EVALUATING THE EFFICIENCY OF PITFALL TRAPS FOR SAMPLING SMALL MAMMALS IN THE NEOTROPICS

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Using standardized small mammal surveys at 26 Atlantic Forest sites, we evaluated the efficiency and compared the weight of captured species and individuals between large pitfall traps and Sherman traps. We also investigated the effects of climatic variables on daily capture success of pitfalls. Pitfalls were clearly more efficient than Sherman traps, capturing 29 species, of which 16 were captured exclusively with this method, mostly represented by rare species. In contrast, Sherman traps captured 14 species, of which just 1 was not captured with pitfall traps. Compared to Sherman traps, pitfalls captured per site 3 times the number of species, 2 times the number of individuals, and significantly more individuals of 7 species. Despite differences in sampling efficiency, positive correlations suggest that at least coarse-scale variation among sites for several assemblage parameters are congruent between the 2 trapping methods. Sherman traps tended to capture adults, whereas pitfalls captured individuals over a broader range of weight classes or tended to capture more juveniles. Total daily capture rates in pitfall traps increased with precipitation. Our results suggest that large pitfall traps are effective at capturing rare species and juveniles, probably because they are less selective, and are thus essential for inventorying the rich and poorly known small mammal fauna of the tropics and for demographic studies.

Key words: Atlantic forest, efficiency of traps, pitfall traps, Sherman traps, small mammals

The establishment of efficient faunal sampling protocols is especially important in the tropics, where species richness is high and scientific knowledge about the faunas is still incomplete. Some results from recent studies that have included pitfall traps for sampling small mammals in the tropics suggest that these traps capture species that are infrequently or never captured in traditionally used live traps (e.g., Hice and Schmidly 2002; Voss and Emmons 1996; Voss et al. 2001). Moreover, because captures in pitfalls do not depend on the attraction of animals to a bait, they probably are less affected by factors known to influence sampling using traditional live traps, such as food availability (Adler and Lambert 1997), species preferences for different baits (Laurance 1992), bait consumption by other animals (McClearn et al. 1994), and tendency to capture only adult individuals (Boonstra and Krebs 1978). On the other hand, capture success in pitfalls probably depends on the size of the traps. The smaller the trap, the higher the probability of escape of larger species or of species that are able to jump or climb, as documented for herpetofaunal sampling (Cechin and Martins 2000; Corn 1994).

In temperate regions of North America and Europe, pitfall traps have been used for decades to sample small terrestrial vertebrates (Bury and Corn 1987; Corn 1994; Gibbons and Bennett 1974; Mengak and Guynn 1987; Williams and Braun 1983) and were shown to efficiently capture small mammals with semifossorial habits, which move along obstacles or trails or which orient themselves mainly through nonvisual cues (e.g., soricids and other insectivores—Bury and Corn 1987; Handley and Kalko 1993; Jones et al. 1996; Moore 1949; Spencer and Pettus 1966; Williams and Braun 1983). In tropical regions, however, the 1st studies using pitfall traps were done in recent years, both for sampling the herpetofauna (Cechin and Martins 2000; Conroy 1999; Enge 2001; Martins and Oliveira 1999; Raxworthy and Nussbaum 1994) and the small mammal fauna.

The use of pitfalls to sample small mammals in the tropics is restricted to few studies in Africa (Goodman and Rakoton-dravony 2000; Maddock 1992; Raxworthy and Nussbaum 1994; Stephenson 1993; Stephenson et al. 1994), in Australia (Laurance 1992), and in South America (Hice and Schmidly 2002; Lyra-Jorge and Pivello 2001; Pardini 2004; Pardini et al. 2005; Voss et al. 2001). Although some of these studies
compared the efficiency of pitfalls to traditionally used live traps (Hice and Schmidly 2002; Laurance 1992; Lyra-Jorge and Pivello 2001; Maddock 1992; Voss et al. 2001), their sampling protocols included only small or medium-sized pitfalls, most in the range of 10–20 liters, and almost all ≤35 liters, which may be inefficient for capturing some species of tropical small mammals, and did not account for temporal or spatial factors that seem likely to influence capture success and to confound comparisons among methods.

We used standardized small mammal surveys at 26 Atlantic Forest sites to compare capture results between large pitfall traps and Sherman traps. In particular, we evaluated the efficiency of the 2 methods by comparing assemblage values obtained in each of the 26 sites between the 2 methods, the congruence between methods by testing the correlation among the assemblage values in the 26 sites, the differences between methods in the weight of species and individuals captured, and the influence of climatic variables on daily captures for pitfall traps.

**Materials and Methods**

**Study area and sites.**—Our study was carried out in Caucaia do Alto, located in the Cotia and Ibiúna municipalities, State of São Paulo, Brazil (Fig. 1). The altitude in the region varies from 850 to 1,100 m and the relief is characterized by convex hills, with slopes >15% (Ross and Moroz 1997). Mean annual maximum temperature is 27°C and mean annual minimum temperature is 11°C. Rainfall is about 1,300–1,400 mm per year and is seasonally variable, with the driest and coldest months between April and August. The vegetation in the region is a transition between the coastal Atlantic rain forest and the Atlantic semideciduous forest, classified as “Lower Montane Atlantic Rain Forest” (Oliveira-Filho and Fontes 2000).

