







# Swimming snakes wipe out endemic lizards from Mediterranean islets

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## Funding information

FSE+, Grant/Award Number: PRE2022-105446; Spanish Ministry of Science, Innovation and Universities (MICIU), Grant/Award Numbers: EUR2021-122000, FPU22/00930, PRE2022-105446

**Handling Editor:** John Pastor

**KEY WORDS:** invasive snake, island colonization, island extinction, overwater dispersal, *Podarcis pityusensis*, *Hemorrhais hippocrepis*

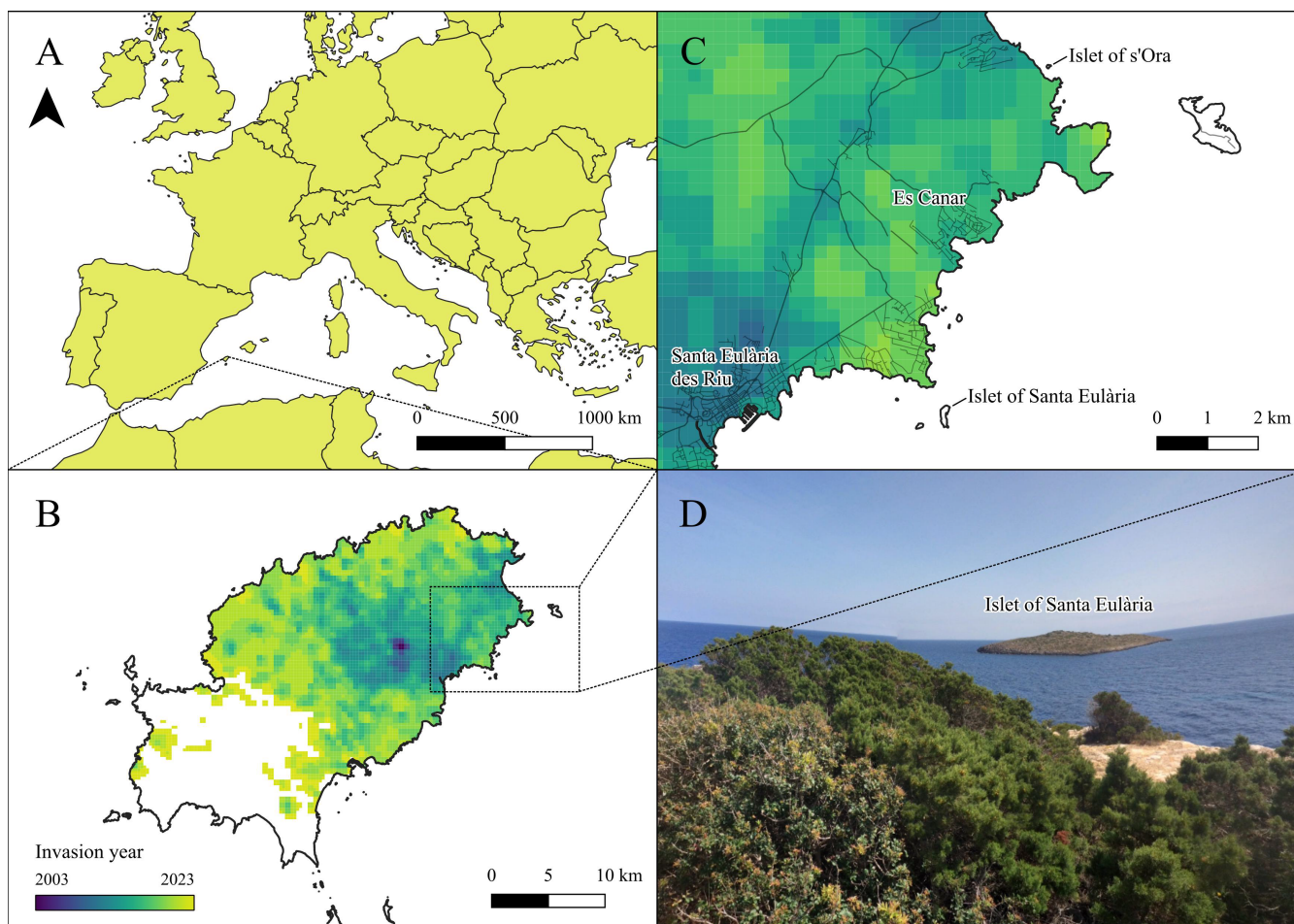
The horseshoe whip snake (*Hemorrhais hippocrepis*) was accidentally introduced to Ibiza in the early 2000s, likely via imported olive trees (Silva-Rocha et al., 2015). Since then, it has rapidly spread across the island, severely impacting local biodiversity. Most notably, it has caused the rapid extirpation of the iconic Ibiza wall lizard (*Podarcis pityusensis*). This is an endemic, keystone species from the two main Pityusic islands (Ibiza and Formentera) and 39 surrounding islets. This lizard represents over half of the diet of this snake in its invasive range in Ibiza (Hinckley et al., 2017; Montes et al., 2021, 2022). In response to this threat, the Ibiza wall lizard was recently re-classified as Endangered by the IUCN (Bowles, 2024). Despite intensive efforts resulting in the culling of over 12,000 invasive snakes since 2016 (COFIB, 2022; authors' data, updated as of 2025), the species continues to expand across the main

