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Adapting a Traditional Hunting Technique to Improve Capture Rates for the Endangered Yellow-footed Tortoise (*Chelonoidis denticulatus*) during Ecological Surveys in Amazonia

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Abstract. The lack of cost-effective methods to detect game species in tropical forests hinders reliable assessments of their population status and the planning of effective actions for their sustainable use. Tortoises are among the most hunted species in Amazonia, but present low detectability in the wild when using current scientific methods. Traditional hunters in the region use specialized methods to capture tortoises, and such knowledge could provide useful insights for improving monitoring methods and, thus, scientific research on this species. Here, we compare the capture rates and cost-effectiveness of two methods to capture the endangered yellow-footed tortoise (*Chelonoidis denticulatus*) in Amazonia: the conventional active search and an adaptation of pitfall traps using attractive baits employed by Indigenous and non-Indigenous people to hunt tortoises. We sampled 40 sites in upland forests and whitewater flooded forests during the dry and wet seasons in central Amazonia and captured 37 yellow-footed tortoises. The highest capture rate (0.29 tortoises/hour) was obtained using traps in upland forests, fourfold higher than by active search. Traps also presented greater cost-effectiveness than the active search (US$63 vs US$256 per captured tortoise). Our capture rate with traps was 67 times greater than those obtained using line transects in western and northern Amazonia. The success exhibited by this widespread hunting technique is a result of centuries of hunters' traditional knowledge in the Amazon. The unveiling of a cost-effective method for capturing tortoises shows the importance of exchanging traditional and scientific knowledge; efficient capturing methods favor the inclusion of the species in long-term monitoring programs and foster in situ studies that help develop strategies for its conservation.

Keywords: *Geochelone*, local ecological knowledge, citizen science, pitfall trap, ethnozoology.

Introduction

Obtaining successful detections and captures of wild species for scientific purposes has been a challenge worldwide (Berish and Leone 2014; Zylstra et al. 2010). The lack of cost-effective scientific methods to detect and oftentimes capture wild animals hinders the reliable estimates of distribution, abundance, and population trends; however, these are crucial parameters for planning management strategies and for assessing species' conservation status (Nomani et al. 2008). For several tropical game species, studies on reproductive parameters and carrying capacity are often conducted in captivity (Robinson and Bennett 2000). However, the information collected from captive populations can differ widely from that of wild populations, leading to management actions that may be biased and result in overharvesting (Mayor et al. 2017).

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The lack of biological information is even more pronounced for rare or elusive species, such as terrestrial chelonians (turtles, terrapins, and tortoises), which are highly targeted by hunters in tropical forests, but which typically present low detection and capturing rates in scientific research, implying high effort and considerable costs for sampling (Balestra et al. 2016; MacKenzie et al. 2002; Zylstra et al. 2010). For instance, most of the current biological and ecological data for the yellow-footed tortoise (*Chelonoidis denticulatus*) comes from captivity due to its cryptic behavior in nature (Ferrara et al. 2017; Noss et al. 2013; Wang et al. 2011). This species is widely distributed in the Amazon and is listed among the top hunted species for subsistence consumption, urban trade, and the pet market throughout its distribution area (Aquino et al. 2007; Bisbal 1994; Peres 2000; van Vliet et al. 2014). The yellow-footed tortoise was considered the most depleted game vertebrate across the Brazilian Amazon (Parry and Peres 2015); its unsustainable hunting was detected by a 12-year-long hunting monitoring study in the Central Amazon (Morcatty and Valsecchi 2015a). As a consequence of this intense use, the yellow-footed tortoise is currently categorized as Vulnerable by the International Union for Conservation of Nature (IUCN) and it is included on Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Turtle Taxonomy Working Group 2017).

Although impacts of hunting on yellow-footed tortoise populations have been reported, the species' life-history parameters required for developing conservation and management actions remain unknown due to the lack of effective methods to detect and capture this species (Vogt et al. 2015). Unlike marine and freshwater chelonians, few methods have been created for surveying tortoises (Balestra et al. 2016; Walker 2012). Line-transect sampling is widely regarded as an effective method to conduct population estimates of some tortoise species (Anderson et al. 2001; Balestra et al. 2016; Nomani 2008; Stevenson et al. 2007; Walker et al. 2013); however, this method is often only effective in open environments (e.g., Anderson et al. 2001; Nomani 2008; Strong and Fragoso 2006). Environmental factors, therefore, may influence the performance of different methods. For instance, in dense vegetation, the majority of tortoise specimens remain hidden under the shrubbery, which restricts the observer's capacity to spot tortoises (Guzmán and Stevenson 2008). For example, individuals of Madagascar spider tortoise (*Pyxis arachnoides*) are normally detected within only 3 meters of perpendicular distance to the center of the transects, leading to a 50% underestimation of the population size when compared to the active search method (Walker 2012; Walker et al. 2013).