The study area comprises a continuous forest, the Morro Grande Reserve, with 9,400 ha of secondary and mature forest, and a fragmented landscape, which extends southwestward from the reserve and harbors 31% of remnants of native secondary vegetation (Fig. 1). All 26 study sites were located in secondary forest from 50 to 80 years old, except 3 sites in the reserve located in mature forest. Study sites were selected for a study on the effects of forest fragmentation on small mammals, as described elsewhere (Pardini et al. 2005). Six study sites were located in the Morro Grande Reserve, 5 were in large remnants (>50 ha), 8 were in medium-sized remnants (10–50 ha), and 7 were in small remnants (<5 ha; Fig. 1).

**Date collection.**—We conducted standardized small mammal sampling between 2002 and 2005. We used both pitfall and Sherman traps in the 26 study sites, using the same number and arrangement of traps and sampling the same area for the same number of days.

At each site, we set a 100-m sequence of 11 pitfall traps (plastic buckets of 60-liter volume, 402-mm diameter at the top, 332-mm diameter at the bottom, and 540-mm depth). Pitfalls were not baited and they were set at 10-m intervals and connected by a 500-mm-tall plastic drift fence. Although digging the pits and installing the fence was time consuming (half a day of work for 4 persons per site, totaling approximately 2 weeks for all of the sites), this effort was made just once, because installed buckets were closed and left at the sites between trapping sessions. We conducted 4 capture sessions of 8 days each, 2 during January and February 2002 and the others during December 2002 and January 2003, totaling 32 days of sampling and 352 trap-nights in each site. In each trapping session, 13 sites were sampled simultaneously and all 26 sites were sampled in a 16-day period. In August 2004 we set a grid of 25 pitfall stations 150 m apart from each other in 1 study site of the Morro Grande Reserve (Fig. 1), covering an area of 36 ha. At each station, we set two 60-litre pitfall traps 4 m from each other. Three 4-m-long and 500-mm-tall plastic drift fences centered at each of the traps diverged at angles of approximately 120°; 1 fence was shared between traps, connecting them. Small mammals were sampled 6 days monthly from August 2004 to February 2005, totaling 42 days of sampling. On these days, we measured daily precipitation and daily minimum and maximum temperature, using a pluviometer and a thermometer installed on the grid.

At each of the 26 sites, we set 2 parallel lines of Sherman traps of 2 different sizes (37.5 × 10 × 12 cm and 23 × 7.5 × 8.5 cm; H. B. Sherman Traps, Inc., Tallahassee, Florida). Lines were 165 m long and separated by 20 m, and 1 line overlapped the sequence of pitfall traps. On each line we established 12 trap stations at 15-m intervals. We set 1 small and 1 large trap at each station (1 on the ground and 1 about 1.5–2 m above ground in the understory vegetation), totaling 48 traps per study site. At adjacent stations we alternated the position (ground or vegetation) of small and large traps. Traps on 1 line were baited with banana and a mixture of peanut butter and oats, whereas those on the other line were baited with banana and a mixture of peanut butter, cornmeal, and sardines. Three capture sessions of 7 days each were conducted in July and October 2003 and in April 2004, totaling 21 days and 1,008 trap-nights per site. Six sites were sampled at the same time, so that all 26 sites were sampled within 1 month.

Animals were marked with numbered ear tags (National Band and Tag Co., Newport, Kentucky) at 1st capture and released. Trapping
and handling conformed to guidelines sanctioned by the American Society of Mammalogists (Animal Care and Use Committee 1998).

Data analysis.—For each study site we calculated the total number of species (richness) and the total number of individuals captured (abundance) for each species, for taxonomic groups (rodents or marsupials) and for groups of species with the same form of locomotion (terrestrial or arboreal). Form of locomotion followed Percequillo et al. (2004) for Rhagomys rufescens, and Fonseca et al. (1996) for other species (Tables 1 and 2), with the exception of Oligoryzomys nigripes, which we consider to be mainly terrestrial (because it was almost always captured on the ground), and Orzyomys angouya, which we treat as arboreal (captured several times in the understory).

We used *t*-tests for dependent samples to compare small mammal richness and abundance obtained in the 26 different capture methods. To investigate if capture rates among sites were congruent between methods, we used the *t*-test for dependent samples comparing the number of individuals captured with pitfall and Sherman traps in the 26 sites in Caucaia do Alto, Brazil. An asterisk (*) indicates *P* ≤ 0.05.

