-bodied species, like some species of Bufonidae, have relative climbing ability that could enable them to escape when tree branches fall within the buckets (Noronha et al., 2013).

We found that pitfall traps represent an efficient method for lizards in the Semi-deciduous Forest but less efficient for snakes. Snakes corresponded to 5.26% of the richness of species found, and the only snake that was trapped was the colubrid *Elapomorphus quinquelineatus*, a small-bodied species. Compared with lizards and anurans, snakes are the least sampled group using pitfall traps, particularly in forested environments (Bernarde, 2012). This is particularly true for large and arboreal species that can easily climb out of the buckets. Arboreal or semi-arboreal species, like the colubrid snakes *Chironius quadricarinatus* Boie, 1827 and *Spilotes pullatus* (Linnaeus, 1758), are present in the study area (Garey et al., 2014). However, we cannot be sure if snakes have fallen and escaped or never fallen in the traps. Other sampling techniques might provide better results when sampling snakes (Ali et al., 2018; Richardson et al., 2018). Active search has been demonstrated to work in regions where snakes are more abundant, e.g., Amazon Forest and Western Australia, whereas funnel traps are a good option for capturing aquatic or semi-aquatic species (Tietje & Vreeland, 1997; Graham et al., 2007; Masseli et al., 2019).

Here, mammals made up the largest portion of the total of individuals trapped, indicating that this method is efficient for small ground-dwelling and semi-arboreal mammals in the Semi-deciduous Forest. This supports other studies indicating that pitfall traps yield better performance than capture methods, such as Sherman or Tomahawk traps (Umetsu & Pardini, 2007; Abreu-Júnior & Percequillo, 2019). However, different from reptiles and anurans, using internal rims led to a slight reduction in the efficiency of capturing rodent individuals in some cases and, consequently, in the total of mammals trapped. We postulated that the animals could perceive the rims – an unstable substratum – and so forth as avoiding the fall, which is indirectly related to the reduction in the size of the bucket opening (Gibbons & Semlitsch, 1982).

Innovations in trapping techniques of terrestrial vertebrates are necessary to gain better sampling results. Still, studies that evaluate modifications on pitfall traps have focused mainly on the drift fence design, e.g., linear, radial, or grid, and on the size of the buckets, varying from 5 to 100 litters (Ribeiro-Júnior et al., 2011; Bovendorp et al., 2017). Larger buckets seem more efficient in capturing snakes, whereas bucket size is less significant for amphibians and other reptiles (Cechin & Martins, 2000; Maritz et al., 2007). Still, in several cases, drift fence design does not affect the capture efficiency of small mammals, reptiles, and amphibians (Ribeiro-Júnior et al., 2011; Rocha & Passamani, 2013). Investigations on modifications of the pitfall structure, such as approaches that prevent escape, could potentially enhance trapping efficiency, especially for larger animals.

We suggest that the use of pitfall trap for small vertebrates sampling could benefit from similar pitfall modifications implemented in entomological sampling. Several factors can affect pitfall efficiency in small vertebrate sampling, and some of these factors also acts over the smaller pitfall traps used in entomological sampling. For example, escape can be facilitated by vegetation that falls within the buckets. In this case, pitfalls with a suspense roof structure over the buckets could prevent this from happening. Similarly, buckets with entrances with a funnel could make it difficult for individuals to escape (see Lange et al., 2011; Császár et al., 2018). The functionality of entrance with a funnel would be analogous to the funnel trap but as a pitfall. Bait is often used in beetles and butterflies sampling in pitfall or Vann Someren-Rydon traps (Hughes et al., 1998; Knapp et al., 2016). Baiting within pitfall could be an efficient method to attract mammals and snake predators. We also propose to evaluate if rubbing Vaseline (petroleum jelly) within the bucket wall testing could prevent animals, like snakes, from climbing out. Nevertheless, more investigations on pitfall trap modifications are necessary to verify which modifications could increase pitfall efficiency in vertebrate sampling.

