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Optimized Pitfall Trap Design for Collecting Terrestrial Insects (Arthropoda: Insecta) in Biodiversity Studies

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Abstract

Pitfall traps are commonly used for the collection of terrestrial insects in ecology and biology studies; they are relatively straightforward to manufacture and there is a large variety of models described in the literature. However, they present a few drawbacks: (i) the removal and transport of the collected material are not practical; (ii) they have low resistance and durability; (iii) they fail to correctly protect the attractive bait against adverse weather conditions and scavengers, and (iv) evaporation of the liquid used inside the trap. We proposed an optimized pitfall trap design for terrestrial insect collection made from cheap and easily accessible materials. The new design allows the transfer of the collected material to the lab by removing only that part of the trap where the insects have been captured; the other part remains in its original place. Thus, the proposed trap allows easier operation since there is no need to transport water to replenish the traps after each transfer; in addition, there is less volume and weight to be carried. The trap can remain in the field for months because of the durability of its material. Furthermore, the collected material is better protected against adverse weather conditions and scavengers. Currently, an efficient and rapid sampling strategy in the field is of global interest to understand mechanisms that can contribute to the monitor changes in phenology, succession, and biodiversity.

Introduction

Problems associated with the logistics (e.g., monitoring of traps and transport of the collected samples) or the specificity (biological and/or ecological) of the organisms, as well as the need to map biodiversity, have constantly challenged researchers to develop and improve the equipment and sampling methods in field collections (Skvarla *et al* 2014; Shimabukuro *et al* 2015; Brown & Matthews 2016).

Pitfall traps, first mentioned more than 110 years ago (Dahl 1896), were developed to collect insects whose foraging habits are characterized by continuous displacement in search of food resources (Danchin *et al* 2008). Compared to other mechanisms used for collection, pitfall trapping has been considered the ideal method for sampling of ground-dwelling arthropods (Sabua & Shiju 2010), most commonly insects such as ants and beetles, and also other arthropods such as spiders (Bestelmeyer *et al* 2000; Southwood & Henderson 2000; Arbogast *et al* 2000; Phillips & Cobb 2005). During a period spanning decades, different materials were employed for making this type of trap, such as metal (Hertz 1927; Fichter 1941), glass (Barber 1931), and plastic (Brown & Matthews 2016). The simplest and most widespread model consists of a container buried at a ground level with an opening at the upper end, which remains static in the environment for as long as the researchers deem necessary for the collection of organisms of their interest (Skvarla *et al* 2014).

The size of the traps has been modified to suit the body mass of the target organisms for capture, resulting in a range of prototypes increasingly more efficient and diversified (Hancock & Legg 2012; Skvarla *et al* 2014). This variety has contributed to the emergence of methodological problems, including the lack of standardization of sampling in ecological studies (Adis 1979; Koivula *et al* 2003; Radawiec & Aleksandrowicz 2013), which may directly influence the sampling and introduce bias, or even alter, the interpretation of the investigations in a given study (Brown & Matthews 2016). This is especially worrisome in studies meant to inform conservation policies.

Coleoptera (Insecta) is the largest order of insects and represents about 30% in number of all known organisms in the animal kingdom (Bouchard *et al* 2011). They are present in almost all the habitats of the planet and are showing the most diverse types of eating habits (Marinoni *et al* 2001). Insects therefore constitute one of the groups of greatest abundance and diversity in studies using pitfall traps (Westberg 1977; Favila & Halffter 1997). The interest in saprophagous beetles—those which feed on decaying organic matter (carcasses, feces or vegetables)—has been increasing both in the environmental (e.g., Bohac 1999; New 2010; Niero & Hernández 2017) and the forensic fields (e.g., Luderwaldt 1911; Monteiro-Filho & Penereiro 1987; Kulshrestha & Satpathy 2001; Mayer & Vasconcelos 2013; Bonacci *et al* 2017). The type of bait that attracts them also draws the attention of other detritivores that feed on the same resource, so the use of more efficient methodologies for the collection of individuals with more specific behavior or food habits is necessary, mainly to avoid a misrepresentation of the dynamics of studies carried out in situations where the scavengers such as reptiles, birds, or mammals steal the baits to eat (Oliveira & Mendonça 2011).