### Table 1—Form of locomotion (Terr, terrestrial or semifossorial; Arb, scansorial or arboreal), adult weight, number of individuals (total; mean per site; SD) of marsupial species, and results of the *t*-tests for dependent samples comparing the number of individuals captured with pitfall and Sherman traps in the 26 sites in Caucaia do Alto, Brazil. An asterisk (*) indicates *P* ≤ 0.05. *Monodelphis* sp. is the new species being described by N. F. Gomes.

| Species            | Locomotion | Weight (g) | Pitfall traps | Sherman traps | *t*-test |
|--------------------|------------|------------|---------------|---------------|----------|
|                    | Total      | Mean       | SD            |               |          |
|                    | Total      | Mean       | SD            |               |          |
|                    | Total      | Mean       | SD            |               |          |
| Marmosops incanus  | Arb        | 64         | 254           | 9.77          | 5.92     | 106      | 4.08       | 3.32     | 6.039     | <0.001* |
| Didelphis aurita   | Arb        | 985        | 86            | 3.31          | 2.62     | 58       | 2.23       | 2.14     | 1.424     | 0.167   |
| Monodelphis americana | Terr    | 29         | 66            | 2.54          | 1.86     | 6        | 0.23       | 0.65     | 6.288     | <0.001* |
| Gracilinanus microtarsus | Arb     | 31         | 41            | 1.58          | 1.39     | 54       | 2.08       | 3.35     | –0.671    | 0.508   |
| Monodelphis scalops | Arb        | 74         | 11            | 0.42          | 1.38     | 0        | –          | –        | –        | –       |
| Philander frenatus  | Arb        | 360        | 3             | 0.12          | 0.43     | 12       | 0.46       | 1.42     | –1.364    | 0.185   |
| Lutreolina crassicudata | Terr    | 537        | 2             | –             | –        | 0        | –          | –        | –        | –       |
| Monodelphis sp.    | Terr       | 11         | 2             | –             | –        | 0        | –          | –        | –        | –       |
| Monodelphis sorex  | Terr       | 48         | 2             | –             | –        | 0        | –          | –        | –        | –       |
| Marmosops paulensis | Arb        | 42         | 1             | –             | –        | 0        | –          | –        | –        | –       |
| Micoureus paraguayanas | Arb      | 124        | 0             | –             | –        | 5        | –          | –        | –        | –       |

| Species                  | Locomotion | Weight (g) | Pitfall traps | Sherman traps | *t*-test |
|--------------------------|------------|------------|---------------|---------------|----------|
| Oligoryzomys nigeripes   | Terr       | 21         | 295           | 11.35         | 7.64     | 19       | 0.73       | 0.87     | 4.460     | <0.001* |
| Akodon montensis         | Terr       | 34         | 179           | 6.88          | 5.23     | 188      | 7.23       | 8.10     | 2.280     | 0.307   |
| Delomys sublineatus      | Terr       | 50         | 151           | 5.81          | 4.14     | 59       | 2.27       | 3.27     | 4.918     | <0.001* |
| Orzyomys angouya         | Arb        | 144        | 106           | 4.08          | 3.95     | 19       | 0.73       | 0.87     | 4.460     | <0.001* |
| Brucepattersonia aff. soricina | Terr | 43         | 63            | 2.42          | 3.40     | 0        | –          | –        | –        | –       |
| Orzyomys russatus        | Terr       | 59         | 63            | 2.42          | 4.13     | 113      | 4.35       | 7.93     | –1.966    | 0.060   |
| Thaptomys nigrita        | Terr       | 20         | 32            | 1.23          | 2.61     | 7        | 0.27       | 1.00     | 2.126     | 0.044*  |
| Julomys pictipes         | Arb        | 34         | 17            | 0.65          | 1.16     | 2        | 0.08       | 0.39     | 2.440     | 0.022*  |
| Oxymycterus dasytrichas  | Terr       | 69         | 11            | 0.42          | 0.86     | 0        | –          | –        | –        | –       |
| Phylomys nigripinnes     | Arb        | 250        | 11            | 0.42          | 0.58     | 0        | –          | –        | –        | –       |
| Calomys tener            | Terr       | 20         | 9             | –             | –        | 0        | –          | –        | –        | –       |
| Rhagomys rufescens       | Arb        | 15         | 3             | –             | –        | 0        | –          | –        | –        | –       |
| Rhidipomys cf. mastacalis | Arb      | 80         | 3             | 0.12          | 0.33     | 2        | 0.08       | 0.39     | 0.570     | 0.574   |
| Bibomys labiosus         | Terr       | 29         | 2             | –             | –        | 0        | –          | –        | –        | –       |
| Bolomys lasiarus         | Terr       | 35         | 2             | –             | –        | 0        | –          | –        | –        | –       |
| Cavia aperea             | Terr       | 549        | 2             | –             | –        | 0        | –          | –        | –        | –       |
| Nectomys squamipes       | Terr       | 249        | 2             | –             | –        | 0        | –          | –        | –        | –       |
| Blarinomys breviceps     | Terr       | 40         | 1             | –             | –        | 0        | –          | –        | –        | –       |
| Undescribed species      | Arb        | 50         | 1             | –             | –        | 0        | –          | –        | –        | –       |
number of captures in the 25 pitfall stations in 1 site in the Morro Grande Reserve.

**RESULTS**

Efficiency between capture methods.—We captured a total of 2,096 individuals of 30 species of small mammals at Caucaia do Alto (Tables 1 and 2). Twenty-nine species and 1,421 individuals were captured with the total effort of 9,152 trap-nights with pitfalls, and 14 species and 675 individuals with the 26,208 trap-nights with Sherman traps, resulting in a substantially higher capture success for pitfalls (15.53%) than for Sherman traps (2.58%).

Pitfall traps captured a significantly greater number of species and of individuals per site than Sherman traps (Table 3). The number of individuals captured with pitfalls was greater for the entire small mammal assemblage as well as for rodents, marsupials, terrestrial species, or arboreal species considered separately (Table 3).