island. In recent years, this spread has accelerated, thereby driving the rapid extirpation of Ibiza wall lizard populations throughout the island (Montes et al., 2022; Vez-Garzón et al., 2025). Until recently, small populations from surrounding islets, which are essential to preserving the evolutionary legacy of the species (Pérez-Mellado et al., 2017), were considered relatively safe to the invasion, buffered by sea water. However, populations from these islets might in fact be at a greater risk than previously assumed.

On 15 April 2024, during a routine monitoring campaign for marine bird nesting on the islet of Santa Eulària, located 430 m off the eastern coast of Ibiza (Figure 1), we observed and filmed a horseshoe whip snake actively swimming from the main island toward the islet and finally reaching it (Video S1; Appendix S1: Figure S1). To illustrate this behavior more clearly, we

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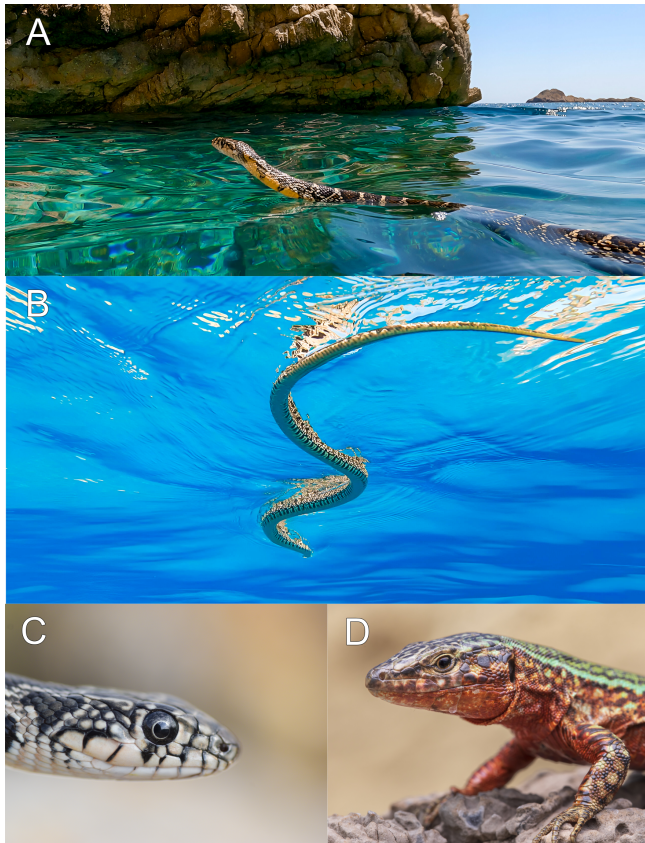
**FIGURE 1** (A) Location of Ibiza within the Mediterranean region (Balearic Islands, Spain). (B) Map of Ibiza and its surrounding islets, colored according to the year in which the invasive horseshoe whip snake reached different areas of the main island. (C) Detail of the eastern coast of Ibiza, also color-coded by year of invasion, showing the two main localities on the eastern side and the islets of S'Ora and Santa Eulària. (D) Photograph of the islet of Santa Eulària taken from the nearest point on the main island (April 2017, Google Maps).

later photographed another individual exhibiting similar open-sea swimming behavior (Figure 2A,B). On that same day of the observation, we also captured and euthanized another snake on this islet. However, these were not the only individuals found. On 28 September 2023, 12 snake traps were installed there, with active monitoring and trapping since then. Across 13 visits until May 2025, a total of 58 snakes have been captured, either via traps or directly by hand. The islet of Santa Eulària covers only 4.67 ha, corresponding to an estimated density of approximately 12.4 snakes per 1 ha. While it remains unclear whether the initial colonization involved a single gravid female or multiple individuals, our direct observation demonstrates that snakes can colonize islets by actively swimming across the sea and that this is likely a recurring phenomenon.

