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# A FUGITIVE LESSEPSIAN FISH IN A SEA-CAGE FARM IN THE AEGEAN SEA: *STEPHANOLEPIS DIASPROS* (MONACANTHIDAE)

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## *ABSTRACT*

*This paper presents the first recorded sighting of a* Stephanolepis diaspros *school at a sea-cage fish farm in the Bay of Izmir, north-eastern Aegean Sea. On 17 December 2024, a group of 20 individuals of* S. diaspros *was observed around a sea cage used for rearing meagre (*Argyrosomus regius*) off Urla, at a depth of 30 m. This study not only documents the first observation of* S. diaspros *in a fish farm in the northern Aegean Sea but also provides the first evidence of this fish species intruding into sea cages.*

**Key words:** Reticulated leatherjacket, behaviour, habitat, feeding, meagre

# PESCE LESSEPSIANO FUGGITIVO IN UN ALLEVAMENTO IN GABBIA NEL MAR EGEO: *STEPHANOLEPIS DIASPROS* (MONACANTHIDAE)

## *SINTESI*

*L'articolo presenta il primo avvistamento registrato di un branco di* Stephanolepis diaspros *in un allevamento di pesci in gabbia nella baia di Smirne, nell'Egeo nord-orientale. Il 17 dicembre 2024, un gruppo di 20 esemplari di* S. diaspros *è stato osservato intorno a una gabbia marina utilizzata per l'allevamento dell'ombrina boccadoro (*Argyrosomus regius*) al largo di Urla, a una profondità di 30 m. Questo studio non solo documenta la prima osservazione di* S. diaspros *in un allevamento ittico nel mare Egeo settentrionale, ma fornisce anche la prima prova dell'intrusione di questa specie ittica nelle gabbie marine.*

**Parole chiave:** monacanto reticolato, comportamento, habitat, alimentazione, ombrina boccadoro

## INTRODUCTION

The reticulated leatherjacket, *Stephanolepis diaspros* Fraser-Brunner, 1940 (Tetraodontiformes: Monacanthidae), is a demersal marine fish typically encountered on rocky bottoms with vegetation, but also on sandy and muddy substrates with seagrass, at depths between 20 and 50 m (Golani *et al.*, 2006; Froese & Pauly, 2024). It feeds on small rock-dwelling organisms that it plucks from among the algae (Golani *et al.*, 2006).

The natural distribution of *S. diaspros* includes the Red Sea and the Arabian Gulf. The species entered the Mediterranean via the Suez Canal and is considered one of the earliest Lessepsian immigrants, now well established in the eastern Mediterranean (Golani *et al.*, 2002, 2006, 2021; Golani, 2010; Froese & Pauly, 2024). The species has also been recorded in the central Mediterranean, including Malta; Lampedusa, the Egadi Islands, and Sicily in Italy (Deidun *et al.*, 2015; Balistreri & Parasporo, 2015); Tunisia (Ben Amor & Capapé, 2008; Zouari-Ktari *et al.*, 2008); and as far north as the Sea of Marmara (Bilecenoğlu & Yokeş, 2013; Bilecenoğlu, 2024) and the northern Adriatic Sea (Lipej *et al.*, 2014).

In Turkish waters, *S. diaspros* was first reported by Koswig (1950). Since then, it has been documented in studies from the Iskenderun Bay in the NE Mediterranean Sea (Gücü *et al.*, 1994; Torcu & Mater, 2000; Başusta & Erdem, 2000; Taşkavak & Bilecenoğlu, 2001; Sangun *et al.*, 2007; Ergüden *et al.*, 2009; Yemişken *et al.,* 2014); Cyprus (Iglésias & Frotté, 2015); the Gulf of Antalya (Türker *et al.*, 2020); the SE Aegean Sea (Öz *et al.,* 2007; Corsini-Foka *et al.*, 2010; Servonnat & Drakulic, 2015; Akyol *et al.,* 2018); and the NE Aegean Sea (Akyol & Özgül, 2015; Metin & Akyol, 2021).