Among the 14 species taken with Sherman traps, only *M. paraguayanus* was exclusively captured by this method, and only *Oryzomys russatus* tended to have more individuals captured in this type of trap (Tables 1 and 2). Alternatively, among the 29 species captured in pitfalls, 16 were captured exclusively by this method, and 7 (*Delomys sublineatus*, *Juliomys pictipes*, *Monodelphis americana*, *Marmosops in-

**Table 4.**—Pearson correlations between capture results with pitfall and Sherman traps for the number of small mammal species and individuals and for the number of individuals of rodents and of terrestrial species (Table 4). Of the 13 species captured with both methods, 8 were represented by at least 15 individuals in each type of trap (Table 1). Among those, we documented positive correlations among captures with pitfall and Sherman traps for 3 terrestrial (*A. montensis*, *D. sublineatus*, and *O. russatus*) and 1 arboreal (*M. incanus*) species (Table 4).

**Comparison of weights for species and individuals between the 2 methods.**—No difference (*t* = −0.111, *d.f.* = 41, *P* = 0.912) was found in the mean weight of captured species between pitfall (*X* = 136.97, *SD* = 218.38) and Sherman traps (*X* = 145.36, *SD* = 257.44). The mean weight of captured individuals was not significantly different between the 2 types of traps for 4 of the 8 analyzed species (*A. montensis*, *D. sublineatus*, *Didelphis aurita*, and *Gracilinanus microtarsus*; Fig. 2). However, individuals of these 4 species captured in pitfalls presented greater variation in weight than those captured in Sherman traps (Fig. 2). For the remaining 4 species, Sherman traps captured significantly heavier individuals than did pitfall traps (Fig. 2).

**Influence of climatic variables on the number of daily captures in pitfall traps.**—Over 7 months, we captured 376 individuals of 18 species in the 36-ha grid at 1 of the sites in the Morro Grande Reserve. Among those, 325 were rodents and 51 were marsupials, and 315 were from terrestrial species and 61 from arboreal species. Daily precipitation varied from 0 to 50 mm, and minimum and maximum daily temperatures varied from 8°C to 20°C, and 16°C to 32°C, respectively.

The linear multiple regression models considering the climatic variables explained significantly the variation in the daily number of captured individuals, both when considering the entire small mammal assemblage and when considering the groups of rodents, marsupials, terrestrial species, or arboreal species separately (Table 5). In each of these models, however,
just 1 climatic variable had a significant, or marginally significant, contribution. Precipitation was positively associated with the number of captured individuals for the whole assemblage, rodents, and terrestrial animals, whereas minimum daily temperature was positively associated with the number of captured individuals for marsupials and arboreal animals (Table 5).

**DISCUSSION**

**Efficiency between capture methods.**—This study highlights the importance of using large pitfall traps for inventorying and sampling small mammals in the Neotropics. Compared to Sherman traps, large pitfalls captured more than 2 times the number of individuals and approximately 3 times the number of species per study site, including several rare and some semifossorial species not captured by Sherman traps. The observed differences in the number of captured species and individuals are probably due to differences in the capture mechanism between trap types and not to differences in sampling protocols. In addition to the fact that the same 26 sites were sampled using the 2 types of traps, both the number of traps and the area covered were higher for Sherman than for pitfall traps.

In fact, several other studies have reported higher capture rates of individuals for pitfalls than for traditional live traps in tropical South America (2.33% compared to 0.45% [Hice and Schmidly 2002] and 12.73% compared to 0.44% [Lyra-Jorge and Pivello 2001]) and Africa (34.9% compared to 8.9% [Maddock 1992]) and in temperate forests (13.4% compared to 4.2% [Bury and Corn 1987] and 9% compared to 0.8% [Williams and Braun 1983]). Pitfall traps should be more efficient for 2 main reasons. First, these traps do not depend on the attraction of animals to bait (Sealander and James 1958; Williams and Braun 1983). They capture all animals that pass over where the traps are installed, the chance of which is substantially increased by the use of drift fences. The importance of bait for captures in traditional live traps can be attested by the fact that capture rates in baited traps usually decline during periods of increased food availability (Krebs and Boonstra 1984), especially for frugivorous and granivorous small mammals in the tropics (Adler and Lambert 1997).

Second, capture of 1 individual in a pitfall does not prevent the capture of other individuals, as is the case for traditional live traps. The fact that 15 of the 16 species captured exclusively in pitfalls in Caucaia had <11 individuals captured suggests that traditional live traps may frequently be occupied by individuals from common species. The chance of capturing rare species, which comprise a large proportion of tropical diversity, seems thus to be drastically reduced in Sherman compared to pitfall traps.

