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Assessing Conservation Monitoring Funds: Comparison of Camera Trapping and Active Search to Survey Lizards in a Xerophytic Neotropical Forest in Paraguay

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Abstract

Background and Research Aims: Sampling squamate reptiles in challenging environments like the Dry Chaco requires efficient methods to overcome logistical and ecological barriers. This study compares the effectiveness of camera trapping (CT) and active search (AS) for surveying lizards in a xerophytic forest in Paraguay, assessing their cost-effectiveness and complementarity. **Methods:** Species richness was compared across a baseline literature dataset, AS, and CT. Detection efficiency (species per hour) and cost per species detected (CPSD) were calculated. Complementarity between methods was assessed using a Complementary Index (CI). **Results:** Literature indicated the presence of seven lizard species in the study area. AS detected three species, CT detected four, with two species detected by both methods. CT was more cost-effective (CPSD = $135) but less efficient in terms of effort (0.00062 spp/h) compared to AS (CPSD = $965; 0.0417 spp/h). CI = 0.43, indicating moderate complementarity. **Conclusion:** Both methods contribute uniquely to documenting lizard diversity, with CT excelling in cost-effectiveness and AS in detection efficiency. **Implications for Conservation:** Combining CT and AS enhances biodiversity inventories, supporting better conservation planning in remote and arid ecosystems like the Dry Chaco.

Keywords

Squamata, indigenous reserve, Dry Chaco, Pantanal, *Tobich*, economics

Introduction

The process of collecting samples from squamates (lizards and snakes) in their natural habitat can be a challenging task, influenced by various ecological, behavioral, and logistical factors. Then, ecological studies of squamates rely on a variety of field techniques, each with distinct advantages and limitations. Traditional methods such as Active Searches (AS) and Visual Encounter Surveys (VES) are widely used due to their direct approach in detecting reptiles in situ (Cacciali, 2013; Rodda & Campbell, 2002). These methods provide valuable ecological insights but are labor-intensive, require trained personnel, security and health measures, and are often limited by environmental conditions such as dense vegetation and animal crypticity. Pitfall trapping, another commonly employed technique, has been particularly effective in capturing fossorial and ground-dwelling species, yet it presents logistical challenges, including the need for frequent revision to reduce mortality or predation of captured animals, for which researchers should not leave the area while traps are open or active (Cacciali, 2013; Willson, 2016). Less than a decade ago advancements in technology have introduced Camera Trapping (CT) as an alternative method for reptile monitoring. While initially designed for mammal studies, CT has demonstrated increasing utility in detecting elusive squamate species, offering the advantage of long-term, non-invasive monitoring (Richardson et al., 2018; Welbourne et al., 2017). CT has been particularly effective for recording species that are difficult to capture using conventional trapping methods, yet it remains underutilized in herpetological research. An additional factor to consider is funding for fieldwork, which is limited and is often constrained due to the high cost associated with conducting surveys in remote areas.

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Less than a decade ago, camera trapping, a technique largely used for mammal monitoring (McCallum, 2012; Tobler et al., 2008; Trolliet et al., 2014), has experienced an exponential growth in this application for lizard inventories (e.g. Welbourne et al., 2017). Camera traps can continuously monitor an area over long periods, enabling researchers to detect elusive species and understand activity patterns without disturbing their natural behaviors, becoming increasingly valuable tools for studying squamates, from large-bodied monitor lizards (Bennett & Clements, 2014; Moore et al., 2020) to inventory of small and elusive snakes and lizards (Broeckhoven & Mouton, 2015; Welbourne et al., 2019). Some studies assessed the difference between camera trapping and pitfall trapping for Squamata, and overall, results suggest that at least for diurnal species, camera traps are more effective than pitfalls (Richardson et al., 2018; Welbourne et al., 2020).

