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Short Communication

Predation of *Ambystoma altamirani* (Caudata, Ambystomatidae) by *Thamnophis scaliger* (Squamata, Colubridae) and *Crotalus triseriatus* (Squamata, Viperidae) in Nevado de Toluca Volcano, Central Mexico

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Abstract

This study reports two notable predation events involving *Thamnophis scaliger* (Jan 1863) and *Crotalus triseriatus* (Wagler 1830), which target *Ambystoma altamirani* (Dugès 1895), a critically endangered salamander species endemic to high-altitude streams in central Mexico. In the first event, *T. scaliger* was observed to capture and consume *A. altamirani* by removing the salamander from its aquatic habitat and consuming it on land – a behavior that underscores the adaptability of the snake to handling aquatic prey. In the second instance, *C. triseriatus* exhibited attempted predation in a montane stream, swimming in pursuit of the salamander but ultimately failing to capture it. These observations provide critical insights into predator–prey dynamics in montane ecosystems, highlighting the ecological pressures faced by *A. altamirani*. Furthermore, the documentation of these events expands our understanding of the feeding behaviors of *T. scaliger* and *C. triseriatus*, emphasizing their potential impact on vulnerable amphibian populations. This study underscores the necessity of further ecological research to assess the frequency and ecological consequences of such interactions, as well as their implications for the conservation of endangered amphibians in high-altitude habitats.

Key words: Endangered amphibians, Montane habitats, Montane stream ecosystems, snake predation, wetlands

Introduction

Thamnophis scaliger (Jan, 1863), commonly known as the Mexican garter snake, is a semiaquatic species that thrives in the wetlands of montane regions across Mexico (Fig. 1A). Its diverse diet includes amphibians, reptiles, small

fish, and invertebrates, reflecting its adaptability to both aquatic and terrestrial environments (Manjarrez et al. 2007; Reguera et al. 2011; González-Fernández et al. 2018; Hidalgo-Licona et al. 2023). Similarly, the Mexican dusky rattlesnake (*Crotalus triseriatus* (Wagler 1830)) is a highland species endemic to the Trans-Mexican Volcanic Belt. Its diet is varied and comprises snakes, lizards, arthropods, and amphibians, such as frogs and salamanders, positioning it as a significant predator in these ecosystems (Mociño-Deloya et al. 2014). Among the amphibian species inhabiting these montane regions, *Ambystoma altamirani* (Dugès 1895), or Altamirano's salamander, stands out as an endemic species with a limited distribution in high-altitude streams and lakes in central Mexico. It plays a critical ecological role as a top predator within these aquatic habitats (Hernández et al. 2020). Despite its predatory dominance in these streams, no reports of natural predators targeting *A. altamirani* in its native environment have been published until recently (Villarreal-Hernández et al. 2019; Heredia-Bobadilla et al. 2021; Hernández-Luría et al. 2023; Méndez-Méndez et al. 2024; Ruiz-Reyes et al. 2024).

Garter snakes are well-documented predators of amphibians that prey on a wide range of species across both aquatic and terrestrial environments (Fraustros-Sandoval et al. 2019; Carbajal-Márquez et al. 2024). Previous studies have highlighted predation on *Ambystoma* species, including *Thamnophis elegans* (Baird and Girard 1853) preying on *Ambystoma macrodactylum* (Baird 1853) and *Thamnophis sirtalis* (Linnaeus 1758) preying on *Ambystoma tigrinum* (Green 1825) and *Ambystoma maculatum* (Shaw 1802) (Jennings et al. 1992; Gray 2015; Bartelt et al. 2023). In Mexico (Fig. 1A), *Thamnophis scaliger* has also been observed to consume *A. altamirani* (Villarreal-Hernández et al. 2019; Hernández et al. 2020). These interactions underline the ecological significance of garter snakes as amphibian predators. *Thamnophis* species exhibit unique and adaptable hunting strategies, such as capturing and consuming prey in aquatic environments. These predation events are ecologically significant because they reveal the intricate predator–prey dynamics within these habitats and their impacts on amphibian populations, many of which are already endangered or vulnerable. Studies have further explored the antipredator responses of *Ambystoma* species to snake predation. For example, Brodie (1989) observed individual variations in antipredator responses in *Ambystoma jeffersonianum* (Green 1827) when exposed to garter snakes. Similarly, Murray et al. (2004) reported that *Ambystoma* species adapt their behavior based on prior experience with predators, while Wirsing et al. (2005) demonstrated that *Ambystoma macrodactylum* exhibits defensive behaviors when exposed to dietary cues from *Thamnophis elegans*.