However, the efficiency of pitfalls should be affected both by the size of the trap and some species attributes, such as the ability to jump or climb. It has been commonly suggested in the literature that the species most commonly captured in pitfall traps are semifossorial, which move along obstacles or trails or which orient themselves mainly through nonvisual cues (Maddock 1992; Williams and Braun 1983). In Caucaia, the efficiency of pitfalls for capturing species with these habits was attested by the higher number of individuals captured of 4 species of *Monodelphis* and of rodent species of the genera *Thaptomys*, *Blarinomys*, *Bruceppattersonius*, *Bibimys*, and *Oxymycterus*, all of which have relatively short tails, small eyes and ears, or strong claws, suggesting a strictly terrestrial or semifossorial habit. Pitfalls seem to be the only adequate way to capture most of these species, some of which were abundant in these traps and very rarely or never captured in Sherman traps in Caucaia. Even using smaller pitfalls, several other studies have already shown higher capture success for species of *Monodelphis* and *Scolomys* in the Amazon (20-liter pitfalls—Hice and Schmidly 2002); species of the genera...
Table 5.—Results from multiple linear regression models of daily number of captured individuals for different groups of small mammal species against daily precipitation and minimum and maximum daily temperature in 1 study site in the Morro Grande Reserve, Caucaia do Alto, Brazil. An asterisk (*) indicates $P \leq 0.05$.

| Species                        | Maximum temperature | Minimum temperature | Precipitation |
|-------------------------------|---------------------|---------------------|--------------|
|                               | $R^2$               | $F$                 | $P$          | $b$  | $t$  | $P$ | $b$  | $t$  | $P$ |
| Total individuals             | 0.371               | 8.865               | $<0.001^*$   | 0.265 | 0.760 | 0.452 | 0.367 | 0.916 | 0.365 | 0.320 | 3.855 | $<0.001^*$ |
| Rodent individuals            | 0.362               | 8.550               | $<0.001^*$   | 0.378 | 1.202 | 0.237 | 0.197 | 0.545 | 0.589 | 0.292 | 3.902 | $<0.001^*$ |
| Marsupials individuals        | 0.193               | 4.181               | 0.012        | $-0.113$ | $-1.544$ | 0.131 | 0.170 | 2.027 | 0.050* | 0.028 | 1.617 | 0.114 |
| Terrestrial individuals       | 0.355               | 8.329               | $<0.001^*$   | 0.309 | 1.028 | 0.311 | 0.149 | 0.430 | 0.670 | 0.287 | 4.014 | $<0.001^*$ |
| Arboreal individuals          | 0.169               | 3.714               | 0.020*       | $-0.044$ | $-0.446$ | 0.658 | 0.218 | 1.915 | 0.063 | 0.032 | 1.374 | 0.178 |

Monodelphis, Thaptomys, and Blarinomys in the Atlantic forest (35-liter pitfalls—Pardini 2004); and several species of Insectivora in North America, Europe, and Africa (Briese and Smith 1974; Bury and Corn 1987; Kalko and Handley 1993; Maddock 1992; Mengak and Guynn 1987; Williams and Braun 1983).

On the other hand, larger species (Briese and Smith 1974; Francel et al. 2002; Hice and Schmidly 2002; Laurance 1992; Lyra-Jorge and Pivello 2001; Maddock 1992; Voss et al. 2001) and those that are able to jump or climb (Maddock 1992; Williams and Braun 1983) were rarely or never captured during studies using small or medium-sized (approximately 20-liter) pitfall traps. Compared to the information found in the literature, our study used the largest pitfalls and obtained the greatest discrepancy between the number of species captured in pitfalls and in traditional live traps. Sixty-liter pitfall traps used in Caucaia captured a variety of scansorial and arboreal species (11), 7 of which were exclusively captured in this type of trap, and several species with adult weight >50 g (14), 4 of which were exclusively captured in this type of trap. Moreover, the mean weight of the captured species did not vary between pitfall and Sherman traps in Caucaia, unlike studies using smaller pitfall traps. In summary, pitfalls should be at least 60 liters in volume and 0.5 m deep for efficiently sampling small mammals in the tropics.

Congruence between capture methods.—Our results highlight the 1st time that, despite differences in trap efficiency (i.e., despite absolute differences among capture results between trap types), the relative differences in capture rates among study sites are proportional using different methods when considering such important assemblage variables as richness and total abundance. This congruence in turn suggests that comparisons of assemblages in distinct areas, obtained with different types of traps, are valid and should lead to similar results. However, the proportion of the small mammal assemblages that is captured with large pitfall traps is greater than with Sherman traps, allowing greater refinement and resolution when comparing areas and assemblages.

The exception to the congruence among the results obtained with different traps was found mainly among the arboreal species. On the one hand, captures in pitfall traps probably do not reflect the real abundance of species that move within or on vegetation part of the time; on the other hand, Sherman traps were clearly less efficient than pitfalls in capturing some of these species (e.g., M. incanus, J. pictipes, Phyllomys nigrispinus, and R. rufescens), either because they were rare or they were not attracted to the bait. Consequently, the number of captured individuals may not be a good index of the abundance of scansorial or arboreal species when sampling with either type of traps analyzed here.

Comparison of weight for species and individuals between the 2 methods.—Although some studies compared the weight of individuals captured with pitfalls and traditional live traps, they considered individuals across all species combined (Lyra-Jorge and Pivello 2001; Maddock 1992; Voss et al. 2001) or analyzed results for just 1 species (Beacham and Krebs 1980; Boonstra and Krebs 1978). We found that pitfalls captured individuals from a broader range of weights or tended to capture more juveniles when compared to Sherman traps, suggesting that the use of pitfalls may improve data sets for population and demographic studies by increasing the number of captured individuals in younger age classes. Pitfall and Sherman traps captured species in the same range of weight in Caucaia (e.g., from approximately 15 to 1000 g), excluding the possibility that young animals would not be captured by traditional live traps because their capture mechanisms would not be triggered by light-weight animals, as suggested by several authors (Francel et al. 2002; Lyra-Jorge and Pivello 2001; Maddock 1992).

