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Hidden in plain sight: the overlooked establishment of the diamond lizardfish *Synodus synodus* (Linnaeus, 1758) in the Mediterranean Sea

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Abstract

The Mediterranean Sea is a global hotspot for marine bioinvasions, with both alien and neo-native species reshaping its biodiversity. Among fishes, the diamond lizardfish *Synodus synodus*, a subtropical Atlantic taxon, has long been considered rare in the Mediterranean basin, with sporadic and questionable records. Here, we provide the first evidence of established *S. synodus* populations in the Mediterranean Sea, based on 34 individuals recorded across 18 sites in the Cyclades, Crete (Greece), and Linosa island (Italy). Most individuals were large, suggesting established populations. These findings indicate that *S. synodus* is more widespread than previously assumed, likely facilitated by ongoing seawater warming and ecological opportunities. Its unnoticed establishment highlights both the ecological relevance of neo-native fishes and the persistent challenges of detecting novel populations, even for conspicuous species, in an era of rapid marine biota restructuring.

Keywords: Non-indigenous species; coastal ecosystems; underwater visual census; neo-native species; rocky reefs; species establishment.

Introduction

Although the redistribution of marine biota is a long-standing ecological phenomenon, its pace has increased sharply in recent decades due to human activities and human-induced climate change (Poloczanska *et al*., 2013). The Mediterranean Sea, a biodiversity hotspot with high endemism (Coll *et al*., 2010), is among the world's most invasion-prone regions, hosting more than 1,000 non-indigenous taxa (Tsirintanis *et al*., 2022; Galanidi *et al.*, 2023). The Suez Canal represents the primary artificial corridor for Red Sea species into the Mediterranean (Zenetos & Galanidi, 2020), whereas Atlantic taxa enter naturally through the Strait of Gibraltar and are often regarded as "newcomers" or "neo-natives" rather than true aliens (Essl *et al.*, 2019; Azzurro *et al*., 2022; Albano *et al*., 2024). Species introduction outcomes vary considerably: some species become established, while others remain rare or fail to persist (Azzurro *et al.*, 2022).

Fish are particularly relevant in this context, being involved in major global invasions and thoroughly documented in the Mediterranean (Giakoumi *et al.,* 2019; Azzurro *et al*., 2022). Compared with other taxa, they are conspicuous, relatively easy to identify, and strongly connected to fisheries, which facilitates both detection and data collection (Azzurro *et al.*, 2022). Despite this, the early stages of invasions are rarely observed, and marine environments pose significant monitoring challenges. However, citizen science, social media, and open-access databases have significantly enhanced detection capacity in recent years (Azzurro *et al*., 2024). These approaches are particularly valuable for identifying rare or non-established species and for documenting biodiversity changes (Katsanevakis *et al.*, 2023).

Within this context, the family Synodontidae presents a compelling case. The genus *Synodus* (Scopoli, 1777) includes 49 species inhabiting tropical and subtropical regions of the Atlantic, Pacific, and Indian Oceans (Froese & Pauly, 2025; Fricke *et al*., 2025). These benthic fishes occupy sandy, rocky, seagrass, and coral reef habi-

tats down to depths beyond 400 m and are predominantly piscivorous (Ergüden *et al.*, 2024; Froese & Pauly, 2025). Recent publications provide evidence from the Mediterranean Sea of the native *S. saurus* (Linnaeus, 1758) coexisting with two congeners of different origins. *Synodus randalli* (Cressey, 1981), native to the Red Sea and Western Indian Ocean (Fricke *et al.*, 2025), likely entered via the Suez Canal and has been recorded since 2023 in Mersin Bay (Türkiye), and Crete (Greece), where a reproducing population is suspected (Langeneck *et al.*, 2023; Ergüden *et al.*, 2024; Christidis *et al.*, 2024) (but see Deidun *et al.*, 2025 for a discussion on the potential misidentification of this species in the Mediterranean Sea). The diamond lizardfish *S. synodus*, a subtropical Atlantic species sporadically reported in the Mediterranean Sea since the 1960s, was recently confirmed in Maltese waters, constituting the first genetically verified record in the central Mediterranean Sea (Deidun *et al.*, 2025). *Synodus synodus* can be distinguished from other *Synodus* species by having 12–14 dorsal fin rays, 8–10 anal fin rays, 54–60 lateral line scales, 4.5–6.5 scale rows above the lateral line, 15–18 pre-dorsal fin scale rows, 12 peritoneal spots, a pectoral fin tip extending beyond the vertical line from pelvic fin origin, a narrow interorbital region, saddle-like blotches on the dorsum, a reddish body, a black blotch on the snout tip, and anterior nostrils bearing a long flap extending beyond the margin of the nares (Whitehead *et al*., 1984; Russell, 2002; Frable *et al*., 2013). Here, we build on these recent findings by providing the first evidence of established *S. synodus* populations across multiple sites in the Mediterranean Sea based on morphological assessments, which remain the most practical and widely used tools for on-site surveys, ecological monitoring, fishery assessments, and rapid biodiversity inventories. Documenting this neo-native species highlights both its ecological significance and the broader challenges of detecting and monitoring marine biota in an era of rapid environmental change.