CONCLUSION

The pitfall trap proved to be an efficient method to capture lizards, amphibians, and mammals but less efficient for snakes, like other studies. Our hypothesis that using internal rims would increase the efficiency of capture of terrestrial vertebrates, in general, was not corroborated. Instead, using rims decreased the traps' efficiency, especially for the high capture rate of mammals Rodentia species. Considering the efficacy and the cost-benefit relationship, we do not recommend using 30-liter buckets with internal rims to sample small vertebrates. However, more studies that evaluate for integrated pitfall trap modifications, for example, the presence of rims on different bucket sizes, could be interesting. In conclusion, investigations on the relationship between pitfall modifications focusing on taxonomic or functional groups, such as terrestrial *versus* arboreal or Rodentia *versus* Didelphimorphia, could reveal trap specifications during sampling.

ACKNOWLEDGMENTS

We thank the *Conselho Nacional de Desenvolvimento Científico e Tecnológico* (CNPq) for the scholarship to the first author (process nº 108877/2004-3). MVG received a research grant from UNILA (public notice PRPPG 77/2022). GSVF received a research *Fundação de Amparo à Pesquisa do Estado de São Paulo* (FAPESP) (Process 2022/ 14451-3). We thank the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) for the collecting permits (nº 151/2003 e 208/04 – NUFAS/MG, nº209/04 – NUFAS/MG e nº041/06 – NUFAS/MG). To Thiago G. Souza for his help with the statistical analyses and critical manuscript reading. To Luiz Fernando Ferreira for creating the map. We thank Diogo B. Provete and Swati Patel for the critical reading of the manuscript. To Maria C. W. Vieira and the *Instituto Sul-Mineiro de Estudos e Conservação da Natureza* for the access to the study area. To Fábio. T. Silveira (*Usina Monte Alegre*) for providing the climatic data. To an anonymous reviewer for her contribution to the improvement of this work.

REFERENCES

Ab'Saber, A. N. (1977). Os domínios morfoclimáticos na América do Sul, primeira aproximação. *Geomorfologia*, *52*, 1-21.

Abreu-Júnior, E. F. D., & Percequillo, A. R. (2019). Small mammals of the Estação Ecológica de Bananal, southeastern Atlantic Forest, Brazil, with description of a new species of Brucepattersonius (Rodentia, Sigmodontinae). *Arquivos de Zoologia*, *50*(1), 1-116. https://doi.org/10.11606/2176-7793/2019.50.01

Ali, W., Javid, A., Bhukhari, S. M., Hussain, A., Hussain, S. M., & Rafique, H. (2018). Comparison of different trapping techniques used in herpetofaunal monitoring: a review. *Punjab University Journal of Zoology*, *33*(1), 57-68. http://dx.doi.org/10.17582/pujz/2018.33.1.57.68

Ardente, N. C., Ferreguetti, A. C., Gettinger, D., Leal, P., Martins-Hatano, F., & Bergallo, H. G. (2017). Differencial efficiency of two sampling methods in capturing non-volant small mammals in an area in eastern Amazonia. *Acta Amazonica*, *47*(2), 123-132. https://doi.org/10.1590/1809-4392201602132

Bernarde, P. S. (2012). *Anfíbios e répteis: introdução ao estudo da herpetofauna brasileira*. Anolis Books.

Bovendorp, R. S., McCleery, R. A., & Galetti, M. (2017). Optimizing sampling methods for small mammal communities in Neotropical rainforests. *Mammal Review*, *47*(2), 148-158. https://doi.org/10.1111/mam.12088

Bury, R. B., & Corn, P. S. (1987). Evaluation of pitfall trapping in northwestern forests: trap arrays with drift fences. *The Journal of Wildlife Management*, *51*(1), 112-119. https://doi.org/10.2307/3801640

Campbell, H. W., & Christman, S. P. (1982). Field techniques for herpetofaunal community analysis. In N. J. Scott Jr. (Ed.), *Herpetological communities* (Wildlife Research Report, 13, pp. 163-172). United States Fish & Wildlife Service.