Although the active search method may provide reliable population estimates for tortoises in several environments (e.g., Kaddour et al. 2006; Williams and Parker 1987), this technique can be considerably expensive and exhaustive (Nomani 2008; Nussear et al. 2008). In addition to these techniques, unbaited pitfall traps have been successfully applied in Gopher tortoise (*Gopherus polyphemus*) studies, in which the traps were positioned directly in front of burrow openings dug and inhabited by this species (Berish et al. 2012; Enge et al. 2012; Wendland et al. 2010). In tropical forests, unbaited pitfall traps have been typically used to monitor other reptile taxa, such as lizards and snakes, but these rarely capture tortoises (Garden et al. 2007). On the other hand, pitfall traps with bait were applied once for the yellow-footed tortoise but had an unsatisfactory capture rate (Guzmán and Stevenson 2008). Given that tortoises can change their activity patterns and food preferences between seasons, the effect of seasonality on tortoise capture rates should also be considered (Jerozolimski et al. 2009; Noss et al. 2013; Wang et al. 2011).

In this context, traditional hunting techniques based on local ecological knowledge of local people show great potential to improve scientific methods in both efficiency and cost-effectiveness (Moller et al. 2004). For instance, El Bizri et al. (2016) compared a traditional hunting technique to a conventional scientific method to capture lowland pacas (*Cuniculus paca*) in Amazonia and found that the local hunting technique was four times more efficient. The use of traditional pitfall traps mimicking natural forest floors and including body parts of wild animals as attractive baits, i.e., caimans, anteaters, peccaries, and fish, is traditionally applied by Amazonian people to hunt tortoises (Álvares 1997; Huntington 2000; Tavares et al. 2020), and this technique may be adapted to be used as a scientific method and improve the species' capture rates.

In this study, we compared the capture rates and the cost-effectiveness of two methods for capturing the endangered yellow-footed tortoise in the Amazon, accounting for the habitat type and seasonality. We compared the conventional active search method with an adaptation of the local pitfall traps using attractive baits employed by local inhabitants to hunt tortoises. Based on our results, we discuss the advantages and disadvantages of each of the methods employed and make recommendations for future studies on the species.

Material and Methods

Study Area

We conducted this study in the Amanã Sustainable Development Reserve (ASDR), located in the middle region of the Solimões River, in the Brazilian Amazon (03°16′ S; 65°23′ W) (Figure 1). The ASDR comprises 2350 km² and is predominantly comprised of upland forests (*terra firme*), whitewater seasonally flooded forests (*várzea*), and small areas of blackwater flooded forests (*igapó*). The mean annual rainfall in the ASDR is 2857 mm, and the mean annual temperature is 26.6 °C. The local seasons are divided according to the water level: high-water period (May–July); receding water level (August–September); low-water period (October–January); and rising water level (February–April) (e.g., Paim et al. 2017). The ASDR has a human population of approximately 4000 inhabitants that live in 23 communities and some isolated settlements.

Data Collection

We performed the fieldwork between August 2013 and July 2015 to compare the efficiency and costs of methods for capturing yellow-footed tortoises. To account for potential differences between habitat types, we surveyed 20 sites in upland forests and 20 sites in whitewater flooded forests (Figure 1). To account for potential differences between seasons, each site was sampled twice in a year, once in the dry season and once in the wet season. Here, we consider as the dry season the low-water period (September–January) and as the wet season the high-water period (May–July). In each site and season, we applied two capture methods, the active search and the baited pitfall traps.

The active search was conducted first in order to avoid any influence of the bait attractiveness on the capture rates. To ensure comparability between methods, the pitfall trap was applied within or near the path where the active search was performed. The research assistants participating in this study were local hunters specialized in hunting tortoises, and the same research assistants sampled the wet and dry seasons and built the traps for each site. Considering the species average home range of 0.8 km² (Tavares et al. 2019), all sites were at least 1 km apart to guarantee independence between samples. We measured the maximum straight-line length (CL) of the carapace of all captured individuals and sexed individuals with CL $>$ 250 mm. Individuals with CL $\leq$ 250 mm were considered as juveniles and were not sexed due to the absence of external morphological dimorphism (Rueda-Almonacid et al.