Materials and Methods

In the coastal waters of Attica and the Cyclades Islands (Greece), underwater visual censuses (UVCs) were conducted in May and June 2025. Underwater observations in Crete (Greece) were performed in July 2025, and in Linosa Island (Italy) in August 2025.

UVCs employing strip transects followed the protocol described by Harmelin-Vivien *et al*. (1985), which is widely adopted across the Mediterranean (e.g., Di Franco *et al*., 2009; Sala *et al*., 2012; Giakoumi *et al*., 2012; 2019; Di Lorenzo *et al*., 2020). Transects measuring 25 m × 5 m were conducted by trained SCUBA divers swimming at a constant speed, completing each transect in approximately 6–8 minutes. All fish species encountered were recorded, with estimates of abundance and total length (TL) for each individual. To support accurate species identification, divers used GoPro HERO9 underwater action cameras to film any individuals requiring confirmation. Surveys were performed at depths between four and 15 m at 53 sites distributed throughout the Cyclades Islands and mainland Greece, in the region of southeast Attica (see Table S1), spanning from Varkiza (37.80000°N, 23.79847°E, northernmost site) to Folegandros Island (36.60300°N, 24.95914°E, southernmost site).

In the coastal waters of Crete and Linosa islands, observations were made by a scientific diver during casual dives (approx. depth range: 5–30 m). For each *S. synodus* individual, data on depth, habitat, and estimated TL were collected. Several individuals were photographed and filmed using GoPro HERO9 underwater action cameras. In Linosa, a Canon PowerShot G16 was used with a Sea&Sea underwater housing and a Sea&Sea YS110 strobe light.

Species identification was confirmed using diagnostic features and images provided by FishBase (Froese & Pauly, 2025) and Reef Life Survey (Edgar & Stuart-Smith, 2014).

On July 10th, 2025, one individual of *S. synodus* was captured by a spear fisher at approximately eight m depth at Akra Vangi, Crete (35.25197°N, 25.75836°E). The specimen was provided to the authors and identified based on morphological characteristics described by Anderson *et al.* (1966) and Deidun *et al.* (2025).

Results

Overall, 34 *S. synodus* individuals were visually recorded at 18 sites: eight in the Cyclades, eight in Crete and two in Linosa (Fig. 1).

The diamond lizardfish *S. synodus* has the characteristics described in the Introduction and can be distinguished from *S. saurus* occurring sympatrically in the Mediterranean by having a snout moderately pointed (*vs* rounded in *S. saurus*), a narrow interorbital region (*vs* broad), a black blotch on the snout tip (*vs* no black blotches), and five saddle-like blotches (*vs* eight) (Whitehead *et al*., 1984; Russell, 2002; Frable *et al*., 2013; Furuhashi, *unpublished data*). This combination of characteristics identifiable through photograph and video analysis facilitated the identification of *S. synodus* and differentiation from other lizardfishes, particularly the native *S. saurus* (Fig. 2). Individuals from all study areas were observed at depths of 4–22 m (11.5 ± 0.7 m, mean ± SE), mostly on rocky habitats and more rarely in mixed patches of rocky and sandy bottoms. Total length ranged from 10 to 26 cm (16.5 ± 0.6 cm).

The highest number of individuals recorded at a site during a single dive was five (at Kamini, Crete, 35.22494°N, 25.73194°E). In terms of density (estimated only in the Cyclades using strip transects), the highest value recorded per site was at Serifos Island (37.20731° N, 24.48494° E), with 0.37 ± 0.18 individuals/125 m^2.