Driven by the concern that the Santa Eulària islet wall lizard population was at risk, we started to regularly conduct transects to quantify the abundance of Ibiza wall

lizards since the fall of 2023. During the first two visits on 28 September and 4 October 2023, we observed only two and one lizards, respectively. In contrast, a 2016 census reported in the conservation status report by Pérez-Cembranos and Pérez-Mellado (2022) recorded 72 individuals along an 869 m transect on the same islet, suggesting that the population was still relatively abundant just a few years ago. Across 11 subsequent visits between 11 October 2023 and 20 May 2025, no lizards were observed. The population on Santa Eulària islet is now considered to be completely extirpated. Figure 2D illustrates the coloration of individuals from this now-extirpated population.

Over 30 evolutionarily significant units (ESUs) of Ibiza wall lizards have been described (Rodríguez et al., 2013), many sometimes described as subspecies due to their distinctive morphology and coloration (Cirer, 1981; Salvador, 2006; Dappen et al., 2013). With the exception of the two ESUs from the main islands of Ibiza and Formentera, the



**FIGURE 2** (A, B) Horseshoe whip snake swimming in open water off the coast of Ibiza, displaying the same behavior observed during the colonization of Santa Eulària islet. (C) A close-up of the invasive snake. (D) An individual from the now-extirpated Ibiza wall lizard population on Santa Eulària islet. This image might be the last picture taken of an individual belonging to this evolutionary significant unit. Photo credits: A, B—Rubén Casas; C—Guillem Casbas; D—Roberto García-Roa.

vast majority of these populations inhabit isolated islets around these two islands (Salvador & Perez Mellado, 1984; Cirer & Berg, 2025). The loss of even a single islet population can therefore represent the extinction of a unique evolutionary lineage. Their small population sizes, restricted ranges, and extreme tameness make islet populations particularly vulnerable to novel predators (Cooper et al., 2014).

Unfortunately, Santa Eulària is not the only islet recently invaded by the invasive horseshoe whip snakes in Ibiza. The populations of Ibiza wall lizard on the nearby islet of S’Ora, a small islet off Ibiza’s northeastern coast, vanished around 2018 (Figure 1; Montes et al., 2022). At the time, although snakes were suspected as the most likely cause of extirpation, the pathway by which they may have reached the islet remained unknown. In fact, there have been anecdotal observations of swimming horseshoe whip snakes, which were assumed to correspond to hitch-hiking events (Hinckley

et al., 2017; Montes et al., 2022). In an effort to investigate how common it is for invasive horseshoe whip snakes to swim in the sea, we gathered reports of sea-swimming snakes from fishermen, local residents, tourists, regional news, and social media. These reports were gathered through both direct inquiries to residents and field collaborators, as well as unsolicited communications from the public. Additionally, we searched regional news outlets and social media posts and verified each report’s location and plausibility before inclusion. This effort yielded a total of 14 independent sightings of snakes swimming in open water around Ibiza between 2015 and 2025 (Appendix S1: Table S1), corresponding to an average of roughly three documented events every 2 years. Most observations (77%) occurred within 200 m of the shoreline (median 50 m; ranging from 10 m to 3.2 km). These sightings do not seem to be associated with difficult weather conditions (all media reports published are in sunny and calm conditions), although no formal data were available about this. These patterns indicate that sea-swimming behavior likely represents active, voluntary dispersal from already invaded coastal sectors rather than weather-driven or accidental drift. While some had proposed boat transport as a plausible route (Cirer & Berg, 2025), these accumulating reports, along with the case we document here, suggest that active swimming alone is sufficient for snakes to colonize nearby islets.

The ability for snakes to actively disperse overwater is supported by experimental evidence demonstrating that most snake species, including terrestrial taxa, exhibit swimming capabilities (Fosseries et al., 2024). Limited and indirect evidence suggests active overwater dispersal in naturally occurring snake populations exists (e.g., De Queiroz & Lawson, 2008). While most documented island colonization events by invasive snakes involve human-mediated transport (Cabrera-Pérez et al., 2012; Richmond et al., 2014), our observation suggests that active swimming may facilitate secondary spread. For example, Burmese pythons (*Python bivittatus*) in Florida exhibit strong aquatic navigation skills, reported crossing open water within wetland ecosystems, but never in the marine environment (Pittman et al., 2014). Similarly, the Montpellier snake (*Malpolon monspessulanus*) has been observed swimming in the open sea within its native distribution along the coast of France (Deso et al., 2021).