It should be noted here, however, that rate of recaptures (ratio between the number of individuals recaptured at least once and the total number of individuals captured) in the 26 study sites obtained with pitfalls ($\bar{X} = 0.13$, $SD = 0.09$) was significantly lower (paired $t$-test, $t = 5.716$, $d.f. = 25$, $P < 0.001$) than that obtained with Sherman traps ($\bar{X} = 0.35$, $SD = 0.18$). It may be important to reward animals that enter pitfalls by leaving food inside traps to increase the rate of recaptures during demographic studies.

Influence of climatic variables on the number of daily captures in pitfall traps.—The influence of climatic variables, especially temperature and precipitation, on the capture rates of different types of traps is well known in the literature (Bury and Corn 1987; Dawson and Lang 1973; Getz 1961; Kalko and Handley 1993). However, few studies have focused on the effects of climatic variables on the rates of captures of neotropical small mammals (Bittencourt et al. 1999). We found that daily capture rates in pitfalls increased with increasing daily precipitation. These results are consistent with previous observations of a very low capture rate in 20-liter pitfalls in the dry compared to the rainy season in the Amazon.
(Hice and Schmidly 2002). Thus, the fact that sampling sessions with pitfalls in the 26 sites in Caucaia were concentrated in 2 consecutive rainy seasons (summers) may partially explain the high capture rates in pitfalls observed in this study.

More importantly, our results indicate that the influence of climatic variables varies for different groups of small mammals. Number of individuals of marsupials and of arboreal species increased only with increasing minimum daily temperature, whereas number of individuals of rodents and of terrestrial species increased only with increasing daily precipitation. However, it is difficult to distinguish if the different responses to climatic factors were related to taxonomic or phylogenetic constraints or to the form of locomotion, because most captured individuals of marsupials were represented by arboreal species, and most rodent species were terrestrial.

It is well known that climatic factors can alter animal activity, which in turn can affect the probability of animals finding traps (O’Farrell et al. 1994; Stokes et al. 2001). Several hypotheses have been proposed for the increased activities of small mammals with increasing precipitation, including increasing food availability (Doucet and Bider 1974), decreasing water loss in small endothermic animals with high metabolic and ventilation rates (Doucet and Bider 1974), and lowering predation risk by decreasing light intensity at night and thus the chance of predators locating prey (Stokes et al. 2001; Vickery and Bider 1981). In tropical rain forest, in particular, another factor could explain the increase of capture rates of terrestrial but not of arboreal small mammals during nights with intense rain as observed in Caucaia. The dens of terrestrial small mammals, which usually are subterranean in the Neotropics (Briani et al. 2001; Miles et al. 1981), could be inundated during intense rain (Dawson and Lang 1973), forcing animals to leave the dens. This would not happen to arboreal species, which nest mainly on the vegetation (Miles et al. 1981).

On the other hand, although temperature has been shown to affect activity rate of small mammals (Bittencourt et al. 1999; Doucet and Bider 1974; Vickery and Bider 1981), there are some indications that low temperatures could affect marsupials more intensively than rodents. Marsupials have lower basal metabolic rate than eutherians of the same size (Eisenberg 1981; McNab 1978) and the occurrence of torpor has been described for some neotropical marsupials (e.g., Marmosa robinsoni, G. microtarsus, and 1 species of Monodelphis—McNab 1978).

Our results suggest that the greater success of large pitfall traps is mainly related to the depth of the traps, which prevents the escape of larger or arboreal species, and to the low selectivity of these traps, which may capture >1 individual, increasing the chance of capturing rare species. The species that are captured exclusively with large pitfalls comprise rare species, semifossorial species, and arboreal species that probably are not attracted to traditional live traps. When sufficiently large and deep, and used in the wet and warm season, these traps may be essential to effectively inventory neotropical small mammal faunas.

**RESUMO**

A partir de amostragens padronizadas de pequenos mamíferos em 26 sítios de Mata Atlântica, avaliamos a eficiência e comparamos o peso das espécies e dos indivíduos capturados entre armadilhas de queda grandes e armadilhas Sherman. Também investigamos os efeitos de variáveis climáticas sobre o sucesso diário de capturas em armadilhas de queda. Armadilhas de queda foram claramente mais eficientes que as Sherman, capturando 29 espécies, das quais 16 foram exclusivamente capturadas com este método e correspondem, em sua maior parte, a espécies raras. Em contraste, as armadilhas Sherman capturaram 14 espécies, das quais apenas 1 não foi capturada com armadilhas de queda. Comparadas às armadilhas Sherman, as armadilhas de queda capturaram (por sítio) 3 vezes o número de espécies, 2 vezes o número de indivíduos e um número significativamente maior de indivíduos de 7 espécies. Apesar das diferenças de eficiência, as correlações positivas sugerem que pelo menos grandes variações de diversos parâmetros da comunidade entre sítios são congruentes entre os 2 métodos de captura. As armadilhas Sherman tenderam a capturar adultos, enquanto armadilhas de queda capturaram indivíduos em uma amplitude maior de peso ou tenderam a capturar mais jovens. As taxas diárias totais de captura em armadilhas de queda aumentaram com a precipitação. Nossos resultados sugerem que armadilhas de queda grandes são eficientes na captura de espécies raras e de indivíduos jovens, provavelmente porque são menos seletivas, e são, portanto, essenciais para inventariar a rica e pouco conhecida fauna de pequenos mamíferos nos trópicos, assim como, para estudos demográficos.