For the specimen collected (Fig. 3), key identification characters matched the species descriptions of Anderson *et al.* (1966) and Deidun *et al.* (2025). The captured *S. synodus* specimen measured 26.5 cm TL, 23.8 cm standard length, and 221 g in total weight. It exhibited a fusiform body, somewhat depressed head, slightly

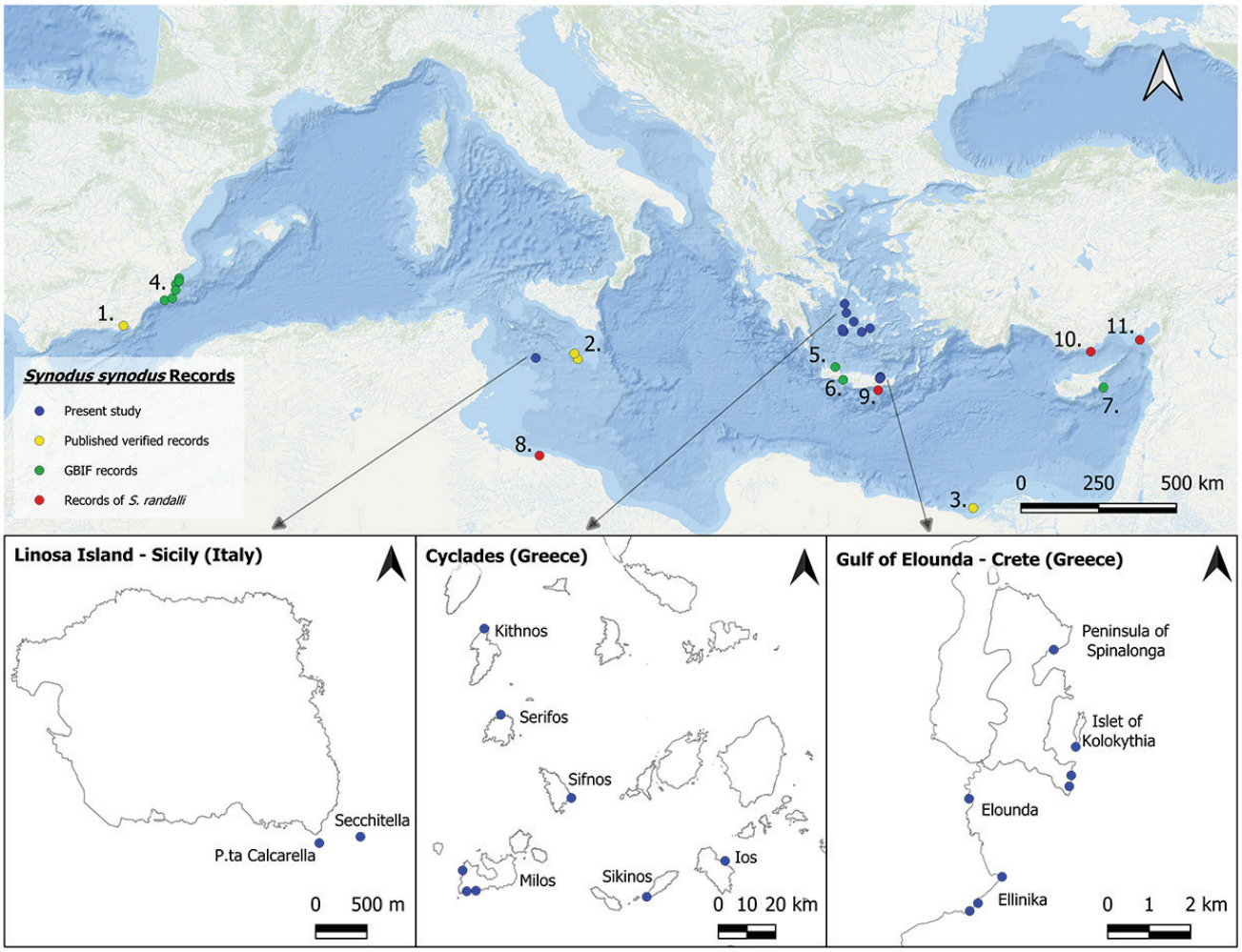

Fig. 1: Geographic distribution of *Synodus synodus* observations in the Mediterranean Sea. The upper panel illustrates the overall distribution, while the three lower panels provide zoomed views of selected areas in which *S. synodus* was recorded during the present study. Blue dots indicate sites where *S. synodus* was recorded in the present study, specifically Linosa (Sicily, southern Italy), the Cyclades archipelago (Greece), and the Gulf of Elounda (Crete, southern Greece). Yellow dots represent verified records published in the scientific literature: (1) Almeria (Southeastern Spain) (Lloris, 2015); (2) Malta (Deidun *et al*., 2025); and (3) Egypt (Akel & Karachel, 2017). Green dots correspond to records reported in the GBIF database: (4) eastern Spain (Valencian Community and Region of Murcia); (5, 6) northern and southern Crete, respectively; and (7) Cyprus. Red dots denote records attributed to *Synodus randalli*, which are likely misidentifications of *S. synodus*, documented from (8) Janzour coastal area, western Libya (Fitori & El-Fituri, 2025); (9) southern Crete (Christidis *et al*., 2024); (10) Mersin Bay (Turkiye) (Erguden *et al.*, 2024); and (11) Iskenderun Bay (Langeneck *et al*., 2023), Türkiye.

