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OPINION

# Cave-dwelling gastropods (Mollusca: Gastropoda) of Brazil, state of the art and conservation: a critical review

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ABSTRACT. In 2022, Salvador and co-authors published an up-to-date list of gastropod species recorded from Brazilian caves. That list included 18 species (15 land and three freshwater species) that were considered by the authors to be restricted to caves (troglobitic). In this contribution we argue that only six of the species listed by them as truly troglobites can be classified in that category. We disagree with some characteristics listed by Salvador and co-authors to diagnose the species they classify as cave-restricted and argue that those species do not have truly troglomorphic traits (characteristic of subterranean habitats). Since the Brazilian legislation considers the degree of association with caves as a decisive attribute to preserve them, it is important to clarify the characteristics are sufficient and necessary for a species to be classified as cave-dependent.

KEY WORDS. Troglobites, troglomorphic, karst, conservation

One of the most challenging tasks for subterranean biologists in the tropics is to determine whether a given species is or is not cave-restricted. While it is widely accepted that troglobionts are the species that inhabit only subterranean habitats, several historical concepts have been proposed over time. Sket (2008) has provided a comprehensive review of these concepts and proposed a unified approach. Hence, troglobitic species are those strictly found in hypogean habitats (Sket 2008). The only definitive way of confirming whether a species is exclusively subterranean is to demonstrate the absence of populations in surface habitats. However, given the high diversity of tropical regions, it is usually impossible to determine with certainty whether a species is troglobitic or not. Therefore, alternative approaches, such as the use of troglomorphic traits or "troglomorphies" (Christiansen 1962), have been proposed to identify potentially troglobitic species.

Despite their limitations, troglomorphies are valuable diagnostic tools for identifying troglobitic species. These traits enable the identification of characteristics that have evolved after isolation in subterranean habitats. Most of the troglomorphic traits are easily recognizable, such as the absence of pigmentation, reduction in eye size, and elongation of appendages, which enhances its applicability. Among gastropods, the most commonly observed troglomorphic traits include reduced size in comparison to their epigean counterparts, absence or reduction of pigmentation in both shells and soft tissues, reduction or complete absence of eyes, and shells that possess thin and translucent walls (Simone 2022). Additionally, adaptations in internal organs can also be observed in troglobitic gastropod species (Prié 2019).

Tropical karst areas are known to have a rich diversity of gastropods, with terrestrial species being the most commonly found (Emberton et al. 1997, von Oheimb et al. 2019). This is primarily due to the abundance of limestone, which is composed mostly of calcium carbonate, a mineral that provides essential elements for shell formation, thereby supporting several species that are restricted to these landscapes. However, due to the high solubility of this mineral, gastropod shells rapidly degrade after their death. Further-

more, because of the obvious physiological constraints, most gastropods are mostly active during rainy periods, becoming inactive during the dry seasons (Nicolai and Ansart 2017). Despite the fast degradation of shells in external habitats, specimens that enter caves, either actively or accidentally, tend to be better preserved due to the favorable conditions in these subterranean environments. These conditions include high environmental stability, low abundance of biological decomposers (compared to external habitats), and the influx of percolating waters containing high levels of calcium carbonate, which directly contributes to several fossilization processes. Consequently, caves are significant paleontological sites for gastropods (Hearty et al. 2004, Paul and Donovan 2005). Therefore, it is anticipated that the abundance of shells found inside caves, whether belonging to species from these environments or transported into the cave, will be higher than the number of shells found in the surrounding external habitats. However, it is noteworthy that many gastropod shells found in caves belong to epigean species that have been transported to the caves, especially by water (Oliveira et al. 2018). Therefore, observing a shell of a particular species in a cave does not necessarily imply that it inhabits that environment. It may have just been transported to a cave and preserved better than if it had remained on the surface, thereby increasing the chances of finding these shells. Hence, in a tropical karst environment, caves are theoretically the most suitable habitats for searching for gastropod shells, even though most of the species found are not typically associated with these environments when alive. Additionally, gastropod diversity in epigean habitats within most Brazilian karst areas remains poorly surveyed, resulting in a significant lack of knowledge regarding species distribution (Wallacean shortfall – Hortal et al. 2015).