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**LITERATURE CITED**

ADLER, G. H., AND T. D. LAMBERT. 1997. Ecological correlates of trap response of a neotropical forest rodent, Proechimys semispinosus. Journal of Tropical Ecology 13:59–68.

ANIMAL CARE AND USE COMMITTEE. 1998. Guidelines for the capture, handling, and care of mammals as approved by the American Society of Mammalogists. Journal of Mammalogy 79:1416–1431.

BEACHAM, T. D., AND C. J. KREBS. 1980. Pitfall versus live-traps enumeration of fluctuating populations of Microtus townsendii. Journal of Mammalogy 61:486–499.

BITTENCOURT, E. B., C. F. VERA Y CONDE, C. F. D. ROCHA, AND H. G. BERGALLO. 1999. Activity patterns of small mammals in an Atlantic
forest area of southeastern Brazil. Ciência e Cultura–Journal of the Brazilian Association for the Advancement of Science 51:126–132.

Boonstra, R., and C. J. Krebs. 1978. Pitfall trapping of Microtus townsendii. Journal of Mammalogy 59:136–148.

Brian, D. C., E. M. Vieira, and M. V. Vieira. 2001. Nests and nesting sites of Brazilian forest rodents (Nectomys squamipes and Orzyomys intermedius) as revealed by a spool-and-line device. Acta Theriologica 46:331–334.

Briese, L. A., and M. H. Smith. 1974. Seasonal abundance and movement of nine species of small mammals. Journal of Mammalogy 55:615–629.

Bury, R. B., and P. S. Corn. 1987. Evaluation of pitfall trapping in northwestern forests: traps arrays with drift fences. Journal of Wildlife Management 51:112–119.

Cechin, S. Z., and M. Martins. 2000. Eficiência de armadilhas de queda (pitfall traps) em amostragens de anfíbios e répteis no Brasil. Revista Brasileira de Zoologia 17:729–740.

Conroy, S. 1999. Lizard assemblage response to a forest ecotone in northeastern Australia: a systematical approach. Journal of Herpetology 33:409–419.

Corn, P. S. 1994. Straight-line drift fences and pitfall traps. Pp. 109–117 in Measuring and monitoring biological diversity: standard methods for amphibians (W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L.-A. C. Hayek, and M. S. Foster, eds.). Smithsonian Institution Press, Washington, D.C.

Dawson, G. A., and J. W. Lang. 1973. The functional significance of nest building by a neotropical rodent (Sigmoidon hispidus). American Midland Naturalist 89:503–509.

Doucet, G. J., and J. R. Bider. 1974. The effects of weather on the activity of the masked shrew. Journal of Mammalogy 55:348–363.

Eisenberg, J. F. 1981. The mammalian radiations—an analysis of trends in evolution, adaptation, and behavior. University of Chicago Press, Chicago, Illinois.

Enge, K. M. 2001. The pitfalls of pitfall traps. Journal of Herpetology 35:467–478.

Fonseca, G. A. B., G. Herrmann, Y. L. R. Leite, R. A. Mittemeier, A. B. Rylands, and J. L. Patton. 1996. Lista anotada dos mamíferos do Brasil. Occasional Papers in Conservation Biology 4:1–38.

Franci, K. E., W. M. Ford, and S. B. Castleberry. 2002. Relative efficiency of three small mammal traps in central Appalachian wetlands. Georgia Journal of Science 60:194–200.

Getz, L. L. 1961. Responses of small mammals to live-traps and weather conditions. American Midland Naturalist 66:160–170.

Gibbons, J. W., and D. H. Bennett. 1974. Determination of anuran terrestrial activity patterns by a drift fence method. Copeia 1974:236–243.

Goodman, S. M., and D. Rakotondravony. 2000. The effects of forest fragmentation and isolation on insectivorous small mammals (Lipotyphla) on the Central High Plateau of Madagascar. Journal of Zoology (London) 250:193–200.

Handley, C. O., Jr., and E. K. V. Kalko. 1993. A short history of pitfall trapping in America, with a review of methods currently used for small mammals. Virginia Journal of Science 44:19–26.

Hice, C. L., and D. J. Schmidly. 2002. The effectiveness of pitfall traps for sampling small mammals in the Amazon basin. Mastozoologia Neotropical 9:85–89.

Jones, C., W. J. McShea, M. J. Conroy, and T. H. Kunz. 1996. Capturing mammals. Pp. 115–155 in Measuring and monitoring biological diversity: standard methods for mammals (D. E. Wilson, F. R. Cole, J. D. Nichols, R. Rudran, and M. S. Foster, eds.). Smithsonian Institution Press, Washington, D.C.

Kalko, E. K. V., and C. O. Handle, Jr. 1993. Comparative studies of small mammal populations with transects of snap traps and pitfall arrays in southwest Virginia. Virginia Journal of Science 44:318.