Adverse weather conditions, lack of practicality, and time spent during the collection and transportation of the samples are problems that may negatively impact the field sampling process when using pitfall traps. Excess rainwater, for example, may cause loss of samples due to overflow. For this reason, some authors have developed techniques for draining the water inside the trap (Duffey 1972; Porter 2005), but this does not solve the problem of loss or dilution of the liquid used to capture the specimens. In addition, the number of pitfalls distributed in the field is directly proportional to issues such as practicality and time availability (Costa-Silva, pers. commun.). Because of the material from which they are made, the pitfall traps most commonly used today are only good for one or a few uses and require the collector to make a greater effort to remove and transport samples, since they generally need to be completely removed to access the samples. As a consequence, researchers often reduce the number of traps and replicas below the desirable amount.

The present study presents a new pitfall trap design that improves the efficiency of trapping by (i) minimizing the time for the removal and transport of the catch collected from the interior of the trap; (ii) increasing the life expectancy of traps through the use of more durable materials; (iii) protecting the trapping and preservation fluid contained within the trap from adverse weather conditions; and (iv) preventing the access of large detritivore animals to the baits.

Material and Methods

Material used in the new pitfall trap design

The proposed model uses ~ 20 cm of polyvinyl chloride (PVC) 75-mm-diameter pipe, 30 cm of 100-mm-diameter PVC pipe, two PVC caps 100 mm diameter, a 250-mL cylindrical plastic container suitable for the 100-mm PVC pipe (with 1.5 mm thickness and 4 mm of side edges to remain attached to the top of the 100 mm pipe), a polyurethane foam strip of 25 × 2 × 2 cm, cyanoacrylate adhesive for PVC, a piece of netting fabric (10 × 15 cm) with ~ 2 mm mesh size, and latex rubber bands.

The structure of the new pitfall trap

The basic structure of the trap is composed of an external and an internal component (Fig 1).

The external component contains the entrance cavities for the insects and the caps that seal the two ends of the trap; the inner part constitutes the container that houses and maintains the liquid fixative. For the construction of the external component, 30 cm of 100-mm PVC pipe is sealed at the lower end with a 100-mm PVC cap. The coupling and sealing can be performed with any PVC plastic adhesive. At the upper end, another 100-mm PVC cap is snapped (not glued) onto the pipe (Fig 1(b)), so that it can be removed, when necessary, to replace the bait or replenish the fixative liquid; its function is to protect both the fixative liquid from weather conditions and the bait from scavengers. The transparent plastic container, whose function is to accommodate the baits or other attractants, should rest against the inner edge of the upper end of the pipe, protected by the upper cap (Fig 1(g)). The upper cap must be drilled laterally (small holes up to 5 mm in diameter) to allow the escape and dispersion of the gases resulting from the process of decomposition of the baits used to attract the organisms to be collected (Fig 1(a)). Four laterally equidistant circular holes (each 6 cm in diameter) (Fig 1(c)) should be made in the upper third of the outer pipe to allow the entrance of the attracted organisms; the lower point of each of these circles should be used to demarcate the maximum level at which the trap can be buried in soil (Figs 1(d) and 2).

For mounting of the internal structure, a 75-mm PVC pipe must be sectioned at a maximum length of 20 cm; this size matches with the lower margin of the holes in the outer pipe, which will be the gateway to the organisms that will remain inside the trap after joining them (Fig 1(j)). We suggest that the polyurethane foam strip should be fixed with cyanoacrylate adhesive around the upper end of the inner pipe to prevent