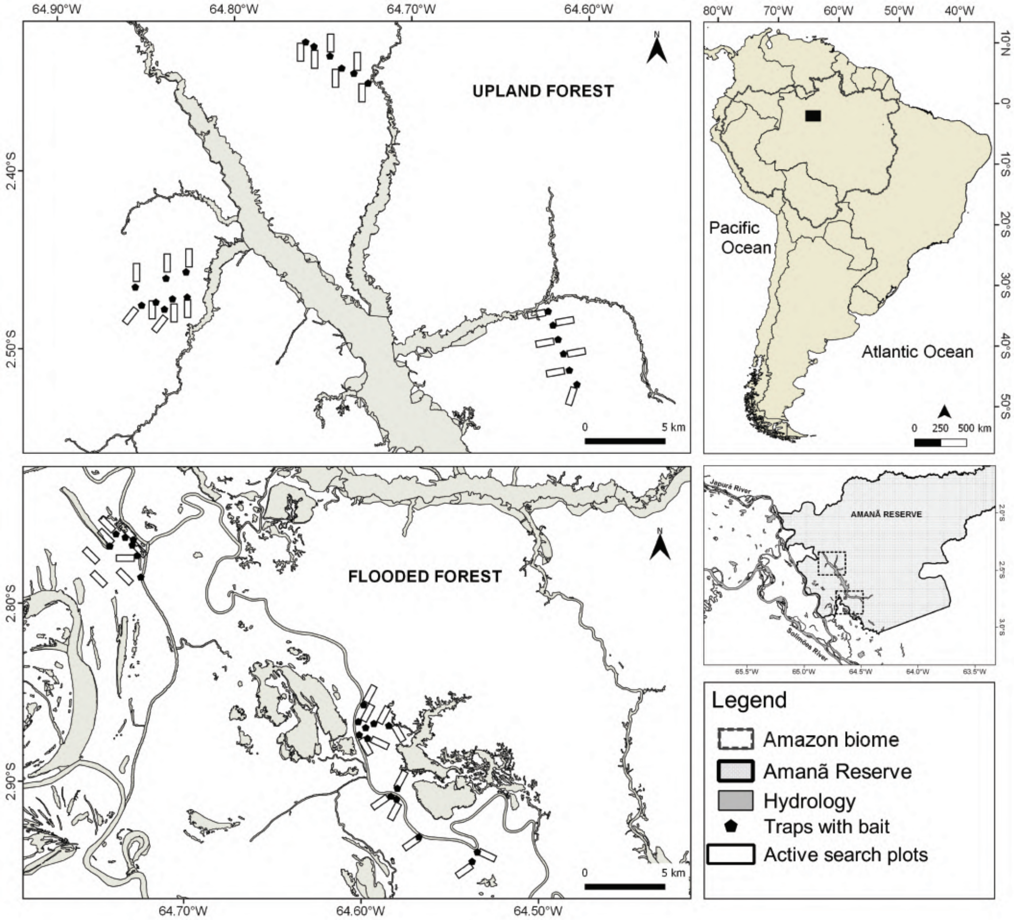

Figure 1. Map of the Amanã Sustainable Development Reserve, Central Amazonia, showing the study area and the 40 traps with bait and 40 active search plots used to capture individuals of *Chelonoidis denticulatus* in upland forest and whitewater flooded forest.

2007; Tavares et al. 2019). The study was approved by the Instituto Chico Mendes de Conservação da Biodiversidade (License SISBIO no. 40358-3) and the Committee on the Ethical Use of Animals and Plants for Research of the Mamirauá Institute (Protocol no. 010/2013).

Active Search

Both in upland forests and whitewater flooded forests, we defined two adjacent upland and lowland patches in each surveyed site to perform the active search on the same day and considered these two patches as a plot. In each patch, we searched for tortoises under the debris piles and fallen trees once per season. We covered 0.5 ha on each upland patch and 0.5 ha on each lowland patch, totaling 1 ha a per plot and 40 ha per season. To guarantee constancy in environmental characteristics along the search in each patch, we used a clinometer to define the patch and performed the search over the same slope and elevation. During the wet season, since all land in the whitewater flooded forest was flooded, the active search was conducted from a canoe, searching for tortoises floating on the water or on branches of flooded trees (as seen by Morcatty and Valsecchi 2015b). All searches were performed accompanied by an experienced tortoise hunter in order to maximize the capture rate.

Trap with Bait

The trap with bait consisted of an adaptation of a hunting technique employed by several traditional inhabitants of the Amazon, already recorded for Indigenous peoples, such as Maijuna, Kichwa, and Kukama-Kukamilla in the Peruvian Amazon, and for non-Indigenous people (*mestizos*) in the central Brazilian Amazon (Tavares et al. 2020). In each site, we followed hunters' suggestions to 1) dig a hole in the ground measuring 1 m in diameter and 0.7 m in depth; 2) cover the hole with dry leaves supported by green palm leaves, simulating a false floor; and 3) place a bait inside a container suspended between a simple wooden frame (Figure 2). The bait was locked within a porous suspended container, which allowed the odor to spread while avoiding the bait being consumed by a tortoise in an eventual capture. We used a 0.2 kg mix of fish species suggested by local hunters as a bait, namely Amazon sailfin catfish (*Pterygoplichthys pardalis*), Trahira (*Hoplias malabaricus*), and black piranha (*Serrasalmus rhombeus*). For all sampled sites, each portion contained at least two of the above-mentioned species in similar proportions, although a mix of all three was preferable. The fish used were donated by local inhabitants, who often incidentally catch these species in their fishing nets, because they are less appreciated as food in the region. We used one trap per site, which remained open for seven days. We checked all traps at the same time once a day and replaced the bait every two days. The trap features were optimized to prevent