Among Squamates, lizards represent one of the most diverse and ecologically significant reptile groups occupying a wide range of habitats, from tropical rainforests and arid deserts to temperate woodlands and montane ecosystems, demonstrating remarkable adaptability, fulfilling essential ecological roles, acting as both predators and prey, contributing to invertebrate population control, seed dispersal, and overall ecosystem balance (Pianka & Vitt, 2003). South American lizards exhibit a remarkable range of habitat preferences and morphological adaptations that allow them to thrive in diverse environments, from dense rainforests to arid scrublands. Species in the Teiidae family, such as *Ameiva ameiva* and *Teius teyou*, are typically found in open habitats with sandy or rocky substrates, where their elongated bodies and powerful limbs enable rapid movement for active foraging (Vitt et al., 1998). Scincids, like *Notomabuya frenata*, prefer leaf litter and forest floors, using their smooth, streamlined scales to burrow and evade predators (Cacciali & Maneyro, 2024). In contrast, tropidurids, such as *Tropidurus spinulosus*, inhabit xeric environments, where their rough, keeled scales provide protection against desiccation, and their cryptic coloration aids in camouflage against rocky or sandy backgrounds (Faria & Araujo, 2004; Pianka & Vitt, 2003). Arboreal species, such as *Polychrus acutirostris*, rely on prehensile tails and elongated limbs to navigate vegetation, while nocturnal geckos like *Phyllopezus przewalskii* exhibit specialized toe pads that allow them to cling to vertical surfaces (Norman, 1994). These morphological specializations reflect the adaptive diversity of lizards across South America, highlighting the importance of studying habitat-specific survey methodologies to ensure comprehensive biodiversity assessments.

Conducting lizards' surveys in the Dry Chaco presents significant logistical challenges due to the region's extreme environmental conditions. The arid, thorny forest makes field access difficult, often causing flat tires and increasing the risk of encounters with aggressive bees during the dry season. In contrast, heavy rains lead to flooding, frequently rendering the area inaccessible. These harsh conditions limit the feasibility of traditional, labor-intensive survey methods such as Active Search (AS), emphasizing the need for alternative approaches. Given these constraints, this study was conducted to evaluate whether Camera Trapping (CT), a non-invasive and long-term monitoring technique, could serve as a cost-effective and practical complement to AS for lizard surveys in this remote and understudied ecosystem. In this sense, the objective of this work is to evaluate and compare the effectiveness, cost-efficiency, and complementarity of two different survey methods—Active Search (AS) and Camera Trapping (CT)—for detecting lizards in a xerophytic Neotropical forest in Paraguay.

Methods

The study area is located in the Dry Chaco, one of the largest dry forests in South America, which is experiencing a rapid and intensive deforestation driven by agricultural expansion and cattle ranching in Argentina and Paraguay, with near the 80% of the remanent forest isolated and fragmented, a situation that is of grave concern for the conservation of this unique ecosystem (Baumann et al., 2017; de la Sancha et al., 2021; Gasparri & Grau, 2009). Nevertheless, there are still some pristine areas in the Dry Chaco of Paraguay. For instance, the *Tobich*, a Yshir word for "Ceremony camp", is a crucial element in preserving the cultural heritage and livelihoods of the Yshiro Ybytoso community (Ozuna Ortiz, 2019), is part of the Complejo de Reservas Pantanal Paraguayo, which is located in the Western region of the Alto Paraguay Department. *Tobich*, a property spanning 4,745.7 hectares, lies in a transition zone between the Dry Chaco and the Pantanal and is notable for exhibiting characteristics of the Humid Chaco, the Cerrado, and the Chiquitania.

A biological monitoring in *Tobich* is taken under a REDD+ approach since 2017 by the organization Guyra Paraguay, using camera traps to identify medium and large mammals. However, the technical and research team that carries out the monitoring makes at least two visits per year, during the dry and wet seasons, where data on fauna (including lizards) are collected. Considering the low representation of lizards in herpetological surveys in the *Tobich*, an experimental camera trap was installed to survey lizards, and assess the data that can be taken, assessing the utility of this method to survey lizards in a remote forest environment. To compare the surveys methods (active search "AS" and camera trapping "CT"), we generated a baseline list based on literature (Cacciali et al., 2016). AS involved two persons exclusively dedicated to herpetological surveys, investing about 12 hours per day during three days in the following dates: 9–11.XII.2020, 13–15.X.2021, 3–5.X.2022, and 9–11.VIII.2023. Observers alternated between walking together and separately, and breaks were taken at random intervals during sampling depending on environmental conditions, such as heat, to ensure observer efficiency and safety. There are only three trails in the study area and walks in the forest are difficult. Figure 1 shows the trails walked for AS surveys. CT consisted of a Browning BTC5HDP model, installed at 3.4 m above ground, at Lat -20.303936, Long -58.552040 (Figure 1) with an angle of ~45° pointing down, for about 10 months (10.XII.2020 – 14.X.2021), although batteries lasted 9 months. This model of camera trap is triggered by motion during daylight, and thermal infrared detection at night. It is important to note that by mistake camera was not configured with the right time and date, this first picture was labeled as 1.I.2007, instead of 10.XII.2020.