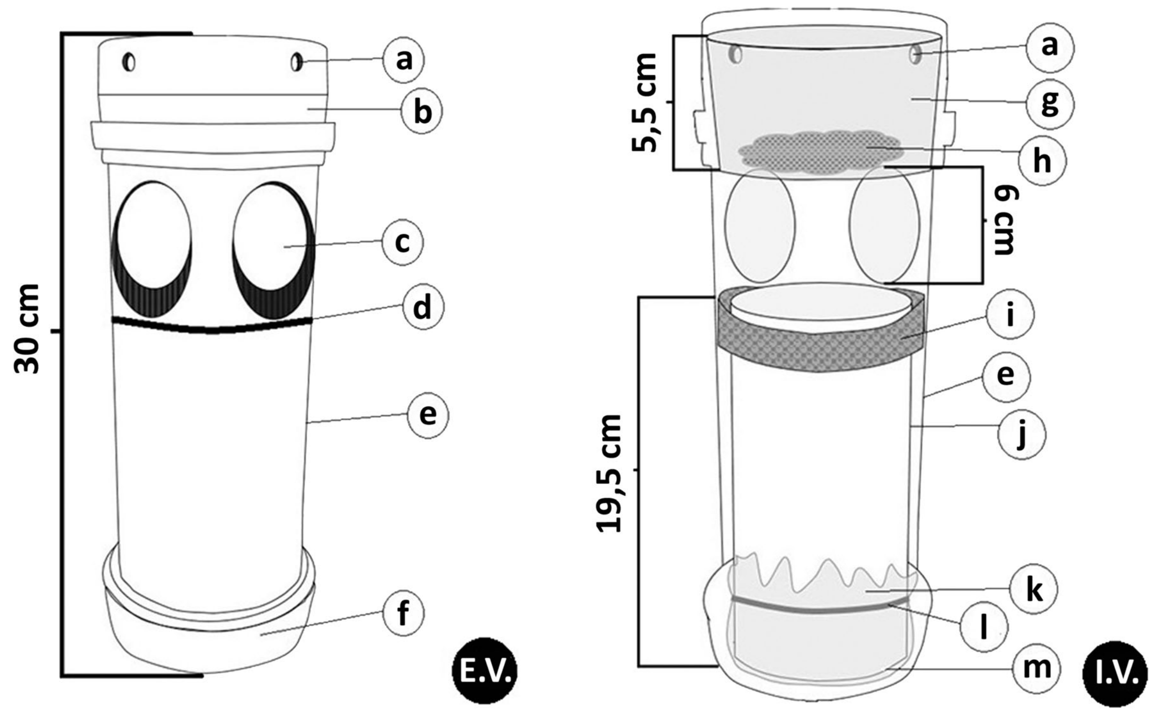

Fig 1 Schematic representation of external view (E.V) and internal view (I.V) of the new pitfall trap design proposed for the collection of terrestrial insects. (a) Holes for the exit of odors and gases; (b) cap for attractive bait protection against adverse weather conditions and scavengers; (c) holes for the entrance of organisms attracted to baits; (d) marking indicating where it should be in relation to the ground level; (e) external PVC structure of 100 mm diameter; (f) PVC cap of 100 mm diameter fixed to the lower end; (g) bait container; (h) attractive bait; (i) polyurethane foam fixed between the inner and outer parts of the trap; (j) PVC internal component 75 mm diameter; (k) netting/synthetic fabric; (l) latex rubber band; (m) rear end of the inner part.

insects from falling into the space between the outer and inner parts due to the difference in diameter between them (Fig 1(i)). The netting fabric (Fig 1(l)) should be fixed to the lower end of the pipe only with the aid of a latex rubber band (Fig 1(m)) to optimize the withdrawal of the samples present in the trap, as shown in Fig 2.