compressed caudal region, sharply pointed snout, a long flap extending well beyond the margin of nares, 13 dorsal fin rays, nine anal fin rays, eight pelvic fin rays, 57 pored lateral line scales, with five scale rows above the lateral line and seven below.

Discussion

In this study, we report the first evidence of established *S. synodus* populations in the Mediterranean based on multiple observations of large individuals across a broad area. The reported morphological and genetic differentiation of *S. synodus* between eastern and western populations suggests a complex biogeographic history (Frable *et al.*, 2013; Russell *et al.*, 2016). This species feeds primarily on small fishes and crustaceans (Fischer *et al.*, 1981), reaching 45 cm TL; however, individuals of approximately 20 cm TL are more common (Froese & Pauly, 2025).

Although *S. synodus* has been sporadically reported in the Mediterranean Sea, published information remains sparse (Deidun *et al.*, 2025). Its apparent rarity may reflect low abundance, cryptic behavior, or confusion with other synodontids (Deidun *et al.*, 2025). Our results confirm the species' widespread presence across the Aegean Sea and beyond, supporting the notion that its apparent rarity has been largely observational. Environmental changes, particularly sea warming, may have facilitated a natural west-to-east expansion from the Atlantic, as proposed for other neo-native fishes (Azzurro *et al.*, 2022) and other taxa (Albano *et al.*, 2024). Neo-natives, sensu Essl *et al.* (2019), are species that establish beyond their native range due to human-driven environmental changes rather than direct introductions. Their impacts can be substantial, often comparable to those of alien species, highlighting the