To measure how much the two methods contribute uniquely to the detection of species we calculated a Complementary Index by $CI=(Usp_{CT}+US_{AS})/Totalsp$, where

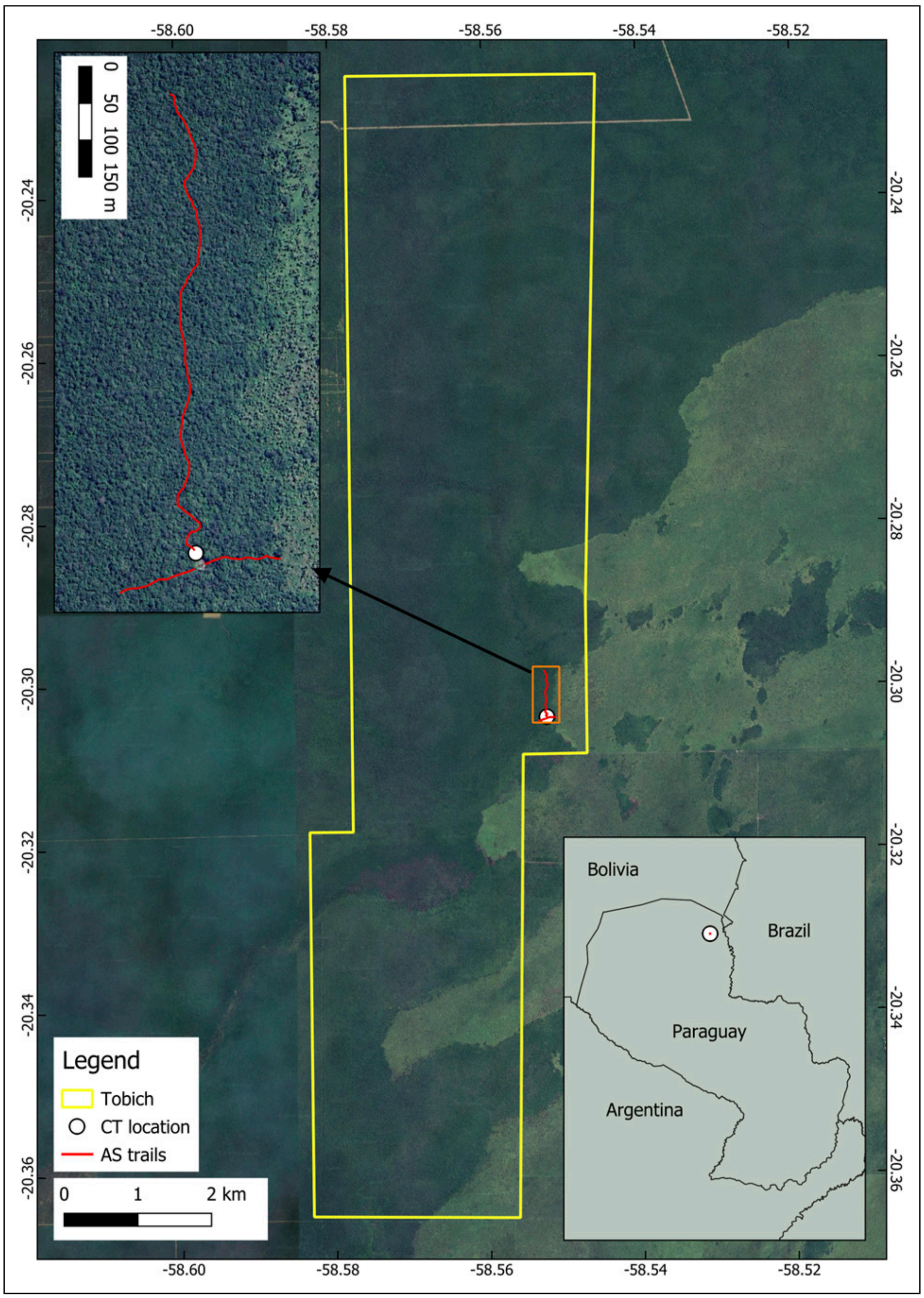

Figure 1. Location of Camera Trap (CT) and Trails Walked During Active Search (AS) in the *Tobich* Area, Northern Chaco

Usp_{CT} represents the unique species detected by CT, US_{AS} represents the unique species detected by AS, and Totalsp is the total species detected. A higher complementarity index (closer to 1) means the methods contribute more uniquely to the overall species detection, making them highly complementary.