Cechin, S. Z., & Martins, M. (2000). Eficiência de armadilhas de queda (*pitfall traps*) em amostragens de anfíbios e répteis no Brasil. *Revista Brasileira de Zoologia*, *17*(3), 729-740. https://doi.org/10.1590/S0101-81752000000300017

Corn, P. S. (1994). Straight-line drift fences and pitfall traps. In W. R. Heyer, M. A. Donnely, R. W. McDiarmid, L. A. Hayek & M. Foster (Eds.), *Measuring and monitoring biological diversity: standard methods for amphibians* (pp. 109-117). Smithsonian Institution Press.

Crosswhite, D. L. (1999). Comparison of methods for monitoring reptiles and amphibians in upland forests of the Ouachita Mountains. *Proceedings of the Oklahoma Academy of Science*, *79*, 45-50. https://ojs.library.okstate.edu/osu/index.php/OAS/article/view/5661

Császár, P., Torma, A., Gallé-Szpisjak, N., Tölgyesi, C., & Gallé, R. (2018). Efficiency of pitfall traps with funnels and/or roofs in capturing ground-dwelling arthropods. *European Journal of Entomology*, *115*, 15-24. https://doi.org/10.14411/eje.2018.003

Dodd Jr., C. K. (1991). Drift fence-associated sampling bias of amphibians at a Florida sandhills temporary pond. *Journal of Herpetology*, *25*(3), 296-301. https://doi.org/10.2307/1564587

Edwards, K. E., & Jones, J. C. (2014). Trapping efficiency and associated mortality of incidentally captured small mammals during herpetofaunal surveys of temporary wetlands. *Wildlife Society Bulletin*, *38*(3), 530-535. https://doi.org/10.1002/wsb.419

Enge, K. M. (2001). The pitfalls of pitfall traps. *Journal of Herpetology*, *35*(3), 467-478. https://doi.org/10.2307/1565965

Enge, K. M. (2005). Herpetofaunal drift-fence surveys of steephead ravines in the Florida Panhandle. *Southeastern Naturalist*, *4*(4), 657-678. https://doi.org/10.1656/1528-7092(2005)004[0657:HDSOSR]2.0.CO;2

Fiorillo, B. F., Faria, C. S., Silva, B. R., & Martins, M. (2018). Anurans from preserved and disturbed areas of Atlantic Forest in the region of Etá Farm, municipality of Sete Barras, state of São Paulo, Brazil. *Biota Neotropica*, *18*, e20170509. https://doi.org/10.1590/1676-0611-BN-2017-0509

Garey, M. V., & Silva, V. X. (2010). Spatial and temporal distribution of anurans in an agricultural landscape in the Atlantic semi-deciduous forest of southeastern Brazil. *South American Journal of Herpetology*, *5*(1), 64-72. https://doi.org/10.2994/057.005.0108

Garey, M. V., Sturaro, M. J., Silva, V. X., & Sacramento, M. A. (2014). A comunidade de anfíbios e répteis. In R. S. Laurinho, R. L. M. Novaes & M. C. W. Vieira (Eds.), *RPPN Fazenda Lagoa: educação, pesquisa e conservação da natureza* (pp. 95-117). ISMECN.

Gascon, C. (1996). Amphibian litter fauna and river barriers in flooded and non-flooded Amazonian rain forest. *Biotropica*, *28*(1), 136-140. https://doi.org/10.2307/2388779

Gibbons, J. W., & Semlitsch, R. D. (1981). Terrestrial drift fences with pitfall traps: an effective technique for quantitative sampling of animal populations. *Brimleyana*, *7*, 1-16.