In the Aegean Sea, the species has been expanding its distribution range towards the northern latitudes. In 2023, Akyol (2023) documented *S. diaspros* among the 15 Lessepsian fish species found in the Bay of Izmir. This fish has occasionally been observed in both sandy areas and seagrass meadows and is typically caught using fishing lines and gillnets in the Bay of Izmir (fisherman E. Akgün, *pers. comm.*). Additionally, *S. diaspros* was observed on 31 May 2024 around the artificial reef near Hekim Island in the Bay of Izmir (pers. obs. by the second and third authors). This ichthyologic note presents the first sighting of a *S. diaspros* school within a sea-cage fish farm in the Bay of Izmir, north-eastern Aegean Sea.

## MATERIAL AND METHODS

On 17 December 2024, a group of *Stephanolepis diaspros* was observed at a sea cage used for rearing meagre (*Argyrosomus regius*) off Urla, Bay of Izmir (coordinates: 38°26′48′′N, 26°36′18′′E), at a depth of 30 m (Fig. 1). Scientific diving was conducted around the sea cages and the intruding fish were recorded using a GoPro 10 Hero camera. In-depth interviews were carried out with the farm owner (manager) to obtain detailed information. The water temperature at the diving site was 17 °C. Species identification and taxonomic nomenclature of an observed specimen follow Golani *et al*. (2006), Froese and Pauly (2024).

## RESULTS AND DISCUSSION

The species description is based on the specimens observed in the video footage: body deep, laterally compressed and rounded ventrally; a single strong spine with barbs on posterior edge of first dorsal fin, originating just above the posterior margin of the orbit; second dorsal fin just above and parallel to the anal fin; pelvic fin poorly developed, resembling a simple flap of skin; snout pointed, with a small terminal mouth containing incisor-like teeth; slit-like gill opening above origin of pelvic fin; body colour brownish green or greyish green with a complex pattern of spots, dark horizontal lines, and sinuous lines; two dark bands on convex caudal fin separated by a pale band, dorsal and anal fins yellow to orange. Based on this description, which aligns with those found in Golani et al. (2006), and Froese and Pauly (2024), the specimens were positively identified as *Stephanolepis diaspros* Fraser-Brunner, 1940 (Fig. 2).

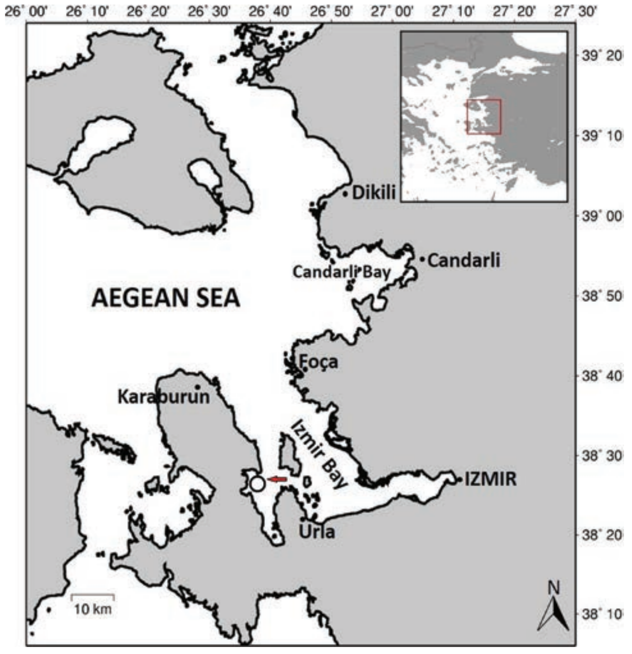

***Fig. 1: Sampling site (circle) of the*** *Stephanolepis diaspros* ***observed in a sea cage in the Bay of Izmir, northeastern Aegean Sea.***

***Sl. 1: Zemljevid obravnavanega območja z lokaliteto (krogec), kjer je bila vrsta*** *Stephanolepis diaspros* ***opažena v ribjih kletkah v Izmirskem zalivu, severovzhodno Egejsko morje.***

***Fig. 2: A school of*** *Stephanolepis diaspros* ***with reared*** *Argyrosomus* ***regius in a sea cage of Izmir Bay, northeastern Aegean Sea.***
***Sl. 2: Jata afriških kostorogov (****Stephanolepis diaspros****) z gojenimi primerki hame (****Argyrosomus regius****) v ribjih kletkah v Izmirskem zalivu, severovzhodno Egejsko morje.***

In our preliminary observations, a group of 20 *S. diaspros* individuals of approximately 15 cm in length were observed (Fig. 2) congregating at the base of the net and consuming the algae that adhered to the net. While the school of meagre were swimming in the upper part of the net cage, showing no interest in the Lessepsian fish group, *S. diaspros* appeared to be avoiding contact with the farmed fish (Fig. 2).