We also estimated the efficiency of both methods by comparing the species detected by the effort invested measured in hours (unit of effort). Thus, the Detection Efficiency was calculated by *DE=Species/Effort*, where "Species" represents the number of species detected by each method, and "Effort" indicates the time consumed (in hours) for each method given that CT was active for 9 months, which represents a total of 6,480 hours. AS totalized about 36 hours on average every field survey.

Finally, to estimate the Cost per Species Detected (CPSD) with both methods, we divided the total cost by the number of species detected by the method: $CPSD_{AS}=Total\$_{AS}/Sp_{AS}$ for AS and $CPSD_{CT}=Total\$_{CT}/Sp_{CT}$ for CT. Costs for these estimations are presented in Appendix S1.

Analyses were performed in MS Excel, and graphics for visualization generated in R 4.4 (R Core Team, 2024) with ggplot2 and fmsb packages (Nakazawa, 2024; Wickham, 2016). Scripts with the data are available in Appendix S2.

Results

The total number of lizards recorded by literature as probably present in the area is seven (Table 1). From which, some were documented by AS and some by CT. Due to the small size of lizards in the pictures, high resolution photographs are available in FigShare (DOI: 10.6084/m9.figshare.29033774.v1). During AS three species were recorded (Appendix S3) and four using CT (Table 1). As unique species, *Phyllopezus przewalskii* was not detected by CT, and *Ameiva ameiva* and *Salvator merianae* were not found during AS. This renders the following equation for the Complementary Index:

$$CI = 1 + 2/7 = 0.4286$$

This value indicates that about 42.86% of the species were uniquely detected by one method or the other, showing a moderate level of complementarity between AS and CT to survey reptiles in the study area. Two species (*Polychrus acutirostris* and *Teius teyou*) were documented by literature but missed by both field methods (Figure 2).

Regarding the detection efficiency, AS gives a total of 0.0417 species/hour, while CT provides 0.00062 spp/h. AS has a higher detection efficiency relative to its sampling effort. Thus, theoretically, 167 h of AS and 11,290 h of CT are needed to reach the seven species of lizards present in the area. In terms of days this represents 7 days of continuous AS and 470 days of CT. This leads to the next results regarding costs.

The CPSD is 135 USD per species detected using CT, while AS has a cost of 965 USD per species. Considering the time invested by both methods, the species detected, and the money spent, CT is more cost-effective in detecting species compared to AS based on the available data (Figure 3).

Discussion

This study highlights the strengths and limitations of camera trapping (CT) and active search (AS) for lizards surveys lizards in the challenging environment of the Dry Chaco. CT proved to be more cost-effective, with a CPSD of \$135 compared to \$965 for AS. However, AS demonstrated superior detection efficiency, identifying species at a rate

Table 1. List of Lizards Present in the Study Area (*Tobich*) According to Literature (Lit), and Those Recorded with Camera Trapping (CT) and Active Search (AS). Some Ecological Affinities (EA) Like Preferred Habitat Use (HU) and Diel Activity (DA) are Included: Arboreal (Ar), Diurnal (Di), Nocturnal (No), and Terrestrial (Te)

		Record			EA	
Species	Common name	Lit	CT	AS	HU	DA
Polychrotidae						
Polychrus acutirostris Spix, 1825	Brazilian Bush Anole	+			Ar	Di
Phyllodactylidae						
Phyllopezus przewalskii Koslowsky, 1895	Przewalsky's Gecko	+		+	Te	No
Teiidae						
Ameiva ameiva (Linnaeus, 1758)	Neotropical Ameiva	+	+		Te	Di
Salvator merianae Duméril & Bibron, 1839	Tegu Lizard	+	+		Te	Di
Teius teyou (Daudin, 1802)	Four-toed Tegu	+			Te	Di
Tropiduridae						
Tropidurus spinulosus (Cope, 1862)	Spiny Lava Lizard		+	+	Ar	Di
Scincidae						
Notomabuya frenata (Cope, 1862)	Cope's Mabuya		+	+	Ar	Di