These studies underscore the complexity of interactions between *Ambystoma* species and snake predators. *Ambystoma altamirani* is currently classified as endangered on the International Union for Conservation of Nature (IUCN) and as threatened under Mexican law (Secretaría de Medio Ambiente y Recursos Naturales, SEMARNAT 2015). Its declining populations face numerous threats, including habitat loss, pollution, and the introduction of invasive species (Estrella-Zamora et al. 2018; Heredia-Bobadilla et al. 2021; Ruiz-Reyes et al. 2024; Sunny et al. 2024).

The documentation of predation and attempted predation on *A. altamirani* by native snake species contributes to a deeper understanding of its ecological

interactions and highlights an additional, previously unrecognized pressure on its populations. This study reports successful predation by *T. scaliger* and attempted predation by *C. triseriatus* targeting *A. altamirani*. These observations provide valuable insights into the predatory behaviors of native snakes and their ecological interactions with amphibians in montane habitats. Furthermore, this work emphasizes the importance of understanding predator–prey relationships in the context of amphibian conservation in high-altitude ecosystems.

Study site

The first observation of *Thamnophis scaliger* occurred in Raíces (Fig. 1C, D, located in the southwestern region of the municipality of Zinacantepec, State of Mexico (Fig. 1B). This population inhabits the northern slope of the Nevado de Toluca, a prominent geographical feature in the area, with coordinates of 19°10'17"N, 99°48'23"W, at an elevation of 3,431 meters above sea level. The Nevado de Toluca Volcano (NTV), rising to 4,680 meters, is a significant part of the Flora and Fauna Protection Area of the State of Mexico (Fig. 1B, C). This protected area is biogeographically critical, as it supports diverse ecosystems requiring ongoing conservation and restoration efforts (González-Fernández et al. 2022; Sunny et al. 2022). The second observation, involving *Crotalus triseriatus*, was documented in Corral de Piedra (Fig. 1C, E), a grassland region surrounded by *Abies–Pinus* forests within the protected area of the Nevado de Toluca Volcano. This site is situated in the municipality of Amanalco, with geographic coordinates of 19°12'24"N, 99°56'36"W, at an elevation of 2,865 meters above sea level. The area is characterized by a cool, high-altitude environment with clear streams meandering through wetlands and grasslands, forming part of a forested landscape (Fig. 1D, E). This ecological setting provides habitats for various montane species and highlights the importance of the Corral de Piedra in conservation efforts (Sunny et al. 2018, 2022; Jaramillo-Alba et al. 2020).

Sampling efforts

From 2016 to 2024, targeted sampling efforts to study *Ambystoma altamirani* were conducted at both Raíces and Corral de Piedra (Fig. 1C). The surveys aimed to monitor the distribution of and potential predatory threats to mole salamanders in these montane habitats. During each sampling session, the researchers systematically walked along the river, moving slowly to visually detect *A. altamirani* individuals and documenting any predation events or attempted predation. The surveys were conducted by teams of two to three participants to ensure thorough monitoring of the stream habitats. Fieldwork took place during daylight hours between 10:00 a.m. and 2:00 p.m. to align with the peak activity periods of both predators and *A. altamirani*. This time frame was selected based on prior field observations of the species' behavior and environmental conditions conducive to their visibility in these habitats. Observations of predatory interactions were recorded in detail, noting the species involved, location, environmental context, and behaviors observed during the encounters. These systematic efforts provided essential insights into the ecological interactions between *A. altamirani* and its native predators.