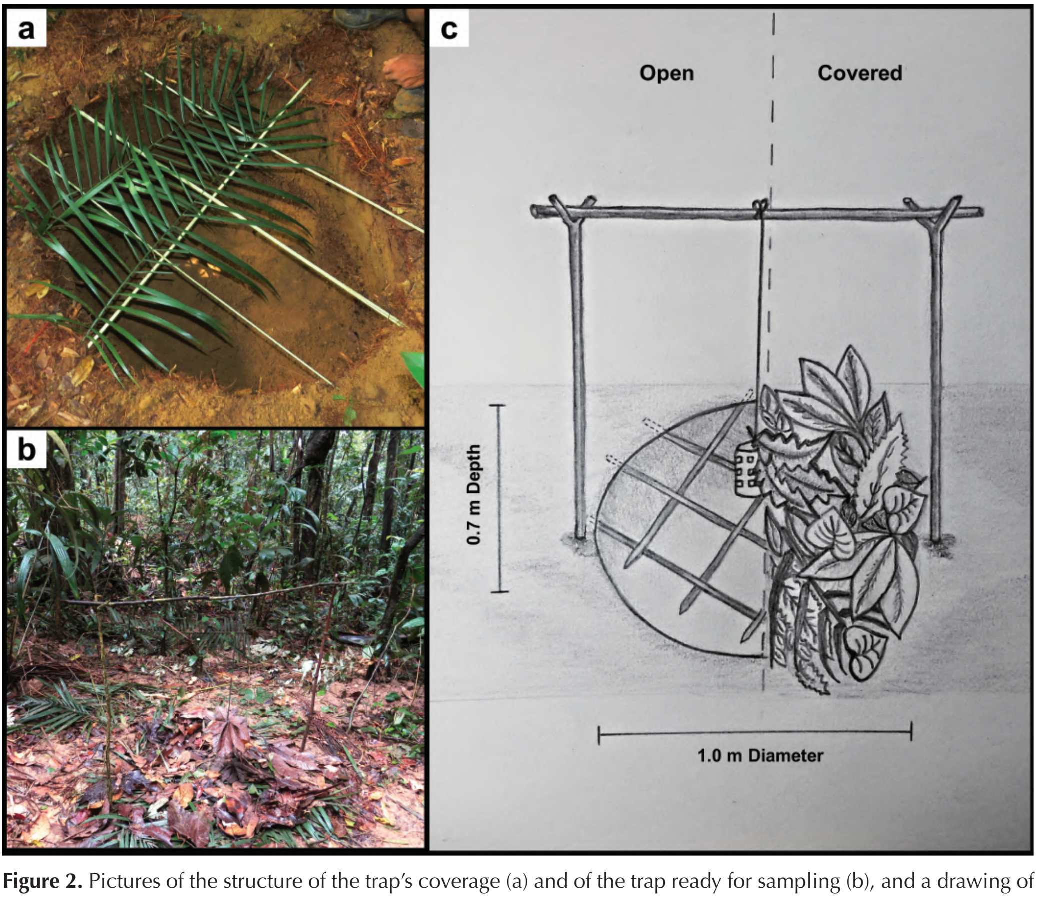

Figure 2. Pictures of the structure of the trap's coverage (a) and of the trap ready for sampling (b), and a drawing of the trap with bait designed based on local hunting knowledge (c) for capturing *Chelonoidis denticulatus* specimens.

the tortoise from leaving and at the same time to reduce the potential for catching individuals of another species. The height and diameter of the hole were designed to allow medium- and large-sized animals to step out from the hole in case they were caught, while small animals were able to climb its walls. Due to the natural flooding period in the study area, the whitewater flooded forest could not be sampled with traps during the wet season. All captured individuals were released at the same place of capturing immediately after individual measurements. No captured individual was injured during this research.

Data Analysis

The time spent by a person to perform each method was unequal between methods, i.e., we spent three hours sampling one site each day for the active search and up to 20 minutes to check and work on the maintenance of each trap at the same site. In order to make both methods comparable, we also estimated the number of tortoises captured by the baited trap, corrected for equal personnel efforts, by considering a standard personnel effort of three hours per day during one-week sampling.

We used E-tests for Poisson distributed data (Krishnamoorthy and Thomson 2004) with Bonferroni correction for multiple comparisons to assess differences in the number of captures between methods, environments, and seasons. We calculated the 95% confidence interval (95% CI) for captures using Wald's equation with continuity correction for small values (less than or equal to 4) (Schwertman and Martinez 1994) and Wilson and Hilferty's (1931) equation for values higher than four captures. Results were considered significant at $p < 0.05$; when the Bonferroni correction was applied, the critical value decreased to $p < 0.0125$.