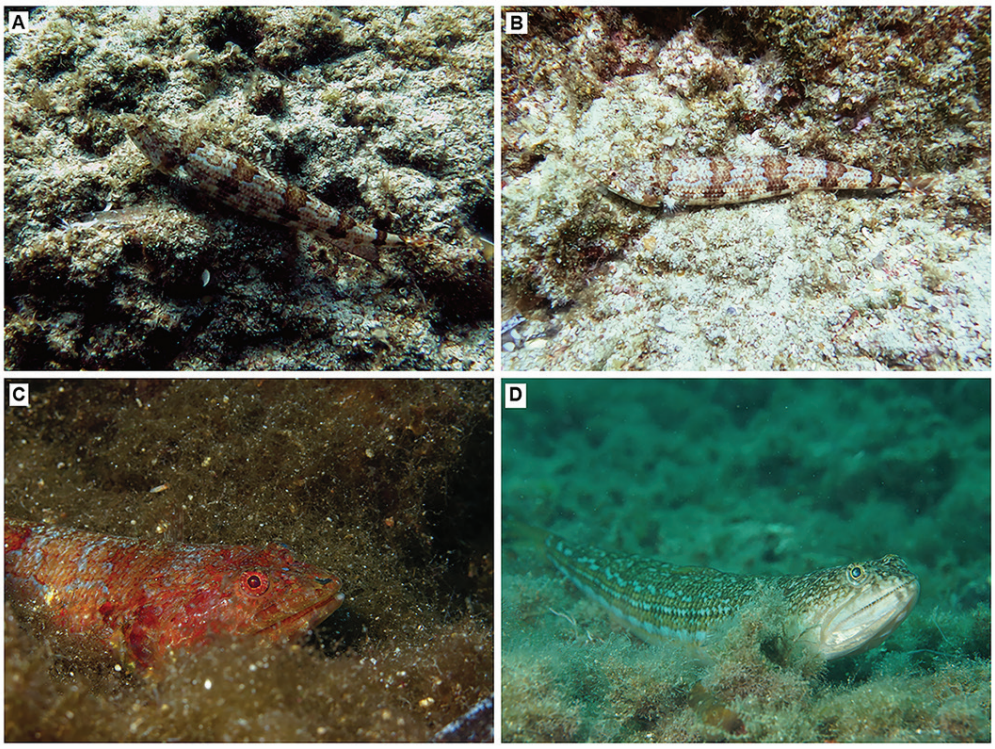

Fig. 2: In situ photographs of three individuals of *Synodus synodus* taken in shallow coastal waters of Cyclades (A-B), and Linosa (C). All images show the characteristic morphology and color pattern of the species. Panel C (Linosa Island) illustrates the natural coloration of the species (photograph taken using underwater strobe lighting, as detailed in Materials and Methods section). Panel D shows an image of *Synodus saurus*, from authors' personal archive, included to highlight differences in species' features.

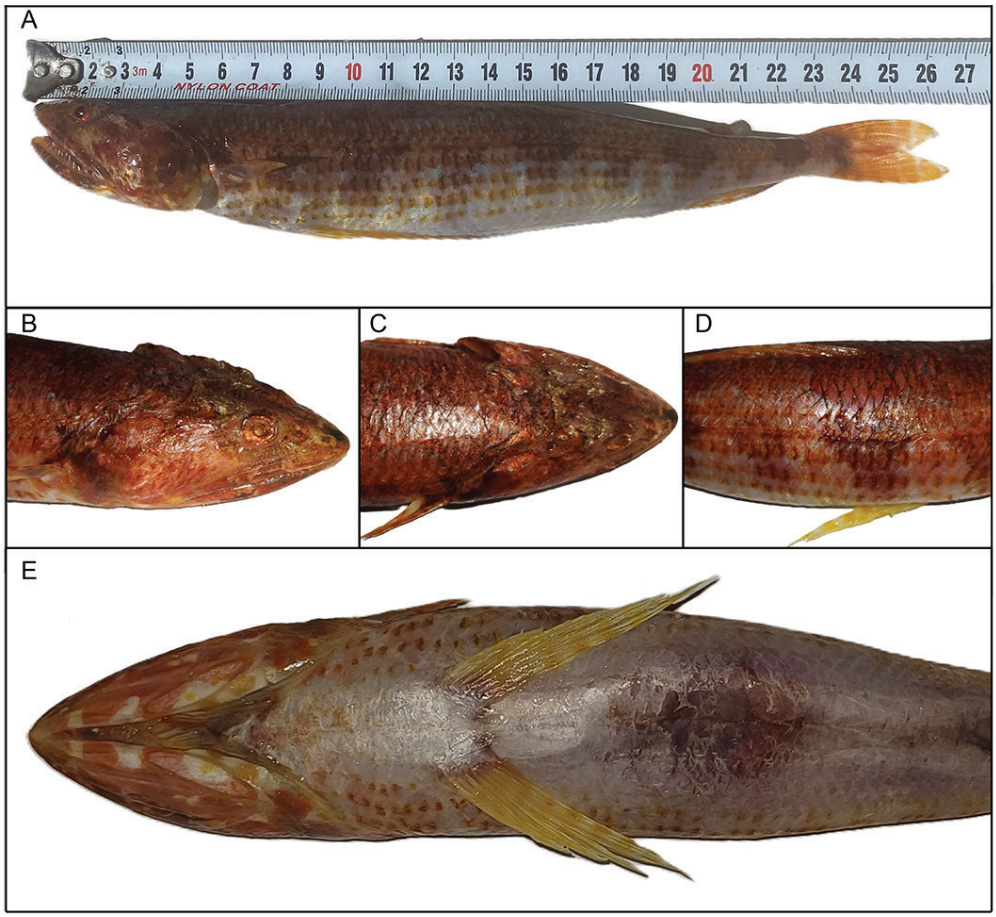

Fig. 3: A) Lateral view of the specimen of *Synodus synodus* caught in Akra Vangi (Crete, Greece) (total length = 26.5 cm); B) Side view of the head; C) Top view of the head; D) Lateral view of the dorsal fin and detail showing the number of scale rows above lateral line from dorsal fin origin; E) Ventral view of head and pelvic fin.

need for careful assessment (Essl *et al.*, 2019).