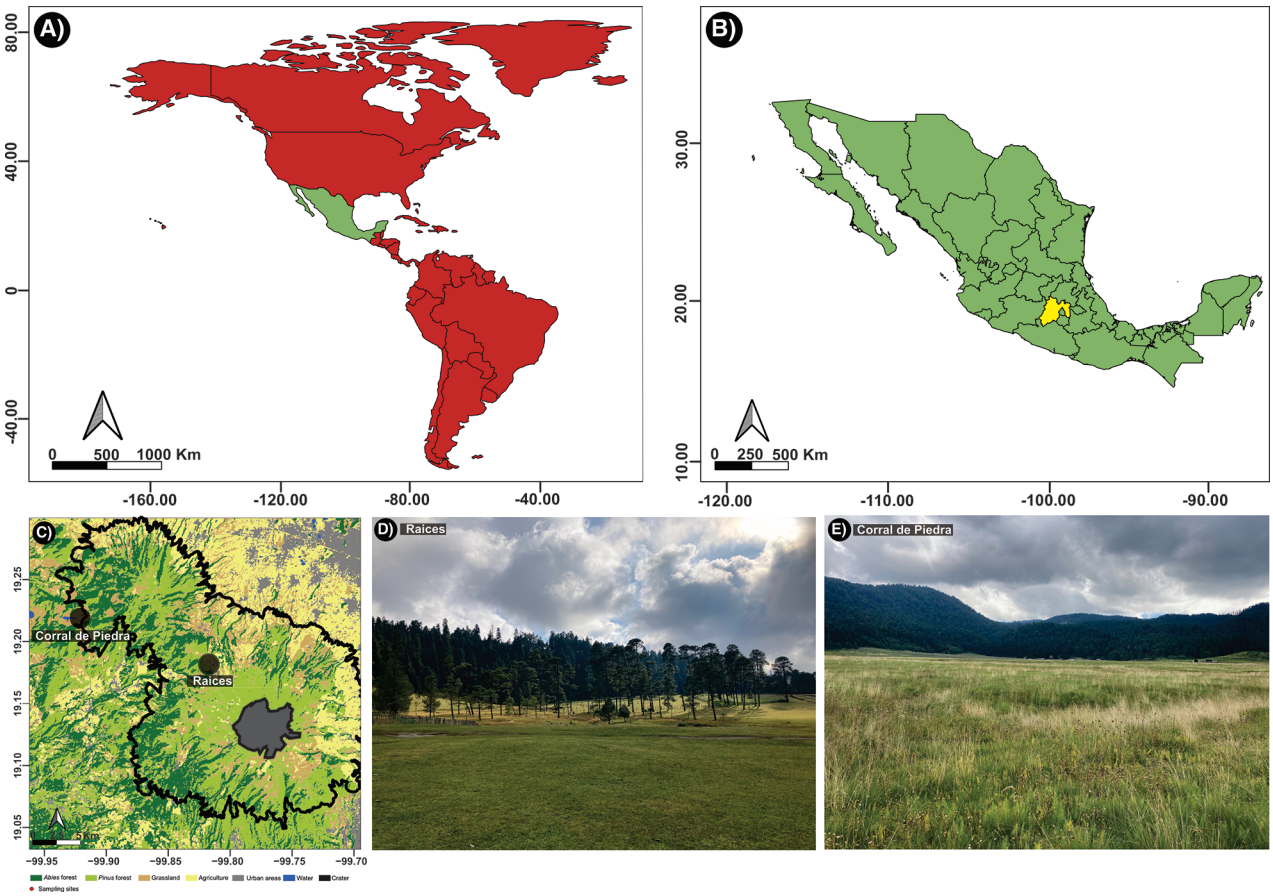

Figure 1. A Map of North America highlighting Mexico **B** map of Mexico with its states, highlighting the State of Mexico **C** polygon of the Nevado de Toluca Volcano, showing the two sampling sites, Corral de Piedra and Raíces, marked with black circles **D** The Raíces study area within the Nevado de Toluca Volcano **E** the Corral de Piedra study area within the Nevado de Toluca Volcano.