Afterwards, we calculated the costs for preparing the traps or plots (i.e., digging the hole on the ground or measuring topography) and for the surveying procedures, considering the materials and personnel effort needed to conduct the surveys. We considered as "preparation costs" those investments to set the plots for the active search and build the traps, and as "surveying costs" those during the standardized period designated for capturing the tortoises (i.e., the actual searching or the baited trap opened; Table 1). We disregarded the travel costs since both methods were applied at the same sites. To calculate the cost of personnel effort, we considered a payment of US$10 (~ 35 Brazilian Real) per working day, a value based on the common compensation for local day wages in the ASDR.

We calculated the cost-effectiveness of the methods by dividing the number of captured tortoises per cost of each technique (tortoise US$$^{-1}$) (as used by El Bizri et al. 2016). We calculated the confidence intervals for cost-effectiveness values using the 95% CI range calculated for the captures. We considered that cost-effectiveness values were distinct between methods when their 95% CI did not overlap. In this work, we considered R$3.50 (Brazilian Real) = US$1. We used Quantum GIS 2.18.9 for building the map.

Results

We captured 37 yellow-footed tortoises, 20 by active search and 17 by traps (Table 1). However, after adjusting for equal effort between methods, we estimated that the number of individuals captured by traps would increase to 29; 22 in the upland forest (17 in the dry season and five in the wet season) and seven in the whitewater flooded forest (dry season only) (Figure 3; Table 1). Half of the tortoises captured by active search were obtained in the wet season using a canoe, when applying traps was impracticable (Figure 3).

We captured 22 adult females, 10 adult males, and five juveniles. The average carapace length (CL) was 370 mm (±72) for males, 318 mm (±81) for females, and 177 mm (±37) for juveniles. Two tortoises were re-captured in the same trap in a subse-

Table 1. Number of individuals of yellow-footed tortoise (*Chelonoidis denticulatus*) captured and the capture rates (tortoise per hour) per method, environment, and season. The numbers in parenthesis represent the Exact Poisson 95% Confidence interval.

	Season	Parameter	Methods		
			Active search	**Trap with bait**	**Trap with bait estimated**[+]
Upland forest	Dry	Individuals captured	4 (-0.17-8.66)^{Aa}	10 (4.79-17.09)^{Ab}	17 (9.90-25.98)^{Ab}
		Capture rate[*]	0.07 (0.02-0.17)	0.29 (0.14-0.53)	0.29 (0.14-0.53)
	Wet	Individuals captured	2 (-0.90-5.60)^{Aa}	3 (-0.60-7.17)^{Aa}	5 (1.61-10.24)^{Ba}
		Capture rate[*]	0.03 (0.004-0.12)	0.09 (0.02-0.25)	0.09 (0.02-0.25)
	Total		6 (2.19-11.67)^{a}	13 (6.92-20.96)^{b}	22 (13.78-32.10)^{b}
Whitewater flooded forest	Dry	Individuals captured	4 (-0.17-8.66)^{Aa}	4 (-0.17-8.66)^{Aa}	7 (2.80-13.06)^{ABa}
		Capture rate[*]	0.07 (0.02-0.17)	0.11 (0.03-0.29)	0.11 (0.03-0.29)
	Wet	Individuals captured	10 (4.79-17.09)^{A}	-	-
		Capture rate[*]	0.17 (0.08-0.30)	-	-
	Total		14 (7.65-22.23)	4 (-0.17-8.66)	7 (2.80-13.06)
Total			20 (12.21-29.67)	17 (9.90-25.98)	29 (19.42-40.47)

[*] Capture rates were calculated using a total effort of 60 hours for the active search and trap with bait estimated, and 35 hours for trap with bait.
[+] Captures were estimated using the same effort applied during the sampling with active search (60 hours).
Different capital letters indicate statistical differences between lines within each column, while different lowercase letters indicate statistical differences between columns within each line.

quent day after the first capture; due to the interdependence of the records, they were not considered in the method comparison. No animals other than tortoises were captured in the traps, although footprints and signs of other vertebrates were commonly recorded, such as deer, agoutis, opossums, and vultures. All tortoises recorded presented no injury resulting from the capture.

Overall, higher capture rates were obtained using traps in comparison to the active search (Table 1). In the upland forest, we captured ~ four times more tortoises using traps in comparison to the active search during the dry season ($p < 0.01$), representing the greatest capture rate obtained (0.29 tortoises per hour^{-1}). In addition, comparing both types of active search applied (canoe or on foot), the active search on canoe amidst the flooded forest yielded between two and five times more captures than on foot, especially comparing between wet seasons. Usually, the dry season tended to yield more captures than the wet season, although statistical significance was only detected for the trap (Table 1). Using the trap, we captured three times more tortoises in the dry season than in the wet season ($p = 0.001$).

While the active search method required slightly more investment for preparing each plot before sampling, the traps demanded slightly more investment for survey conduction (Table 2). Considering both preparation and surveying costs, the traps presented a cost-effectiveness value greater than the active search for the upland forest in the dry season ($p < 0.001$): US$62.74 against US$256.29 per tortoise captured, respectively (Table 3). Although the cost-effectiveness for the whitewater flooded forest was also higher using traps (US$152.37 per tortoise) than using active search (US$256.29 per tortoise) during the dry season, the greatest cost-effectiveness found for this environment was obtained by active search in the wet season, which demanded US$102.52 per tortoise captured.