Krebs, C. J., and R. Boonstra. 1984. Trappability estimates for mark–recapture data. Canadian Journal of Zoology 62:2440–2444.

Laurance, W. F. 1992. Abundance estimates of small mammals in Australian tropical rainforest: a comparison of four trapping methods. Wildlife Research 19:651–655.

Lyra-Jorge, M. C., and V. R. Pivelio. 2001. Combining live trap and pitfall to survey terrestrial small mammals in savanna and forest habitats, in Brazil. Mammalia 65:524–530.

McClearn, D., J. Kohler, K. J. McGowan, E. Credeno, L. G. Carbone, and D. Miller. 1994. Arboreal and terrestrial mammal trapping on Gigante Peninsula, Barro Colorado Nature Monument, Panama. Biotropica 26:208–213.

Maddock, A. H. 1992. Comparison of two methods for trapping rodents and shrews. Israel Journal of Zoology 38:333–340.

Martins, M., and M. E. Oliveira. 1999. Natural history of snakes in forests of the Manaus region, Central Amazonia, Brazil. Herpetological Natural History 6:78–150.

McNab, B. K. 1978. The comparative energetics of neotropical marsupials. Journal of Comparative Physiology, B. Biochemical, Systemic, and Environmental Physiology 125:115–128.

Mengak, M. T., and D. C. Guyitt. 1987. Pitfalls and snap traps for sampling small mammals and herpetofauna. American Midland Naturalist 118:284–288.

Miles, M. A., A. A. Souza, and M. M. Povoa. 1981. Mammal tracking and nest location in Brazilian forest with an improved spool-and-line device. Journal of Zoology (London) 195:331–347.

Moore, J. C. 1949. Notes on the shrew, Sorex cinereus, in the southern Appalachians. Ecology 30:234–237.

O’Farrell, M. J., W. A. Clarke, F. H. Emmerson, S. M. Juarez, F. R. Kay, T. M. O’Farrell, and T. Y. Goodlet. 1994. Use of mesh live traps for small mammals: are results from Sherman live traps deceptive? Journal of Mammalogy 75:692–699.

Oliveira-Filho, A. T., and M. A. L. Fontes. 2000. Patterns of floristic differentiation among Atlantic forests in southeastern Brazil and the influence of climate. Biotropica 32:793–810.

Pardini, R. 2004. Effects of forest fragmentation on small mammals in an Atlantic forest landscape. Biodiversity and Conservation 13:2567–2586.

Pardini, R., S. M. Souza, R. Braga-Neto, and J. P. Metzger. 2005. The role of forest structure, fragment size and corridors in maintaining small mammal abundance and diversity in a tropical forest landscape. Biological Conservation 124:253–266.

Percequillo, A. R., P. R. Gonçalves, and J. A. Oliveira. 2004. The rediscovery of Rhagomys rufescens (Thomas, 1886), with a morphological redescriptions and comments on its systematic relationship based on morphological and molecular (cytosome b) characters. Mammalian Biology 69:238–257.

Rayworth, C. J., and R. A. Nussbaum. 1994. A rain-forest survey of amphibians, reptiles and small mammals at Montagne-Dambre, Madagascar. Biological Conservation 69:65–73.

Ross, J. L. S., and I. C. Moroz. 1997. Mapa geomorfológico do Estado de São Paulo: escala 1: 500.000. FFLCH-USP, IPT e FAEPES, São Paulo, Brazil.

Sealander, J. A., and D. James. 1958. Relative efficiencies of different small mammal traps. Journal of Mammalogy 39:215–223.

Spencer, A. W., and D. Pettus. 1966. Habitat preferences of five sympatric species of long-tailed shrews. Ecology 47:677–683.
STEPHENSON, P. J. 1993. The small mammal fauna of Réserve Spéciale-d’Analamazaotra, Madagascar—the effects of human disturbance on endemic species diversity. Biodiversity and Conservation 2:603–615.

STEPHENSON, P. J., H. RANDRIAMAHAZO, N. RAKOTOARISON, AND P. A. RACEY. 1994. Conservation of mammalian-species diversity in Ambohitantely Special Reserve, Madagascar. Biological Conservation 69:213–218.

STOKES, M. K., N. A. SLADE, AND S. M. BLAIR. 2001. Influences of weather and moonlight on activity patterns of small mammals: a biogeographical perspective. Canadian Journal of Zoology 79:966–972.

VICKERY, W. L., AND J. R. BIDER. 1981. The influence of weather on rodent activity. Journal of Mammalogy 62:140–145.

VOSS, R. S., AND L. H. EMMONS. 1996. Mammalian diversity in neotropical lowland rainforests: a preliminary assessment. Bulletin of the American Museum of Natural History 230:1–115.

VOSS, R. S., D. P. LUNDE, AND N. B. SIMMONS. 2001. The mammals of Paracou, French Guiana: a neotropical lowland rainforest fauna—part 2. Nonvolant species. Bulletin of the American Museum of Natural History 263:3–236.

WILLIAMS, D. F., AND S. E. BRAUN. 1983. Comparison of pitfall and conventional traps for sampling small mammal populations. Journal of Wildlife Management 47:841–845.

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