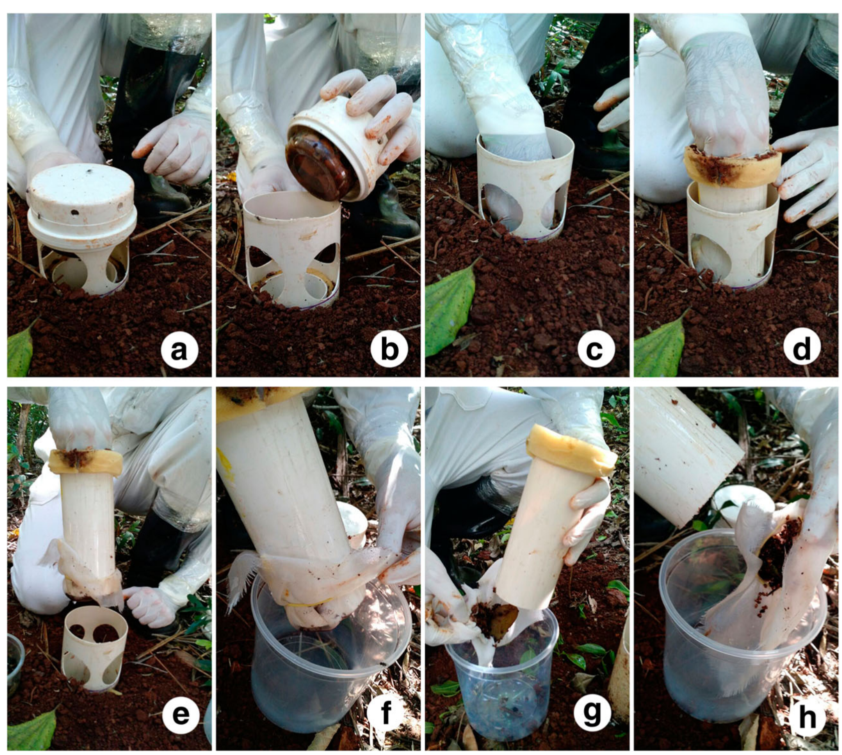

Fig 2 Sequence of steps in the removal of samples using the optimized pitfall trap design. **A** pitfall trap installed; **B** removal of the upper cap and the container containing the attractive bait; **C**, **D** removal of the inner part; **E** completely removed internal part; **F** positioning of the inner part for removal of netting fabric; **G**, **H** removal of trap content.

Comparative test between traps using beetles as models

The collections were made in five different fragments of vegetation and in preservation areas belonging to the Atlantic Forest biome (Campinas 22°48′18″S, 47°04′42″W; Vassununga State Park 21°43′15″S, 47°36′46″W; Morro do Diabo State Park 22°30′41.50″S, 52°21′26.47″W; Serra do Mar State Park 23°44′45.96″S, 45°55′45.80″W) and the Cerrado biome (Itirapina Experimental Station 22°13′20″S, 47°51′03″W) in the State of São Paulo, Brazil.

Twelve traps disposed in a 3 × 4 grid (Fig 3) were used in each of the five collection areas. Each grid contained six new pitfall traps (NPTs) and six conventional pitfall traps (CPTs) (Fig 4), laid out over four transects 100 m long and 100 m apart. In each grid, two transects were chosen to contain three NPTs each, and the remaining transects contained three CPTs each. Along each transect, the traps were 50 m apart (to ensure sample independence, as proposed by Larsen & Forsyth 2005). Each trap contained 200 g bait (chicken gizzard, rotten bovine kidney, and fresh human feces) also chosen randomly. Each trap received approximately 300 mL of water and 1 mL of liquid detergent. The samples were collected at the fourth day. After being appropriately separated, the samples were taken to the laboratory for screening and identification (Almeida & Mise 2009; Rafael *et al* 2012).

To evaluate the efficiency between NPT and CPT, a generalized linear mixed model (GLMM) was performed to compare family abundances per trap, considering a level of significance of $p < 0.05$. A Poisson distribution was used to model the count data with "type of trap" (i.e., NPT vs. CPT) as an explanatory effect and "site" as a random effect. A *t* test was performed, considering the same level of significance of *p*, in order to evaluate the hypothesis that a removable internal structure for pitfall trap would allow the investigator greater agility in the field, thus minimizing the time spent in the field during the collections; for this, a digital timer was used and the time spent to remove the specimens from the interior of each type of trap was registered. We also compared the trap communities of beetle family abundance in diversity (species richness *S*, Shannon-Wiener diversity *H*′) and similarity (Jaccard's *I*). Statistical analyses and ecological indexes were carried out with the help of R™ (R Core Team 2017) and DIVES™ (Rodrigues 2007), respectively.