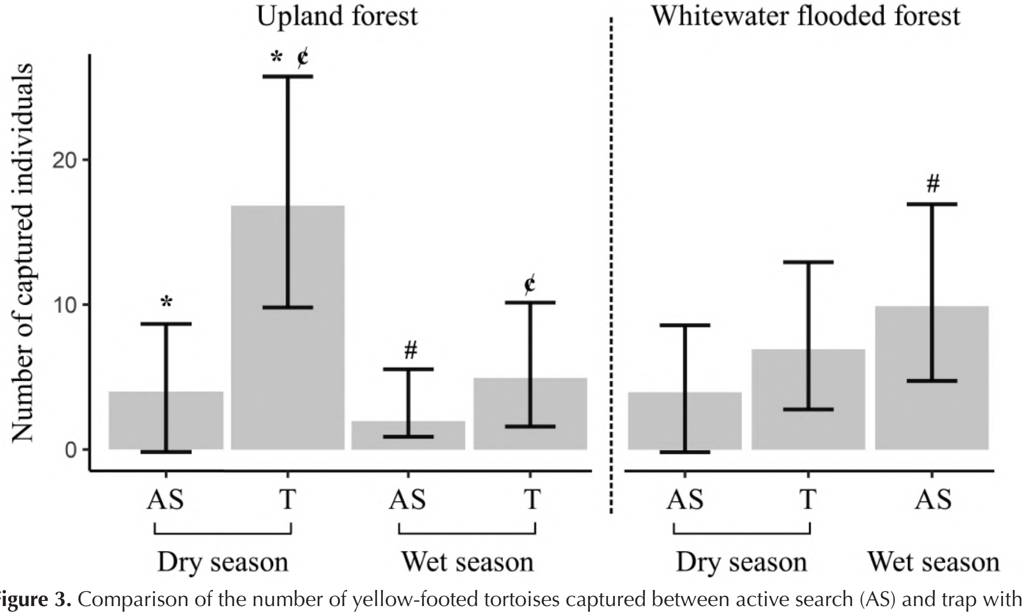

Figure 3. Comparison of the number of yellow-footed tortoises captured between active search (AS) and trap with bait (T) within and between seasons and environments. Captures by trap were corrected using the same effort applied for active search as standard (60 hours). Equal symbols represent significant difference between classes ($p < 0.0125$ after Bonferroni corrections).

Table 2. Costs of the items necessary for implementation and conduction of both capturing methods, the active search and the trap with bait.

Item	Purchase unit	Price per unit (US$)	US$ (No of items)	
			Active search	Trap with bait
Preparation of plots and traps				
Personnel[a]	assistant	11.43	137.16 (12)	137.16 (12)
Food[a]	meal	7.14	85.68 (12)	85.68 (12)
Clinometer	unit	57.14	57.14 (1)	0 (0)
Round mouth shovel	unit	7.14	0 (0)	14.28 (2)
Post hole pincer	unit	7.14	0 (0)	14.28 (2)
Machete	unit	2.29	2.29 (1)	2.29 (1)
Container	unit	1.00	0 (0)	20.00 (20)
Total			282.27	273.69
Surveying procedures				
Personnel[a]	assistant	11.43	457.20 (40)	480.06 (42)
Food[a]	meal	7.14	285.70 (40)	299.88 (42)
Bait	kilogram	0.29	0 (0)	6.96 (24)
Total			742.90	786.90

[a] purchase unit costs estimated per day. The currency used for calculations was the US Dollar (US$) (exchange rate 1 US Dollar = 3.50 Brazilian Real).

Discussion

Although the yellow-footed tortoise faces significant exploitation in several parts of its occurrence range (De Souza-Mazurek et al. 2000; Morcatty and Valsecchi 2015a; Ojasti 1996; Peres 2000), the species remains barely studied in the wild due to difficulties in conducting live-captures (Ferrara et al. 2017; Guzmán and Stevenson 2008). Our findings using two methods for capturing the species indicated that the hunting-inspired trap with bait was usually more efficient than the active search to capture tortoises, although the environment and the seasonality influenced the efficiency, the cost-effectiveness, and applicability of the capturing methods.