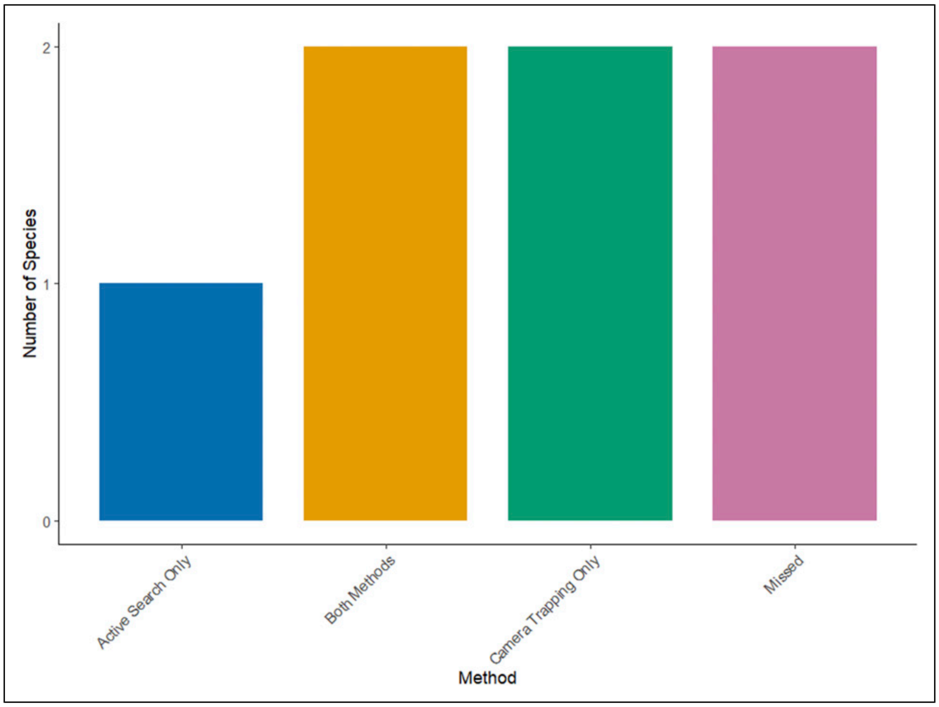

Figure 2. Bars Chart Illustrating the Proportion of Species Detected by Active Search (AS) and Camera Trapping (CT) Relative to the Total Species Recorded in the Literature (Seven Species)

67 times greater than CT per hour of effort. These findings are consistent with previous studies by Richardson et al. (2018) and Welbourne et al. (2020), which highlight the cost-effectiveness of CT for terrestrial squamates, particularly in remote or large-scale studies. It is important to highlight that arboreal lizards such as *T. spinulosus* and *N. frenata* were spotted by CT.

The moderate Complementary Index (CI = 0.43) observed in this study suggests that CT and AS uniquely contribute to