The recent checklist of cave-restricted species in Brazil by Salvador et al. (2022) has greatly increased the number of species considered obligate cave-dwellers. However, it is worth noting that out of the 18 species designated as troglobionts by the authors, only seven were originally described as such (with three only tentatively classified as troglobitic). Furthermore, one of these species, *Habeastrum strangei* Simone, Cavallari & Salvador, 2020, previously described as troglobitic has since been reevaluated and is no longer considered as such (Simone 2022). The list was inflated by other species that do not exhibit any distinctive morphological features that would link them to a subterranean-restricted life. The primary criterion used by the authors for designating these species as troglobitic was their exclusive occurrence in cave environments. However, as previously mentioned, comprehensive surveys of gastropods in surface habitats have not been conducted in most karst areas.

It is worth mentioning that the speleogenesis of some caves occurring in areas considered by Salvador et al. (2022) as hosting a high diversity of subterranean gastropods, such as those located in Presidente Olegário municipality in the Minas Gerais state, was primarily influenced by existing rock fractures or diaclases. Consequently, most of these caves typically exhibit vertical slits that connect their inner conduits to the surface (RL Ferreira pers. obs.). These openings facilitate the importation, albeit often passive, of epigean species into caves, as previously mentioned. As an example, despite being described as a troglobitic species, *H. strangei* (the only species described for caves in Presidente Olegário) has a wide distribution, occurring in caves located in different karst areas of Minas Gerais state, such as the municipalities of Pains, Lagoa Santa and Presidente Olegário, some of which are more than 200 km apart. Therefore, it is unlikely that this species is restricted to subterranean environments, as there are no contiguous subterranean voids connecting those regions, making it improbable that it could disperse among such regions without crossing surface environments. Consequently, Salvador et al. (2022) and Simone (2022) suggested that this species is probably troglophilic.

It is important to mention that Salvador et al. (2022) designated many species as troglobitic based on their shells, as living specimens are yet to be discovered. Even though, the authors attested that "*Several of the species listed here show some of those classical troglomorphisms, such as reduction/absence of eyes and lack of body/periostracum pigmentation…*" thereby indicating some troglomorphic traits that are only observable in living organisms. Furthermore, they also mentioned "*…many of the troglobitic species listed here (more than half of which are stylommatophorans) do not present obvious troglomorphisms…*" Hence, the only criteria used to classify these species as troglobitic was their current known distribution only in caves. However, it is important to acknowledge that most Brazilian karst areas remain unexplored with regards to gastropods, and species found only in one cave and described solely based on shells should not be assumed to be restricted to such habitats. Hence, in the absence of sufficient and reliable external surveys, the presence of troglomorphic traits is the most reliable way to identify a species as cave-restricted. This approach is widely adopted in the tropics to diagnose many invertebrate taxa (e.g., Bastos-Pereira and Ferreira 2017, Ázara et al. 2020, Souza and Ferreira 2022). Salvador et al. (2022) also mentioned five genera that are exclusively subterranean (*Clinispira* Simone

& Casati, 2013, *Habeas* Simone, 2013, *Habeastrum* Simone, 2019, *Lavajatus* Simone, 2018, and *Spiripockia* Simone, 2012). However, among these genera, only *Spiripockia* is genuinely troglobitic (Simone 2022).