Higher capture rates and cost-effectiveness values were obtained with traps compared to the active search on foot during both the dry and wet seasons. Guzmán and Stevenson (2008) also reached greater density estimates of tortoises using an equivalent pitfall trap compared to line-transects in the Peruvian Amazon. However, our capture rate (0.03 tortoises trap^{-1} day^{-1}) was 67 times greater than that obtained by these authors (0.00045 tortoises trap^{-1} day^{-1}). Our remarkable capture success may be related to the trap design with a false floor, built based on local peoples' knowledge, a potential higher local density of tortoises, or, most likely, the bait selection, since Guzmán and Stevenson (2008) employed cow meat as bait instead of fish. The odor may be an important factor in the capture efficiency, since tortoises have a very developed olfactory sense; it is known that tortoises sniff carefully to choose the item for consumption (Moskovits and Bjorndal 1990). The odor detection in tortoises has been associated with food selection and discrimination of species, sex, and maturity (Frye 1995; Galeotti et al. 2007). Although not yet recorded in the literature, according to local inhabitants, fish is a natural item in the tortoise diet when temporary water bodies dry up and fish die on the land. If correct, this factor possibly makes

Table 3. Cost-effectiveness calculated for capturing *C. denticulatus* by both methods, environment, and season. The numbers in parenthesis represent the Exact Poisson 95% Confidence interval.

		Cost-effectiveness (tortoises US$$^{-1}$)	
Environment	**Season**	**Active search**	**Trap with bait***
Upland forest	Dry	0.0039 (−0.0002-0.0084)[Aa]	0.0159 (0.0093-0.0244)[Ab]
	Wet	0.002 (−0.0009-0.006)[Aa]	0.0047 (0.0015-0.0096)[Ba]
Whitewater flooded forest	Dry	0.0039 (−0.0002-0.0084)[Aa]	0.0066 (0.0026-0.0122)[Ba]
	Wet	0.0098 (0.0047-0.0167)[B]	-
		Price per tortoise	
Environment	**Season**	**Active search**	**Trap with bait***
Upland forest	Dry	256.29 (118.38-n.a.)	62.74 (41.05-107.74)
	Wet	512.59 (183.07-n.a.)	213.32 (104.16-662.48)
Whitewater flooded forest	Dry	256.29 (118.38-n.a.)	152.37 (81.67-380.93)
	Wet	102.52 (59.99-214.02)	-

* Cost-effectiveness and price per tortoise calculated based on captures estimated using the same time effort between methods (60 hours).
Different capital letters indicate statistical differences between lines within each column, while different lowercase letters indicate statistical differences between columns within each line.

the smell more familiar and attractive to the tortoises. Although not tested here, we also believe the odor of rotten cow meat may not be as strong as that of spoiled fish, which limits its potential of spreading over long distances and, consequently, its attraction power. In addition, fish is a commonly obtained by-product of fishing in remote areas of the Amazon, which would facilitate ease of replication in new sites. Although fish has been shown to be an efficient bait, many local people also suggested the use of native fruits, i.e., hog plum (*Spondias mombin*) and murumuru palm (*Astrocaryum murumuru*), as promising attractors. Therefore, we argue that testing efficiency among different baits is a potential topic for subsequent studies.

In addition to the bait selection, the availability of food resources in the forest may lead to differences in trapping success. Individuals are likely less attracted by the bait when local food availability is high (Gehrt and Fritzell 1996), which is the case of the whitewater flooded forests in comparison to the upland forest. This may be the reason for the superior effectiveness of the baited trap in upland forests. The end of the dry season coincides with the beginning of the fructification period in white flooded forests (Freitas et al 2003; Paim et al. 2017), and fruits are the main component in the yellow-footed tortoise diet (Guzmán and Stevenson 2008; Jerozolimski et al. 2009; Moskovits and Bjorndal 1990; Sobral-Souza et al. 2017; Strong and Fragoso 2006), hindering the attraction of the baits. In upland forests, although Tavares et al. (2019) did not find an influence of the fruit availability in the tortoise displacement within the wet season, Stevenson et al. (2007) found that the peak of tortoise activity coincided to the season with higher fruit availability. The activity pattern may be an important factor influencing the efficiency for both trap and active search, and it is relevant to consider this when establishing the capture period to maximize the number of detections. However, the activity pattern of yellow-footed tortoises varies considerably among study sites. The higher activity level has been shown to be associated with the dry season in the northwestern edge of the Colombian Amazon (Stevenson et al. 2007), while in the southern border of the Brazilian Amazon, tortoises' activity level and home range were found to be higher in the wet season (Jerozolimski et al. 2009). In our sampled upland forest, both methods presented higher capture rates and cost-effectiveness values during the dry season, which possibly reflects the peak of activity of the species in the area. However, further studies on activity patterns of yellow-footed tortoise between seasons in the Central Amazon, as well as in whitewater flooded forests, are still required.

The active search on canoe was the only feasible method to be applied in the whitewater flooded forest in the wet season, when a large area remains totally flooded and the vegetation may be at least two meters below the water surface (Ferreira-Ferreira et al. 2015). During this period, tortoises remain floating amidst the flooded forest or sheltering on branches and trunks, facilitating visual detections (Morcatty and Valsecchi 2015b); local hunters also frequently apply the active search on canoe to hunt yellow-footed tortoises in whitewater flooded forests during the wet period (Morcatty and Valsecchi 2015a, 2015b).