Results

Two predation events were documented in Raíces, a high-altitude montane stream characterized by cool, clear waters and dense riparian vegetation.

The first event occurred on May 5, 2020, at approximately 12:00 p.m. A *Thamnophis scaliger* was observed capturing an *Ambystoma altamirani* by the head while the salamander was in the water in Raíces (Fig. 2A). The snake exerted pressure to subdue and drown the prey, ultimately consuming the salamander in a process that lasted approximately 30 minutes.

The second event was recorded on May 12, 2024, at approximately 1:00 p.m. Another *Thamnophis scaliger* was observed actively hunting along the water's edge. The snake displayed typical predation behavior by patrolling the bank before lunging into the shallow water to capture a small *A. altamirani* through the base of its tail, close to the body. Despite a brief struggle from the salamander, the snake maintained a firm grip, dragging the prey from the water onto a nearby grassland (Fig. 2B, C). This sequence of actions exemplifies the snake's ability to adapt its predation strategies to aquatic environments. On land, the snake began swallowing the salamander tail first, completing the ingestion process in approximately one hour. After feeding, the snake retreated into nearby vegetation to digest its meal,

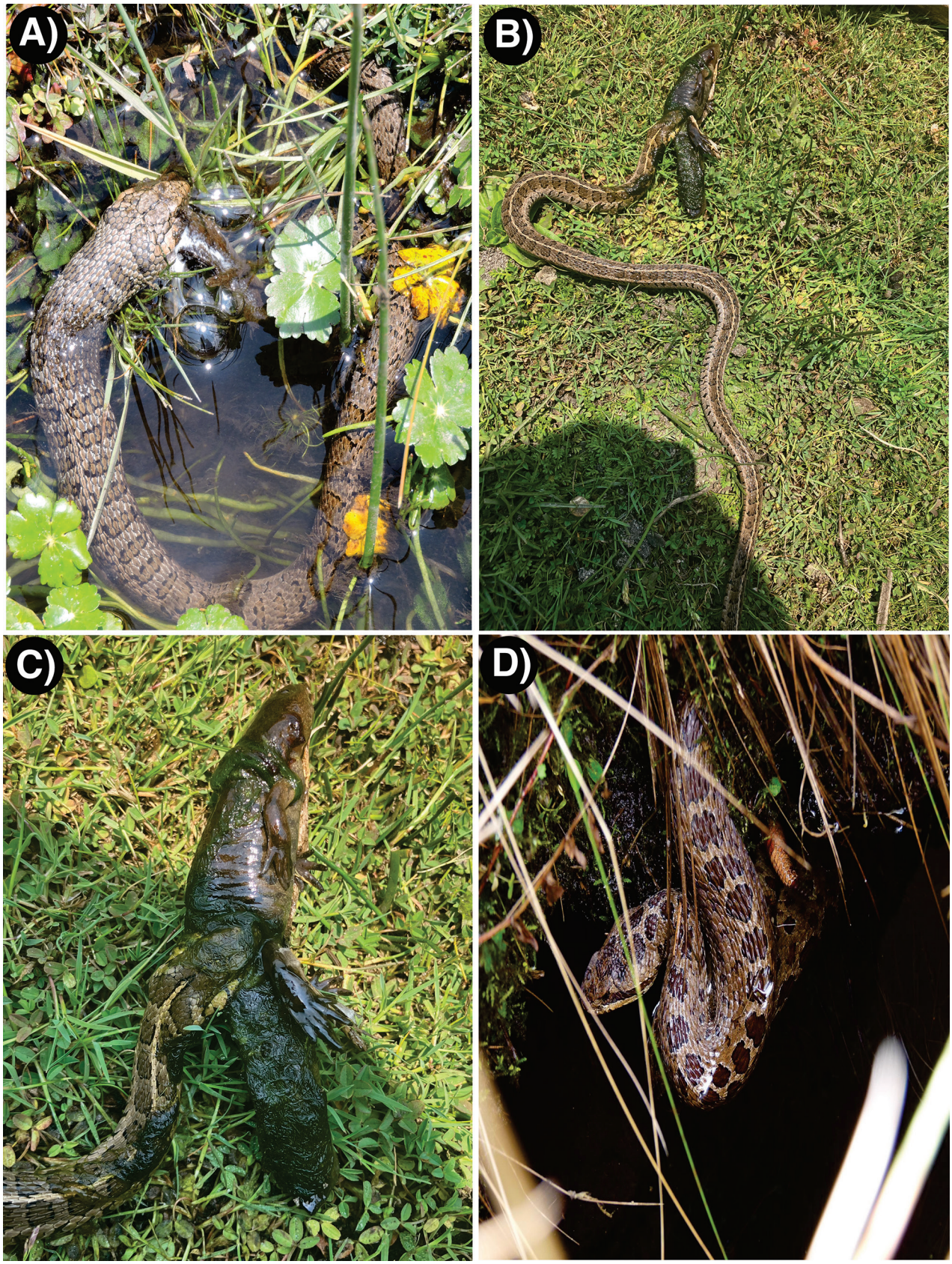

Figure 2. A A *Thamnophis scaliger* observed capturing an *Ambystoma altamirani* by the head while in the water **B** *Thamnophis scaliger* preying on a live *Ambystoma altamirani*, dragging it from the water onto the grassland **C** close-up of *Thamnophis scaliger* preying on a live *Ambystoma altamirani* on the grassland **D** an attempted predation event involving *Crotalus triseriatus* targeting *Ambystoma altamirani*.

further demonstrating its behavioral adaptation for handling aquatic prey in a terrestrial environment.

A third observation dated November 20, 2016, at approximately 11:00 a.m., occurred in Corral de Piedra. A *Crotalus triseriatus* was observed attempting to prey on an *Ambystoma altamirani* within a montane stream (Fig. 2D). The rattlesnake was partially submerged in the water, with half of its body positioned above the riverbank and directly targeting the mole salamander (Fig. 2D). Although this predation attempt was ultimately unsuccessful, the observation underscores the versatility of *C. triseriatus* in pursuing amphibious prey, including its ability to navigate and hunt within aquatic environments.