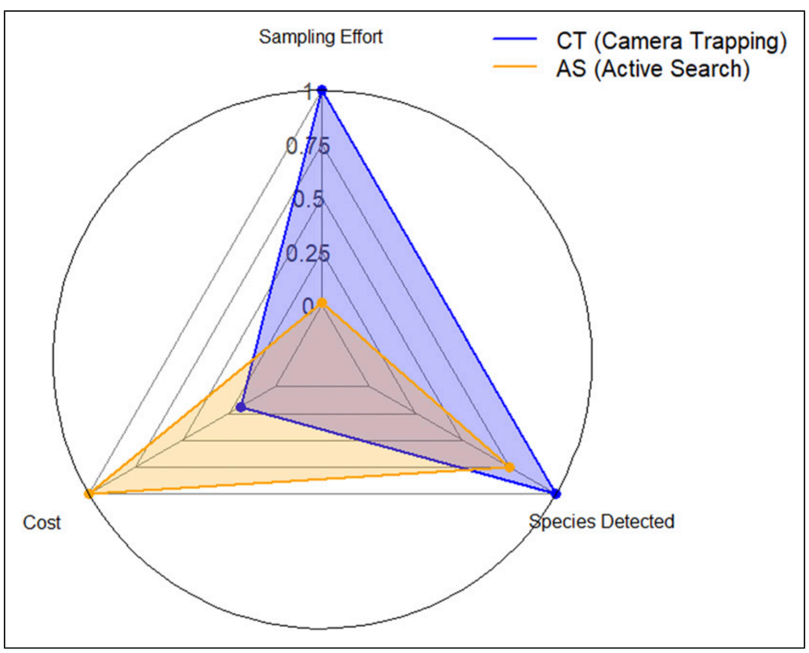

Figure 3. Comparison of CT and AS Across Three Dimensions: Costs, Sampling Effort, and Species Detected. Values Presented in Percentages (0–1)

species detection, supporting studies such as that of Broeckhoven and Mouton (2015), which highlighted the ability of CT to detect elusive or cryptic lizards. Importantly, species such as *Ameiva ameiva* and *Salvator merianae* were only detected by CT, while *Phyllopezus przewalskii* was only observed through AS. This complementarity underscores the importance of using multiple methods to obtain a comprehensive snapshot of biodiversity, as no single method is universally effective. Even though *A. ameiva* and *S. merianae* are common species widely distributed in the country (Cacciali et al., 2016), these animals sometimes exhibit low activity when the climatic conditions are not suitable. For example, *Teius teyou*, despite being heliothermic, decreases its activity during hot days (Cacciali & Köhler, 2014).

The study's findings must be contextualized within the specific challenges of the Dry Chaco, including extreme environmental conditions and limited accessibility. The high costs associated with AS reflect logistical constraints and the labor-intensive nature of manual surveys in such habitats. Conversely, the long operational time CT (6480 hours) compensates for its low detection efficiency, aligning with Welbourne et al. (2019), who identified CT as a practical tool for long-term monitoring.

Despite the advantages of CT, the method's reliance on stationary deployment may result in missed detections of highly mobile or arboreal species, a limitation addressed by Richardson et al. (2018). Similarly, AS's reliance on observer expertise and effort limits its scalability. It is important to emphasize that effective ecological monitoring requires a balance of costs and benefits, with careful prioritization of objectives and recognition of often overlooked costs such as data management and quality assurance (Caughlan & Oakley, 2001). Overall, the findings highlight the complementary nature of CT and AS. Using both methods in tandem maximizes detection across a diversity of species while balancing cost and effort, thereby providing a robust framework for biodiversity monitoring in remote and resource-constrained settings.

We recognize the limitations of our study and agree that Active Search (AS) provides additional valuable ecological data beyond species presence, including sex identification, behavioral observations, and potential density estimates. While Camera Trapping (CT) offers long-term, non-invasive monitoring and cost-effectiveness, it is inherently limited in providing detailed individual-level data, particularly for small, cryptic species. Additionally, a key limitation of CT is its reduced effectiveness in detecting reptiles at night, as most passive infrared (PIR) sensors rely on thermal contrast to trigger the camera, which can be less effective for homeothermic animals when ambient temperatures closely match their body temperatures. AS, by contrast, allows for direct interaction with specimens, enabling morphological assessments, demographic studies, and behavioral observations that CT cannot capture. However, AS is highly dependent on observer effort, environmental conditions, and accessibility, which are significant constraints in remote and challenging environments such as the Dry Chaco.

In conclusion, research and conservation funds are always limited, so CT is a good way to complement traditional herpetological surveys. We encourage the use of CT along with AS methods in herpetological surveys, especially in tropical dry forest as it is the Dry Chaco, to maximize biodiversity knowledge, especially in areas where habitat loss is surpassing conservation efforts (de la Sancha et al., 2021; Mosciaro et al., 2022; Prieto-Torres et al., 2022). Based on our findings, we recommend using the CT method to increase species richness in surveys and the AS method for studying the detection and abundance of specific species, particularly those that are more easily detectable. This combined approach allows for more comprehensive biodiversity assessments, balancing cost-effectiveness and species detectability in challenging environments.

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Declaration of Conflicting Interests

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Supplemental Material

Supplemental material for this article is available online.

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