In-depth interviews with the managers revealed that, in the past few years, juvenile *S. diaspros* have entered the cages during the annual net changes, remaining resident for approximately eight to nine months and departing during the subsequent net change. Cultivated meagre (*A. regius*) in sea cages are initially fed a diet of fresh fish, transitioning to pellet food during summer months. According to farm managers, when the meagre is hungry, it may pursue *S. diaspros*, sometimes chasing, biting, or even killing it. Their diet consists of fouling organisms, algae, and bait fish accumulating at the base of the net (S. Şanlı & K. Şanlı, *pers. comm.*).

Pelagic fish are strongly attracted to floating structures, including coastal cage farms, and may form highly dense aggregations. It is well-known that wild fish communities can be attracted to sea-cage farms; consequently, sea cages as floating structures have been categorised as Fish Aggregation Devices (FADs) (Dempster &Taquet, 2004; Sanchez-Jerez *et al.*, 2007). A recent study (Akyol *et al.*, 2020) identified a total of 39 wild species around the six fish farms in the Turkish Aegean Sea. Notably, one single specimen of *S. diaspros* was documented in proximity of a sea-cage farm in Güllük Bay in the south-eastern Aegean Sea (Akyol *et al.*, 2020).

The tendency of juvenile demersal fish to enter floating cages in pelagic waters may be attributed to the ease of access to food in these environments. While the level of interest in pellet food for *S. diaspros* remains equivocal, this could be determined through of stomach content analyses. Due to lost pellets, wild fish may feed on excess feed around coastal fish farms. If this occurs, the condition of wild fish can improve within no-take areas (leasehold areas) and their lipid profiles may become modified (Izquierdo-Gomez *et al.,* 2015). A recent study documented a *S. diaspros* specimen with a total length of 305 mm (weighing 464 g) captured by hand-line in the Bay of Izmir, which has been recorded as the maximum reported size (Metin & Akyol, 2021). However, FishBase (Froese & Pauly, 2024) lists 250 mm as the maximum size. We believe this individual likely exhibited signs of further growth due to feeding near sea cages.

In conclusion, this study not only reports the first observation of *S. diaspros* in a fish farm in the northern Aegean Sea but also provides the first recorded instance of this species intruding into sea cages.

## ACKNOWLEDGEMENTS

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# UBEŽNI LESEPSKI MIGRANT IZ RIBOGOJNICE V EGEJSKEM MORJU: *STEPHANOLEPIS DIASPROS* (MONACANTHIDAE)

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## *POVZETEK*

*Pričujoči zapis predstavlja prvo zabeleženo pojavljanje jate afriškega kostoroga (*Stephanolepis diaspros*) v bližini ribogojnice s kletkami v Izmirskem zalivu v severovzhodnem Egejskem morju. Sedemnajstega decembra 2024 so opazili jato 20 osebkov v bližini kletke z gojenimi primerki hame (*Argyrosomus regius*) v vodah blizu Urle, na globini 30 m. Poleg dejstva, da gre za prvi zapis o opazovanju afriškega kostoroga v severnem Egejskem morju, je to tudi prvi zabeležen primer vdora te vrste v morske kletke.*

**Ključne besede:** afriški kostorog, vedenje, habitat, prehranjevanje, hama

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# ADDITIONAL RECORD OF THE PEA CRAB *PINNOTHERES BICRISTATUS* (BRACHYURA: PINNOTHERIDAE) IN THE ADRIATIC SEA

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## *ABSTRACT*

*The pea crab* Pinnotheres bicristatus *lives in symbiosis with the saddle oyster* Anomia ephippium. *The first record in the Adriatic Sea dates to 2021, when one male specimen was observed in the Gulf of Trieste. This study reports additional findings from fouling samples collected in the port of Trieste as part of the Marine Strategy Framework Directive monitoring program. Seven specimens were identified based on morphological features, confirmed through CoxI DNA marker analysis, showing 100% similarity with GenBank reference sequences. This record represents the fourth occurrence of the species in the Mediterranean Sea and confirms its continued presence in the Adriatic. Due to the identification challenges in pinnotherids, its small sizes and the fact that its host, the saddle oyster, has no commercial value,* P. bicristatus *presence could have gone unnoticed in the past and its real distribution could be more widespread, resembling those of its host.*