To calculate the theft rate of baits, for each type of trap, the following equation was used: $\frac{\text{number of traps without baits at the end of the 4th day}}{6} \times 100$.

Results

Table 1 shows the comparative results between the two types of traps, NPT and CPT, respectively. In NPT, we collected 2583 specimens belonging to 14 families of Coleoptera, while in CPT, we collected 2185 specimens of 11 families. The mean values for abundance of all beetle families showed a significant difference between the two collection methods ($\chi^2 = 30.238$; $p = 0.001$). We did not find significantly different trapping efficiencies between trap types in beetle families with a wide range of trophic preferences (necrophagous, copronecrophagous, saprophagous, xylophagous, phytophagous, mycophagous, and generalists), with two exceptions: one and one-half times more scarabs (coprophagous) were collected at CPT, and predators (Histeridae, Silphidae, Staphylinidae, and Carabidae) were found to be more abundant in NPT ($n = 404$) than in CPT ($n = 168$).

Species richness and diversity in NTP ($S = 14$; $H' = 0.9361$) were higher than those in CPT ($S = 11$; $H' = 0.7462$). The

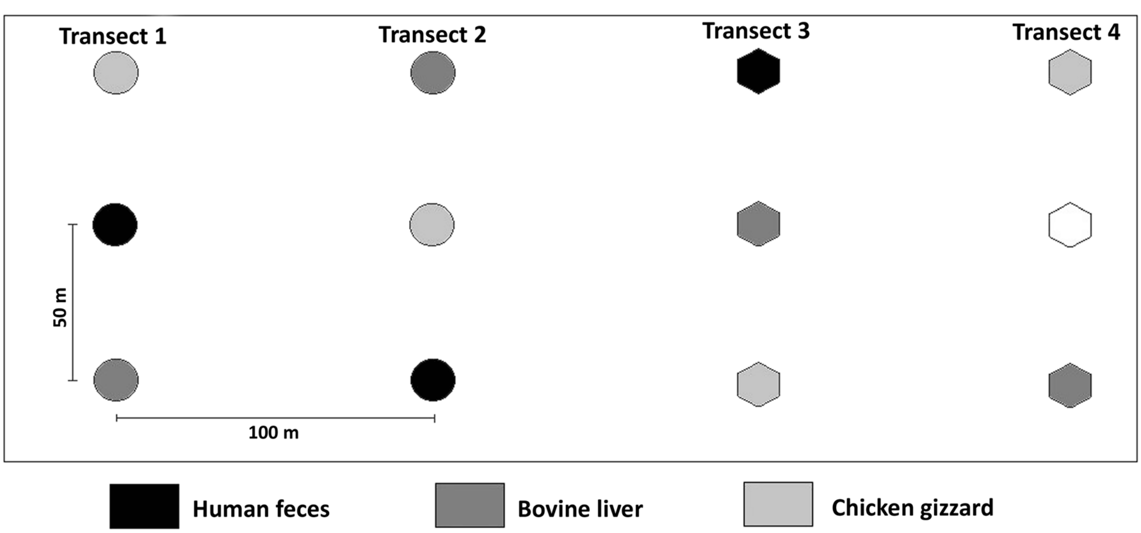

Fig 3 The 3 × 4 grid used for arrangement of traps in each of the five collection areas.

Fig 4 Conventional pitfall trap used in this study.

Jaccard index showed that there was similarity (*I* = 0.6667) in faunistic composition, at the family level, between the two traps, with the presence of ten families in common.

The analysis of the time needed to collect the trapped specimens from the interior of the trap showed that NPT ranged between 15 and 20 s, while for CPT between 80 and 90 s. This difference was significant ($t = 5.1798$; $p = 0.0004$).