These documented interactions provide rare insights into the predatory behaviors of *T. scaliger* and *C. triseriatus* toward *A. altamirani*. These observations highlight the ecological interactions between predators and prey in montane stream habitats and emphasize the importance of understanding such dynamics for the conservation of endangered amphibian populations.

Discussion

The findings of the present study provide a rare and valuable insight into the predatory behaviors of *Thamnophis scaliger* and *Crotalus triseriatus*, which target the endangered *Ambystoma altamirani*.

While *T. scaliger* is recognized as a predator of amphibians, documented predation events involving *A. altamirani* are exceedingly rare (Villarreal-Hernández et al. 2019; Méndez-Méndez et al. 2024). This scarcity is likely attributed to the limited range of the salamander, its strict habitat requirements, and its endangered status, which reduce the probability of observing these interactions in the wild.

The documentation of such events underscores the need for further ecological investigations into these predator–prey dynamics and their implications for conservation strategies. Understanding the pressures faced by *A. altamirani* is critical for its conservation, given its endangered status both internationally (IUCN 2024) and locally (SEMARNAT 2015). Habitat loss, pollution, and the introduction of invasive species are well-documented threats to *A. altamirani* populations (Estrella-Zamora et al. 2018; Ruiz-Reyes et al. 2024). However, natural predation by native species such as *T. scaliger* and *C. triseriatus* adds another layer of complexity to these threats.

Predation may exacerbate population declines, particularly in fragmented or degraded habitats where the availability of refuges for amphibians is reduced (Heredia-Bobadilla and Sunny 2021; Sunny et al. 2024). The predatory behaviors of *T. scaliger* and *C. triseriatus* toward *A. altamirani* highlight the interconnectedness of ecosystem dynamics, where even minor shifts in predator populations or behavior could have cascading effects on vulnerable species.