Similar to many studies, both active search and traps resulted in a small number of juveniles, and no individuals with carapace length less than 100 mm were caught (Nussear et al. 2008; Strong and Fragoso 2006). Small-sized individuals are indeed hardly detected by eye searching on the forest ground and might not be efficiently attracted by the bait due to possible ontogenetic diet shift between young and adults, which was already observed in other chelonian species (e.g., Bouchard and Bjorndal 2005; Luiselli et al. 2011; Morais et al. 2014). In addition, the trap was also very specific to, and only captured, the target species, thus it does not affect any other non-targeted vertebrate species (apart from the bait species) through unintended captures, therefore, reducing its impact on other species and the environment. Different from the pitfall trap commonly used in herpetological studies (e.g., Garden et al. 2007), our trap did not use plastic containers. The wall made with clay (ground material) instead of plastic allows small vertebrates, such as rats, and invertebrates, such as insects, to climb out without any harm, while the height allowed medium- and large-sized animals to step out from the trap in case they were caught. The trap features were also designed for preventing possible injuries in the captured tortoises. As we observed, the subsequent behavior after capturing was similar between tortoises caught by trap and by active search in Tavares et al. (2019). However, we highlight that the use of fish as bait may pose an impact on fish populations. In this study, we used specimens incidentally caught by local fisherman that are not appreciated for consumption, and we highly advocate that the use as a bait of any species that suffers from local or global overexploitation should be avoided. The use of a mix of species may also dissuade the impact of the use as bait on the chosen species' populations, in addition to making it easier to obtain these in isolated areas.

Since financial and personnel resources are often limited in conservation projects, the selection of methods for wildlife surveys is often based on its cost-effectiveness (Garden et al. 2007). Although higher and significant cost-effectiveness values were found only for traps in the upland forest in the dry season, our findings show that the traps presented superior absolute cost-effectiveness in all situations in which they were applied. Therefore, capture using traps required less personnel effort and financial resources than the conventional method, which may benefit studies that cover large areas or that are applied over long-term periods. In addition, the quality of the active search is deeply associated with the time-effort applied and the level of experience of the searcher. These factors add a considerable level of uncertainty when making comparisons using this method among sites in research conducted by different researchers and assistants.

Since the yellow-footed tortoise is currently threatened with extinction and remains a poorly studied species in wild conditions, an average investment of US$143 per tortoise captured using traps seems feasible. For instance, the cost of sampling the cryptic desert tortoises (*Gopherus agassizii*) in the United States of America is much higher, estimated at US$777 per captured tortoise by the active search conducted by humans and US$1312 per captured tortoise detected by trained dogs (Nussear et al. 2008).

The successful cost-effectiveness presented by the trap and the active search on canoe may be a result of centuries of ongoing traditional knowledge, since both methods were adapted from local hunting techniques, highlighting the great potential of applying hunting knowledge to replace or improve conventional scientific methods (El Bizri et al 2016; Fernandez-Gimenez et al. 2006). Although successfully applied for hunting, and now for scientific studies, the active search on canoe has limited potential, since its application is restricted to the flooded forest only during flooding periods. Conversely, the use of the trap is feasible for any non-flooded environment throughout the yellow-footed tortoise's distribution range, mostly consisting of upland forests (Ferrara et al. 2017).

The trap with bait tested here is one of the most employed hunting techniques for hunting tortoises across the Amazon, used widely by both Indigenous and non-Indigenous communities, consisting of likely ancient knowledge shared among cultures (Álvares 1997; Tavares et al. 2020). Local people in the Peruvian and Brazilian Amazon also indicated this technique as one of the most efficient techniques for capturing tortoises (Tavares et al. 2020). The intrinsic cultural connection of local people to this method may propitiate a higher adherence of local inhabitants to collaborative research and favor the establishment of community-based monitoring (e.g., Castello et al. 2009). For instance, in the Amazon, the use of a traditional method to estimate the abundance of the giant arapaima (*Arapaima gigas*) allowed the development and spreading of community-based management programs throughout the biome, leading to a successful recovery of the species' populations after decades of overexploitation (Castello 2004; Castello et al. 2009).

Tortoises are among the most consumed species in the Amazon (Peres 2000). However, the lack of crucial data in the wild, such as reproductive traits, behavior, and population trends (Balestra et al. 2016; Ferrara et al. 2017) hampers understanding the role of the species in ecosystem services provision, as well as developing management strategies, such as regulating the amount of hunting and/or the areas or seasons used for hunting, to conserve the species in accordance with local peoples' needs. In this sense, standardizing the trap as a scientific method and publicizing its efficiency is very unlikely to increase its use by local people for harvesting the species. We expect that it will actually improve and boost in situ studies on yellow-footed tortoise and promote the species' inclusion in long-term programs for chelonian conservation, which have been mostly focused on freshwater turtles (Moller et al. 2004). Therefore, this method values the traditional knowledge and encourages both local people and researchers studying the species, which in turn helps in elucidating key biological and ecological information needed for developing strategies to conserve yellow-footed tortoises in the Amazon.

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