The theft rate of baits by scavengers varied between 6.7 and 50% for CPTs, whereas none of the bait was stolen from NPTs (Table 1).

Discussion

The optimized pitfall trap design responded well to the problems of the type and durability of the material, the practicality of the collection, and the protection offered to the resource (bait) used for the attractiveness of a given target group.

Comparing costs and material durability between the NPT and CPT, the first takes advantage over the second when considered the time factor: each new trap made of PVC has a cost of approximately US$ 5 against US$ 1 considering all the material used for the confection of the conventional trap; however, PVC pipes have high resistance to corrosion and the action of time, they last around 25 years, can reach 45 with good care and maintenance (Medeiros & Wiebeck 2013),

Table 1 Abundance (*n*), relative abundance (% in parentheses), species richness (*S*), Shannon-Wiener diversity (*H*′), Jaccard's similarity (*I*), and trophic preference of collected beetles by family, including the theft rate of baits (%), in five different locations in comparing both trap designs, new pitfall traps (NPTs) and conventional pitfall traps (CPTs).

Sampled areas/families	New pitfall trap (NPT)						Conventional pitfall trap (CPT)						Trophic preference
	SM *n*	CP *n*	IT *n*	VA *n*	MD *n*	Total *n* (%)	SM *n*	CP *n*	IT *n*	VA *n*	MD *n*	Total *n* (%)	
Hybosoridae	0	1922	0	0	0	1922 (74.41)	0	1672	0	0	0	1672 (76.52)	n
Scarabaeidae	130	14	14	63	14	235 (9.10)	208	20	24	112	30	394 (18.03)	c, n, cn
Histeridae	4	25	2	18	190	239 (9.25)	0	16	5	0	30	51 (2.33)	p
Silphidae	8	65	2	8	16	99 (3.83)	0	9	0	1	1	11 (0.50)	p, n
Staphylinidae	11	20	17	12	5	65 (2.52)	0	26	3	2	13	44 (2.01)	p
Leiodidae	3	0	0	0	2	5 (0.19)	0	3	0	0	1	4 (0.18)	n
Trogidae	3	0	0	0	0	3 (0.12)	5	0	0	0	0	5 (0.23)	n
Tenebrionidae	0	0	4	0	0	4 (0.15)	0	0	0	0	1	1 (0.05)	g
Nitidulidae	1	3	0	0	0	4 (0.15)	0	1	0	0	0	1 (0.05)	s
Curculionidae	2	0	0	0	0	2 (0.08)	0	0	0	1	0	1 (0.05)	ph
Dermestidae	0	0	0	0	2	2 (0.08)	0	0	0	0	0	0 (0)	n
Scolytidae	0	0	0	0	1	1 (0.04)	0	0	0	0	0	0 (0)	x
Elateridae	0	0	0	0	0	0 (0)	0	0	0	0	1	1 (0.05)	s
Ptiliidae	0	1	0	0	0	1 (0.04)	0	0	0	0	0	0 (0)	m
Carabidae	0	1	0	0	0	1 (0.04)	0	0	0	0	0	0 (0)	p
Total	162	2051	39	101	230	2583 (100)	213	1747	32	116	77	2185 (100)	–
Theft rate (%)	0	0	0	0	0	–	6.7	50	13.6	0	13.6	–	
Richness (*S*)				14						11			
Diversity (*H*′)				0.9361						0.7462			
Similarity (*I*)							0.6667						

SM Serra do Mar State Park, *CP* Campinas, *IT* Itirapina Experimental Station, *VA* Vassununga State Park, *MD* Morro do Diabo State Park, *c* coprophagous, *cn* copronecrophagous, *g* generalist, *m* mycophagous, *n* necrophagous, *p* predator, *ph* phytophagous, *s* saprophagous, *x* xylophagous.

while plastics made of polyhydroxybutyrate (base material of CPTs) have a durability estimated from 6 months to 2 years (Pachekoski *et al* 2009). After 12 months of testing, our traps remained intact and in perfect condition for immediate use.