**Key words:** *Pinnotheres bicristatus*, *Anomia ephippium*, DNA barcoding, CoxI, Gulf of Trieste

# ULTERIORE SEGNALAZIONE DEL GRANCHIO PISELLO *PINNOTHERES BICRISTATUS* (BRACHYURA, PINNOTHERIDAE) NEL MARE ADRIATICO

## *SINTESI*

*Il granchio pisello* Pinnotheres bicristatus *vive in simbiosi con l'ostrica a sella* Anomia ephippium. *La prima segnalazione nell'Adriatico risale al 2021, quando un esemplare maschio è stato osservato nel Golfo di Trieste. Lo studio riporta un'ulteriore segnalazione da campioni di fouling raccolti nel porto di Trieste durante il monitoraggio della Direttiva Quadro sulla Strategia Marina. Sette esemplari sono stati identificati tramite caratteristiche morfologiche, confermate dall'analisi del marcatore DNA CoxI, con una similarità del 100% rispetto alle sequenze di riferimento GenBank. Questa è la sua quarta segnalazione nel Mediterraneo e ne conferma la presenza nell'Adriatico. Per le difficoltà di identificazione nei Pinnotheridae, le sue piccole dimensioni e il fatto che l'ostrica ospite non ha alcun valore commerciale, la presenza di* P. bicristatus *potrebbe essere passata inosservata in passato e la sua reale distribuzione più ampia, simile a quella dell'ospite.*

**Parole chiave:** *Pinnotheres bicristatus*, *Anomia ephippium,* DNA barcoding, CoxI, Golfo di Trieste

## INTRODUCTION

The family Pinnotheridae De Haan, 1833 consists of small brachyuran crabs that live in symbiosis/commensalism with other invertebrates, mainly bivalves (Schmitt et al., 1973). This family was originally represented by five species from European waters: *Nepinnotheres pinnotheres* (Linnaeus, 1758), *Pinnotheres ascidicola* Hesse, 1872, *Pinnotheres marioni* Gourret, 1887, *Pinnotheres pectunculi* Hesse, 1872, and *Pinnotheres pisum* (Linnaeus, 1767). However, Becker (2010) and Becker & Türkay (2010) established that *P. ascidicola* and *P. marioni* are synonyms of *N. pinnotheres*, reducing the number of recognized pinnotherid species in European waters to three: *N. pinnotheres*, *P. pisum*, and *P. pectunculi*. The African pea crab *Afropinnotheres monodi* Manning, 1993 was subsequently reported in European waters from the Gulf of Cádiz (SW Iberian Peninsula) (Subida *et al.,* 2011; Perez-Miguel *et al.,* 2019). More recently, *Pinnotheres bicristatus* Garcia Raso & Cuesta, 2019 was described from southern European waters (Cuesta *et al*., 2019), bringing the number of known pinnotherid species in European waters back to five (Marco-Herrero *et al*., 2020).

The common saddle oyster *Anomia ephippium* Linnaeus, 1758 appears to be the exclusive host of this species in the pallial cavity, although it has also been found once in the flat oyster *Ostrea edulis* Linnaeus, 1758 (Cuesta *et al*., 2019; Marco-Herrero *et al*., 2020; Cuesta *et al*., 2024). The present record of the species from the port of Trieste follows its recent finding in the Adriatic Sea, documented in an underwater photograph by Mavrič & Vrezec (2024). Therefore, up to date, three species of the family Pinnotheridae are recorded in the Adriatic Sea: *N. pinnotheres*, *P. pisum* and *P. bicristatus*, whereas in the rest of the Mediterranean there are only two: *N. pinnotheres* and *P. pisum*. However, there are other two exceptions in the Mediterranean waters: the Alboran Sea where *A. monodi*, *P. pectunculi* and *P. bicristatus* are also present (Perez-Miguel *et al*., 2019, Cuesta *et al*., 2019), and the Catalan Sea where *P. bicristatus* was reported (Marco-Herrero *et al*., 2020).