Invasive snakes can be extremely efficient predators of native fauna; even a few individual snakes (or even a single gravid female) could potentially cause rapid declines or complete local extirpations. The existence of active overwater dispersal by snakes in the sea has profound implications for island biodiversity conservation in the Mediterranean and worldwide. In Guam, the brown tree snake (*Boiga irregularis*) caused the extirpation of

10 out of 12 native forest bird species within 30 years of introduction (Savidge, 1987; Wiles et al., 2003). Similarly, the California kingsnake (*Lampropeltis californiae*) on Gran Canaria has reduced native reptile populations by 50%–90% within invaded areas since its introduction in 1998, with the largest declines (over 90%) reported for the Gran Canaria giant lizard (*Gallotia stehlini*). Dispersal is likely facilitated by both human transport and natural movement (Piquet & López-Darias, 2021). A comparable case has been reported on Christmas Island, where the introduced wolf snake (*Lycodon capucinus*) is suspected to have caused the rapid collapse of nearly the entire native reptile community within two decades (Emery et al., 2021). The observation reported here demonstrates that actively swimming to islands located relatively far from the coast is a pathway of colonization that invasive snakes can use without human voluntary or involuntary assistance. The ability of horseshoe whip snake to colonize islets located almost 0.5 km away from the coast indicates that even moderately isolated islets ( $\leq 1$  km offshore) are likely at risk. Together with evidence that seawater is not an effective barrier to dispersal, our observations have strong implications for the management of endemic species on small islets. In the case of the Ibiza wall lizard, the documented overwater dispersal of snakes suggests that undetected individuals may already be present on nearby islets close to invaded coastlines. Consequently, management and culling efforts should proactively include these adjacent islets, which could act as stepping stones for further colonization.

Our observation of a snake actively swimming toward an offshore islet, along with the confirmed presence of multiple individuals on that same islet, suggests that geographical isolation is not always an effective barrier to invasion. In fact, recent global studies have also challenged this assumption by showing that remoteness can actually make islands more vulnerable to invasion due to their reduced biological resistance and naïve native fauna (Moser et al., 2018). In addition, the ecological consequences of this snake invasion may go far beyond the loss of a single species. The ecological cascading consequences of the extirpation of Ibiza wall lizards are profound, as they play a keystone role on islet ecosystems, including seed dispersal, pollination, and the regulation of arthropod communities (Hinckley et al., 2017; Traveset et al., 2019; Donihue et al., 2023). Our finding prompts new open questions about what drives snakes to disperse overwater. Is this behavior triggered by intra-specific competition driven by prey depletion, or the consequence of increased exploratory tendencies in invasive lineages?

Exploring these questions will help us consider all possible mechanisms of invasive predator spread and therefore improve our ability to predict the consequences of these invasions.

The islet of Santa Eulària may not be an exception, but a warning signal. As a response to evidence of active overwater colonization by horseshoe whip snakes in Ibiza, we have launched a monitoring program to assess how widespread snake islet colonization is. Early detection of new colonization events while tracking the status of lizard populations is crucial to understand how invasions unfold over time. Beyond local conservation, this case illustrates how unpredictable the behavior of invasive species can be, and why sustained research is critical to anticipate and prevent future ecological impacts. Recognizing and responding to these overlooked dispersal pathways will be key to protecting the biodiversity of small islands in the Mediterranean and beyond.

## AUTHOR CONTRIBUTIONS

Guillem Casbas, Oriol Lapiedra, and Marc Vez-Garzón wrote the manuscript. All authors contributed with data, fieldwork, and have reviewed and helped write the manuscript. All authors approved the final version of the manuscript.

## FUNDING INFORMATION


The project that has generated these results has been supported by EUR2021-122000 grant funded by the Spanish Ministry of Science, Innovation and Universities (MICIU) (ref. MICIU/AEI/10.13039/501100011033). Marc Vez-Garzón has received support from the MICIU through the predoctoral FPU grant (ref. FPU22/00930) funded by MICIU/AEI/10.13039/501100011033. Guillem Casbas has received support from the MICIU through the predoctoral FPI grant (ref. PRE2022-105446) funded by MICIU/AEI/10.13039/501100011033 and by FSE+.

## CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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## SUPPORTING INFORMATION

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**How to cite this article:** Casbas, Guillem, Marc Vez-Garzón, Ariadna Sanglas, Victor Colomar, Esteban Cardona, Elba Montes, Juan Pleguezuelos, and Oriol Lapedra. 2026. "Swimming Snakes Wipe out Endemic Lizards from Mediterranean Islets." *Ecology* 107(4): e70373. <https://doi.org/10.1002/ecy.70373>