The new trap design proposed in this paper is based on the work done by Work *et al* (2002), who used equipment with different diameters (4.5, 6.5, 11, 15, and 20 cm). We modified this design in order to have a trap that did not select, by size, against certain taxa and groups of organisms. In our NPTs, specimens ranging from 0.5 mm to 7 cm in length were effectively sampled, showing that the trap is appropriate for collecting both small and large specimens.

Different trap depths (i.e., the length of the buried part) have shown not to influence the rate and diversity of individuals collected. For example, larger insects such as species belonging to the genus *Coprophanaeus* Olsoufieff, 1924 (Coleoptera, Scarabaeidae), which generally range between 2 and 6 cm, can escape from shallow traps (i.e., those less than 10 cm deep, Pendola & New 2007), resulting in a false absence of this genus. We included these experiences into our design of the NPT (whose collector pipe depth is ~ 20 cm) which successfully prevented the escape of this and similar larger species.

Our results show that the development of a removable internal trap structure, which is being proposed for the first time in this study, led to a greater efficiency in fieldwork by reducing the time needed for the collection of samples by almost 80%. This is extremely advantageous and one of the strongest points of the NPT, because most of the field work involves the installation of a large number of traps, which sometimes have to be sampled on a daily bases, for example if the researcher does not always have a large team to assist him/her. Another factor in which this new design saves a lot of time, in special in studies that involve years of monitoring, is that the external part of the trap can stay in the soil for several years until enough samples were gathered; thus, there is no need to excavate the soil in each sample campaign. The internal structure associated with the netting fabric attached to its lower contributes to the preservation of the fixative liquid, since the samples in this type of system are only filtered, leaving most the liquid inside the trap. The researcher does not need to replace the fixative liquid on a regular basis, which reduces both the time to check the pitfall traps and the financial resources needed for their maintenance, as well as reduces the volume and weight of the material to be transported to and from the field.

As seen in the calculations of similarity, the faunal composition was not substantially affected by the fact that the new trapping device was closed on the upper surface, which agrees to the observations by Work *et al* (2002), who first proposed this design element. On the contrary, the diversity of the community obtained in the new protected NPTs was higher than that in unprotected CPTs. In the field, NPTs showed signs of external depredation, probably performed by large scavengers, but the baits remained intact inside the traps throughout the exposure period while in the CTPs, the attractive substrates often did not last 24 h. According to Ferguson & Forstner (2006), the protection of the trap bait against possible predators and/or scavengers is important to guarantee accuracy and performance in studies aiming to sample organisms attracted to a particular type of food. In our studies, we focused on saprophagous insects; however, the NPT can easily be adapted to capture organisms with different trophic and behavioral habits by changing the type of bait. For example, our new trap design was useful to generate a list of carrion fly species that use the bait as a site of oviposition and larviposition) (Ansaloni *et al* 2017). In turn, eggs and larvae of dipterans attract certain species of beetles, thus explaining the abundance of the latter in the NPTs. We are confident that researchers could use any other chemical attractant—for a summary of those, see the different types of baits in the catch rate in Zumr & Starý (1992).

In addition to time efficiency, durability, and versatility, NPTs were also more successful to withstand adverse weather conditions compared to CPTs. There was no change in the level of the preservative liquid of NTPs even under heavy rainfall (we recorded accumulated daily precipitations ranging from 9 to 12 mm). In contrast to this, fluid levels in CPTs increased substantially due to lack of protection. The increase in the volume of liquid inside the collecting containers can be a great problem for researcher. First, the dilution of the fixative components can promote the decomposition of the collected material (Holland & Reynolds 2005) and overflows lead to a substantial loss of collected specimen. Thus, the protection provided by NTPs may eliminate the chance for under-representation of taxa in quantitative studies.

In summary, the new pitfall trap design presented and tested could be validated as a more efficient methodology for collecting organisms that move at the ground level. There is a global need for efficient and rapid field sampling methods that are needed to investigate the mechanisms that may contribute to the maintenance and changes in biodiversity.

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