## MATERIAL AND METHODS

In October 2024, seven specimens of *Pinnotheres bicristatus* were collected in the frame of the monitoring program for the Marine Strategy Framework Directive (MSFD - Directive 2008/56/EC), under Descriptor 2 (D2) "Non-indigenous species." Since 2017, semi-annual sampling of hard substrate macrobenthos was conducted by scraping a 33.3 × 33.3 cm square (0.1 m$^2$), with a total of three samples at 2 m depth and three at 5 m. The monitoring station

***Fig. 1: Trieste and the port area with the sampling station located in the port breakwaters.***
***Sl. 1: Trst in tržaško pristanišče z označeno lokaliteto vzorčenja na pristaniških valobranih.***

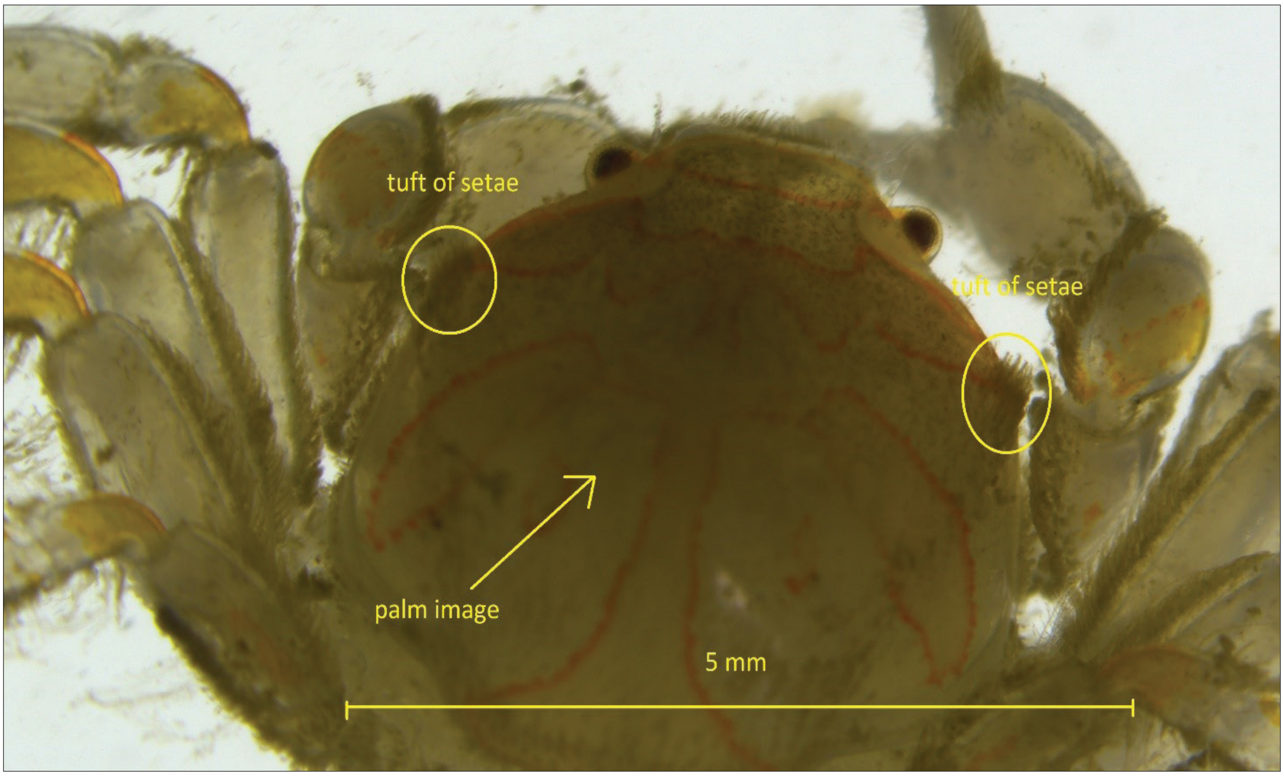

***Fig. 2: Male specimen of*** *Pinnotheres bicristatus* ***sampled in the port of Trieste (photo Arpa FVG).***
***Sl. 2: Samček vrste*** *Pinnotheres bicristatus* ***iz vzorca v tržaškem pristanišču (slika Arpa FVG).***

(45°37′28.2″ N, 013°44′13.8″ E) is located along the vertical wall of the breakwaters facing the industrial port of Trieste (Fig. 1).