Although *S. synodus* individuals were detected using UVC, their cryptic behavior likely leads to underestimations of true abundance (Thiriet *et al*., 2016). Even with relatively high numbers recorded, the population density reported here likely underrepresents the species' actual abundance in the Mediterranean. The repeated observation of numerous large individuals suggests the establishment of one or more populations on shallow rocky reefs. As a piscivore, *S. synodus* could affect native fish communities through predation on juveniles and small species.

Our observations of *S. synodus* occurred within a depth range that does not overlap with published observations of *S. randalli*, a congener recently recorded in deeper, soft-bottom habitats (Cressey, 1981; Langeneck *et al.*, 2023; Christidis *et al.*, 2024). Our observations were restricted to the first 30 m due to the observational methods adopted (underwater visual census and casual observations by divers), while *S. randalli* was recorded through observations from professional fishing operations. Since our surveys were limited to the first 30 m, our observations likely do not capture the entire depth range of *S. synodus,* which has been reported down to 90 m (Froese & Pauly, 2025). In this context, it is important to note that Mediterranean records attributed to *S. randalli* may in fact correspond to *S. synodus* (Deidun *et al.*, 2025). We support this interpretation based on the morphological features described in these studies (Langeneck *et al.*, 2023; Christidis *et al.*, 2024), which also apply to a recent record from Libya (Fitori & El-Fituri, 2025). Since the taxonomy of *Synodus* is complex, misidentifications are possible (Furuhashi & Motomura, 2025a, b). Notably, this challenges the reliability of existing records for these species.

Despite continuous research on non-indigenous species (Tiralongo *et al.*, 2022) and large-scale monitoring initiatives such as the Occurrence Records of Mediterranean Exotic Fishes (ORMEF) Database (Azzurro *et al.*, 2024), a species can become established undetected even in extensively monitored habitats, as demonstrated by *S. synodus*. Therefore, maintaining updated and validated species inventories is crucial for assessing their ecological and societal impacts (Azzurro *et al.*, 2022; Tsirintanis *et al*., 2022).

Although early detection remains central to managing biological invasions, traditional monitoring methods for marine biology studies, such as trawls and UVC, often lack the resolution to detect low-density or cryptic species (Evangelopoulos *et al.*, 2024). Although opportunistic records, citizen science, and underwater photography are essential for documenting occurrences (Roberts *et al*., 2022), determining whether these observations represent transient individuals or self-sustaining populations is challenging and requires information that is rarely available, including long-term demographic data on reproduction and spread (Vagenas *et al.*, 2024). Emerging tools, including environmental DNA (eDNA) analysis (Aglieri *et al.*, 2023; Varrella *et al.*, 2025) and geospatial platforms such as the ORMEF Database (Azzurro *et al*., 2024) and the European Alien Species Information Network (EASIN; https://easin.jrc.ec.europa.eu), offer potential for early detection and mapping; however, their integration into long-term monitoring remains limited by logistical and financial constraints (Katsanevakis *et al.*, 2023).

Our findings demonstrate that *S. synodus* has established previously undetected populations in the Mediterranean, spanning a wide area and reaching considerable sizes. Although no molecular analyses were performed in this study, the consistent and diagnostic morphological characters of *S. synodus* facilitate robust identification, while DNA-confirmed records (e.g., Deidun *et al*., 2025) further support the reliability of our identifications. This case highlights how even conspicuous species can remain undetected for years, emphasizing the difficulty of tracking rapid changes in marine biota in a warming sea.

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Supplementary Data

The following supplementary information is available online for the article:

Table S1. List of all sampling sites in Greece (Attica and the Cyclades Islands) where underwater visual census (UVC) surveys were conducted. For each site, location name, site code, geographic coordinates, sampling date and the recorded presence of *Synodus synodus* are reported.