Graham, G., Thompson, A. C., & Thompson, S. A. (2007). Usefulness of funnel traps in catching small reptiles and mammals with comments on the effectiveness of the alternatives. *Wildlife Research*, *34*(6), 491-497. https://doi.org/10.1071/WR06081

GraphPad. (n. d.). *GraphPad Prism Analyze, graph and present your scientific work*. San Diego, California USA. www.graphpad.com

Greenberg, C. H., Neary, D. G., & Harris, L. D. (1994). A comparison of herpetofaunal sampling effectiveness of pitfall, single-ended, and double-ended funnel traps used with drift fences. *Journal of Herpetology*, *28*(3), 319-324. https://doi.org/10.2307/1564530

Hughes, J. B., Daily, G. C., & Ehrlich, P. R. (1998). Use of fruit bait traps for monitoring of butterflies (Lepidoptera: Nymphalidae). *Revista de Biología Tropical*, *46*(3), 697-704. http://www.scielo.sa.cr/scielo.php?script=sci_arttext&pid=S0034-77441998000300025&lng=en&nrm=iso

Hutchens, S. J., & DePerno, C. S. (2009). Efficacy of sampling techniques for determining species richness estimates of reptiles and amphibians. *Wildlife Biology*, *15*(2), 113-122. https://doi.org/10.2981/08-024

Knapp, M., Baranovská, E., & Jakubec, P. (2016). Effects of bait presence and type of preservative fluid on ground and carrion beetle samples collected by pitfall trapping. *Environmental Entomology*, *45*(4), 1022-1028. https://doi.org/10.1093/ee/nvw047

Lange, M., Gossner, M. M., & Weisser, W. W. (2011). Effect of pitfall trap type and diameter on vertebrate by-catches and ground beetle (Coleoptera: Carabidae) and spider (Araneae) sampling. *Methods in Ecology and Evolution*, *2*(2), 185-190. https://doi.org/10.1111/j.2041-210X.2010.00062.x

Laurindo, R. S., Novaes, R. L. M., Souza, R. F., Souza, V. F., Felix, F., Souto, T. M., Cunha, R. G. T., & Gregorin, R. (2017). Mammals in forest remnants of an ecotonal Atlantic Forest-Cerrado area from southeastern Brazil. *Neotropical Biology and Conservation*, *12*(1), 19. https://doi.org/10.4013/nbc.2017.121.03

Lawrence, M. A., & Lawrence, M. M. A. (2016). *Package 'ez'. R package version, 4(0)*. https://CRAN.R-project.org/package=ez

Lyakurwa, J. V., Howell, K. M., Munishi, L. K., & Treydte, A. C. (2019). Uzungwa Scarp Nature Forest Reserve: a unique hotspot for reptiles in Tanzania. *Acta Herpetologica*, *14*(1), 3-14. https://doi.org/10.13128/Acta_Herpetol-25008

Mamba, M. L., Dalton, D. L., Mahlaba, T. A. A., Kropff, A. S., & Monadjem, A. (2021). Small mammals of a West African hotspot, the Ziama-Wonegizi-Wologizi transfrontier forest landscape. *Mammalia*, *85*(2), 127-144. https://doi.org/10.1515/mammalia-2020-0013

Maritz, B., Masterson, G., Mackay, D., & Alexander, G. (2007). The effect of funnel trap type and size of pitfall trap on trap success: implications for ecological field studies. *Amphibia-Reptilia*, *28*(3), 321-328. https://doi.org/10.1163/156853807781374746

Masseli, G. S., Bruce, A. D., Santos, J. G., Vincen, T., & Kaefer, I. L. (2019). Composition and ecology of a snake assemblage in an upland forest from Central Amazonia. *Anais da Academia Brasileira de Ciências*, *91*(Supl. 1), e20190080. https://doi.org/10.1590/0001-3765201920190080

Menezes, F. A., Abegg, A. D., Silva, B. R., Franco, F. L., & Feio, R. N. (2018). Composition and natural history of the snakes from the Parque Estadual da Serra do Papagaio, southern Minas Gerais, Serra da Mantiqueira, Brazil. *ZooKeys*, *797*, 117-160. https://doi.org/10.3897%2Fzookeys.797.24549

Monteiro-Filho, E. L. A., & Conte, C. E. (2017). *Revisões em Zoologia*. Editora UFPR.