Interactions between species of *Crotalus* and *Ambystoma* have rarely been documented in the scientific literature. A notable example includes a *C. triseriatus* neonate preying on *Pseudoeurycea* sp. in central Mexico (Mociño-Deloya et al. 2014). Similarly, *Crotalus viridis lutosus* has been observed preying on *Ambystoma tigrinum* (Diller 1990). These events highlight the opportunistic and highly diverse dietary habits of *Crotalus* species, which are known to adapt to a range of prey types depending on availability (Mociño-Deloya et al. 2014).

Our observations of a swimming *C. triseriatus* attempting to prey on *A. altamirani* are particularly significant, as they reveal an understudied aspect of rattlesnake behavior: its ability to exploit aquatic habitats for predation. This adaptability may provide *C. triseriatus* with a competitive advantage in montane ecosystems, where prey availability and environmental conditions are highly variable.

Similarly, the ability of *T. scaliger* to capture and remove *A. altamirani* from its aquatic environment underscores the behavioral flexibility of this garter snake species. *Thamnophis* species are well-documented predators of amphibians, with records of *T. elegans* preying on *Ambystoma macrodactylum* (Jennings et al. 1992) and *T. sirtalis* consuming *Ambystoma tigrinum* (Bartelt et al. 2023) and *Ambystoma maculatum* (Gray 2015).

The behavior observed in our study, where *T. scaliger* dragged its prey onto land for consumption, reflects an ability to adapt predation strategies to maximize success, even when targeting semiaquatic prey. Such adaptability highlights the ecological significance of predator–prey interactions in maintaining ecosystem balance but also raises concerns about the conservation of vulnerable prey species such as *A. altamirani*.

The predator–prey dynamics between *Thamnophis* snakes and *Ambystoma* species have been well-studied in terms of antipredator strategies. For example, salamanders exhibit behaviors such as tail autotomy, biting, and the detection of chemical cues to evade predation (Brodie et al. 1983; Murray and Jenkins 1999; Sullivan et al. 2002). The removal of *A. altamirani* from its aquatic environment by *T. scaliger* represents a direct challenge to such strategies, suggesting that *A. altamirani* populations may be under significant evolutionary pressure to adapt to new defensive behaviors.

Similarly, the ability of *C. triseriatus* to navigate aquatic environments and pursue amphibian growth could influence the behavioral and ecological responses of prey species in these habitats. These predation events add valuable data to the broader understanding of ecological interactions in montane stream habitats of central Mexico.

The predatory behaviors of *T. scaliger* and *C. triseriatus* not only demonstrate their ecological roles as top predators but also underscore the need for comprehensive studies on the diets and feeding behaviors of these snakes, particularly in regions inhabited by endangered amphibians (Preston and Johnson 2012). Such studies are essential for developing informed conservation strategies that address both direct anthropogenic threats and natural ecological pressures (Manjarrez et al. 2007; Jobe et al. 2019).

However, further research is needed to quantify the frequency and impact of these predation events on *A. altamirani* populations. Future studies should also explore potential mitigation strategies, such as habitat restoration or the creation of refuges, to reduce predation pressure. By integrating ecological, behavioral, and conservation research, we can better understand the intricate dynamics of montane ecosystems and work toward preserving their unique biodiversity (Sunny et al. 2023, 2024; Venegas-Barrera et al. 2024).

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Conceptualization: AS, ESS. Data curation: AS, RLHB, HDV, ESS, YGO, CCV. Formal analysis: AS, RLHB, HDV, ESS, YGO, CCV. Funding acquisition: AS, ESS. Investigation: AS, ESS. Methodology: AS, RLHB, HDV, ESS, YGO, CCV. Project administration: AS. Writing – original draft: AS, RLHB. Writing – review and editing: AS, RLHB, HDV, ESS, YGO, CCV.

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Data availability

All of the data that support the findings of this study are available in the main text.

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