Simone and Casati (2013) in their work describing the species *Clinispira insolita*, *Cyclodontina capivara*, *Anctus prolatus*, *Rhinus gilbertus* and *Streptartemon molaris* (five of the 18 species reported as troglobites by Salvador et al. 2022), made the following comments regarding the fact that these species were found in caves: *"…given in the habitat is the available information about that sample. It does not represent obligate subterranean taxa; the specimens can simply represent surface species that also live in caves; or they are dead assemblages of surface species that have washed down from the surface through cracks. Under the present level of knowledge, we cannot infer further, as these taxa has not been exhaustibly searched for above the ground"*. Moreover, in their work, the species were described from samples obtained from cave entrance zones and from points on the surface (exokarst), based on dry shells that were mostly in poor condition (fragmented or encrusted by sediments). Likewise, Simone (2016) reported that the samples of *Gonyostomus elinae* Simone, 2016, were composed of dry shells collected inside caves, which were considered to be accidental in caves and possibly transported by rainwater.

We would like to emphasize that the recently published list by Simone (2022) includes only six species that are currently classified as troglobites, with three of them being tentatively classified. Thus, in accordance with Simone (2022), we emphasize that only these species have been supported by sufficient evidence to classify them as troglobitic: *Potamolithus troglobius* Simone & Moracchioli, 1994, *Spiripockia punctata* Simone, 2012 and *Spiripockia umbraticola* Simone & Salvador, 2021. Additionally, three other species are tentatively classified as troglobites, which are *Gastrocopta sharae* Salvador et al., 2017, *Habeastrum omphalium* Simone, 2019 and *Habeastrum parafusum* Simone, 2019.

It is worth noting that the challenge of properly classifying species found in caves regarding their ecological and evolutionary status is not limited to a single taxonomic group. Recently, Dutra-Rêgo et al. (2022) published an article on the diversity and potential transmission of leishmaniasis by sand flies (Diptera: Psychodidae: Phlebotominae) found in Brazilian caves. In their article, the authors erroneously classified all sandfly species with known occurrences solely in caves as "obligate – found exclusively inside caves". However, for most species classified by them as troglobitic, there is no morphological, behavioral or physiological evidence to support their evolution in the subterranean environment. As a result, Andrade et al. (2022) in a review of the occurrence of such flies in Brazilian caves removed almost all sandfly species from troglobitic status. Therefore, it is essential for experts in other taxonomic groups to comprehend and properly employ the concepts used in subterranean biology before designating a given species as troglobitic. Furthermore, taxonomists should consider different aspects of the local and regional geology of the different karst regions, since such information can provide significant insights into the existence of subterranean connections between distinct areas, which, in turn, may indicate the potential for dispersal through the subterranean environment. In a continental country like Brazil, with the potential for hundreds of thousands of caves across different biomes and associated with different rock types (e.g., carbonate, siliciclastic, ferruginous, granitic, among others), it is essential to consider all these environmental heterogeneities to determine accurately whether a given species is restricted to caves or not.

It is essential to note that Salvador et al. (2022) have provided an important contribution to the current knowledge of gastropods found in Brazilian caves. However, their designation of certain species as troglobitic solely based on their occurrence in caves is problematic. Brazil has speleological legislation that partially protects its cave heritage. Nevertheless, recent changes in such decrees have the potential to severely affect cave ecosystems in the country (Ferreira et al. 2022). For environmental licensing purposes, Brazilian caves should be classified according to their degree of relevance, and only those with maximum relevance are protected. The presence of troglobitic species is one of the criteria used to determine the relevance degree of a cave in Brazil. Therefore, the misidentification of epigean species as troglobitic may weaken a key tool for cave protection in Brazil and provide justification for increasingly flexible environmental legislation. This is because troglobitic species are often endemic, rare and highly specialized to subterranean habitats and play an important role in Brazilian legal criteria. Therefore, when non-troglobitic species are included in such lists, many of these attributes disappear over time with further studies, since epigean species are typically more widely distributed and exhibit lower levels of endemism. As a result, if a non-troglobitic species is listed as troglobitic, what ends up happening over time is the relaxation of these criteria, caused by the false impression that "troglobitic" species are not as endemic, rare or specialized as previously assumed. Thus, for purposes of cave conservation, misconceived diagnoses can be quite harmful over time.

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