Morellato, L. P. C., & Haddad, C. F. (2000). Introduction: The Brazilian Atlantic Forest. *Biotropica*, *32*(4b), 786-792. https://doi.org/10.1111/j.1744-7429.2000.tb00618.x

Narvaes, P., & Rodrigues, M. T. (2005). Visual communication, reproductive behavior, and home range of *Hylodes dactylocinus* (Anura, Leptodactylidae). *Phyllomedusa*, *4*(2), 147-158. https://doi.org/10.11606/issn.2316-9079.v4i2p147-158

Noronha, J. C., Barros, A. B., Paixão, E. C., Almeida, E. J., Miranda, R. M., & Rodrigues, D. J. (2013). Climbing behaviour of terrestrial bufonids in the genus *Rhinella*. *Herpetological Bulletin*, *124*, 22-23.

Palmeirim, A. F., Benchimol, M., Peres, C. A., & Vieira, M. V. (2019). Moving forward on the sampling efficiency of Neotropical small mammals: insights from pitfall and camera trapping over traditional live trapping. *Mammal Research*, *64*(3), 445-454. https://doi.org/10.1007/s13364-019-00429-2

Pardini, R., & Umetsu, F. (2006). Pequenos mamíferos não-voadores da Reserva Florestal do Morro Grande: distribuição das espécies e da diversidade em uma área de Mata Atlântica. *Biota Neotropica*, *6*(2), 1-22. https://doi.org/10.1590/S1676-06032006000200007

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences*, *11*(5), 1633-1644. https://doi.org/10.5194/hess-11-1633-2007

Privet, K., Vedel, V., Fortunel, C., Orivel, J., Martinez, Q., Cerdan, A., Baraloto, C., & Pétillon, J. (2020). Relative efficiency of pitfall trapping vs. nocturnal hand collecting in assessing soil-dwelling spider diversity along a structural gradient of neotropical habitats. *Diversity*, *12*(2), 81. https://doi.org/10.3390/d12020081

R Development Core Team. (2017). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Ribeiro-Júnior, M. A., Gardner, T. A., & Ávila-Pires, T. C. (2008). Evaluating the effectiveness of herpetofaunal sampling techniques across a gradient of habitat change in a tropical forest landscape. *Journal of Herpetology*, *42*(4), 733-749. https://doi.org/10.1670/07-097R3.1

Ribeiro-Júnior, M. A., Rossi, R. V., Miranda, C. L., & Ávila-Pires, T. C. (2011). Influence of pitfall trap size and design on herpetofauna and small mammal studies in a Neotropical Forest. *Zoologia*, *28*(1), 80-91. https://doi.org/10.1590/S1984-46702011000100012

Richardson, E., Nimmo, D. G., Avitabile, S., Tworkowski, L., Watson, S. J., Welbourne, D., & Leonard, S. W. (2018). Camera traps and pitfalls: an evaluation of two methods for surveying reptiles in a semiarid ecosystem. *Wildlife Research*, *44*(8), 637-647. https://doi.org/10.1071/WR16048

Rocha, C. F. D., Van Sluys, M., Alves, M. A. S., Bergallo, H. G., & Vrcibradic, D. (2001). Estimates of forest floor litter frog communities: a comparison of two methods. *Austral Ecology*, *26*(1), 14-21. https://doi.org/10.1111/j.1442-9993.2001.01073.pp.x

Rocha, C. F. D., Van Sluys, M., Hatano, F. H., Boquimpani-Freitas, L., Marra, R. V., & Marques, R. V. (2004). Relative efficiency of anuran sampling methods in a restinga habitat (Jurubatiba, Rio de Janeiro, Brazil). *Brazilian Journal of Biology*, *64*(4), 879-884. https://doi.org/10.1590/S1519-69842004000500018

Rocha, D. G. D., & Passamani, M. (2013). Influence of pitfall designs and use of baits on the capture of small mammals in Southern Minas Gerais State, Brazil. *Acta Sientiarium*, *35*(4), 499-503. https://repositorio.inpa.gov.br/handle/1/16023

Rocha, R. G., Ferreira, E., Serafini, A., Costa, L. P., Nogueira, A. J., Malvasio, A., Martins, I. C. M., & Fonseca, C. (2015). The usefulness of different methods for biodiversity surveys in the Amazonia/Cerrado ecotone. *Natureza OnLine*, *15*, 33-45.

Rossa-Feres, D. D. C., Sawaya, R. J., Faivovich, J., Giovanelli, J. G. R., Brasileiro, C. A., Schiesari, L., . . . Haddad, C. F. B. (2011). Anfíbios do estado de São Paulo, Brasil: conhecimento atual e perspectivas. *Biota Neotropica*, *11*(Supl. 1), 47-66. https://doi.org/10.1590/S1676-06032011000500004

Santos-Filho, M. D., Lázari, P. R. D., Sousa, C. P. F. D., & Canale, G. R. (2015). Trap efficiency evaluation for small mammals in the southern Amazon. *Acta Amazonica*, *45*(2), 187-194. https://doi.org/10.1590/1809-4392201401953

Sierra Ramírez, N. M. (1998). *Análise comparada entre comunidades de anfíbios anuros do Sudeste brasileiro e uma região dos Andes baixos da Venezuela* [Dissertação de mestrado. Universidade de Campinas]. https://bdtd.ibict.br/vufind/Record/UNICAMP-30_5556e3f19d93ace2759c8b7d43a132a8

Spence-Bailey, L. M., Nimmo, D. G., Kelly, L. T., Bennett, A. F., & Clarke, M. F. (2010). Maximizing trapping efficiency in reptile surveys: the role of seasonality, weather conditions and moon phase on capture success. *Wildlife Research*, *37*(2), 104-115. https://doi.org/10.1071/WR09157

Stašiov, S., Čiliak, M., Wiezik, M., Svitok, M., Wieziková, A., & Diviaková, A. (2021). Pitfall trap design affects the capture efficiency of harvestmen (Opiliones) and millipedes (Diplopoda). *Ecology and Evolution*, *11*(14), 9864-9875. https://doi.org/10.1002/ece3.7820

Sturaro, M. J., & Silva, V. X. (2005). Amostragem dos répteis da fazenda Lagoa, Monte Belo, Minas Gerais. In *Anais do 2th Congresso Brasileiro de Herpetologia*, Belo Horizonte, Minas Gerais, Brazil.

Szinwelski, N., Fialho, V. S., Yotoko, K. S., Seleme, L. R., & Sperber, C. F. (2012). Ethanol fuel improves arthropod capture in pitfall traps and preserves DNA. *ZooKeys*, *196*, 11-22. https://doi.org/10.3897%2Fzookeys.196.3130

Tietje, W. D., & Vreeland, J. K. (1997). The use of plywood cover boards to sample herpetofauna in California oak woodland. *Transactions of the Western Section of the Wildlife Society*, *33*, 67-74.

Todd, B. D., Winne, C. T., Willson, J. D., & Gibbons, J. W. (2007). Getting the drift: examining the effects of timing, trap type and taxon on herpetofaunal drift fence surveys. *The American Midland Naturalist*, *158*(2), 292-305. https://doi.org/10.1674/0003-0031(2007)158[292:GTDETE]2.0.CO;2

Umetsu, F., & Pardini, R. (2007). Small mammals in a mosaic of forest remnants and anthropogenic habitats—evaluating matrix quality in an Atlantic forest landscape. *Landscape Ecology*, *22*(4), 517-530. https://doi.org/10.1007/s10980-006-9041-y

AUTHOR CONTRIBUTIONS

M. V. Garey contributed to project administration, conceptualization, data curation, writing (original draft, review and editing), research and methodology; Vicente-Ferreira, G.S. with formal analysis, data curation, writing (review and editing), software and supervision; V. X. Silva with project administration, data curation, funding acquisition, conceptualization, writing (review and editing), methodology, resources, supervision, validation and visualization; and M. J. Sturaro with project administration, data curation, funding acquisition, conceptualization, writing (review and editing), methodology, resources, supervision, validation, and visualization.