Specimens were identified based on morphological features following the description in Cuesta *et al.* (2019). Total genomic DNA was extracted from 20 mg of muscle tissue from the propodus of one specimen using the PCRBIO Rapid Extract PCR Kit (PCR Biosystems, London, UK), following the manufacturer's instructions. PCR amplification was performed using PCRBIO Taq Mix Red (PCR Biosystems, London, UK) with an annealing temperature of 50 °C and 400 nM of CoxI primers LCO1490 and HCO2198, as designed by Folmer *et al.* (1994). The final sequence obtained was compared with Pinnotheridae CoxI sequences available in the GenBank database.

## RESULTS AND DISCUSSION

The specimens of *Pinnotheres bicristatus* were identified by two unique carapace characteristics: a pair of dorso-anterolateral tufts of curved setae resembling tubercles and an orange-reddish "palm-tree" marking covering the dorsal surface (Fig. 2) (Cuesta *et al.*, 2019). Species identity was also confirmed using the CoxI DNA marker, which showed 100% similarity to *P. bicristatus* sequences in GenBank.

This record represents the fourth occurrence of the species in the Mediterranean Sea. The first was from the Alboran Sea (Cuesta *et al.*, 2019), the second from the Catalan Sea (NW Mediterranean) (Marco-Herrero *et al.*, 2020), and the third from the Adriatic Sea on September 5, 2021, when a specimen was photographed at a depth of approximately 9 m in Slovenian waters in the Gulf of Trieste (Mavrič & Vrezec, 2024).

During previous semi-annual samplings of hard substrates, Pinnotheridae specimens were collected in July 2021 (two individuals at -2 m), followed by two others in October 2021 at -5 m and one in October 2022 at -2 m. These specimens were 'soft' females and initially identified simply as *Pinnotheres* sp., as their morphological characteristics did not match those of *Nepinnotheres pinnotheres* and *Pinnotheres pisum,* common species in the Gulf of Trieste. Unfortunately, these specimens were not preserved, but the presence of *P. bicristatus* in the study area prior to the present record is plausible.

Despite the permanent and abundant presence of *Anomia ephippium* and *Ostrea edulis* in the breakwater of the Trieste port, sampled since 2017, the first pinnotherid specimens only appeared in 2021, coinciding with the record by Mavrič & Vrezec (2024).

The first description of Pinnotheridae in the Adriatic Sea dates to Scopoli (1763), who described *Cancer nu-*

*trix* as a crab living inside *Ostrea edulis* (Cuesta *et al*., 2019). De Wulfen (1791) described *Cancer minutus* from the Adriatic Sea, a species very similar to *C. nutrix* and living inside *O. edulis* and other bivalves (Ng *et al*., 2008). In this context, Cuesta *et al*. (2019) assumed that both taxa belong to *P. pisum*, because it is present in the Adriatic Sea and inhabits several different species of hosts, including *O. edulis*, and moreover there are not extant type specimens of these two species that would allow checking their identity.

Cuesta *et al*. (2019) did not rule out the possibility that *P. bicristatus* could be one of those described by Scopoli (1763) and de Wulfen (1791). Thus, either this species has remained hidden even though *A. ephippium* has always been an abundant bivalve on both soft and hard bottoms of the Adriatic Sea, or we were unable to identify it prior to the description by Cuesta *et al*. (2019). Also, the saddle oyster has no commercial interest, therefore it is not commonly sampled and examined, and for this reason the presence of *P. bicristatus* could have gone unnoticed. Besides, the pinnotherid identification is not easy due to their small sizes and changes in the morphology depending on the stage of their life cycle. Therefore, samples examined by non-specialists may have been attributed to the more common species like *P. pisum*.

Although *O. edulis* is a bivalve of commercial interest, highly consumed and extensively studied, until now only one specimen of *P. bicristatus* has been recorded inside a flat oyster (Marco-Herrero *et al*., 2020). Probably it was an accidental host, surely due to a high infestation rate of *A. ephippium* in the area with consequent problems for preferential host availability.

The real distribution of *P. bicristatus* may mirror that of its host, *A. ephippium,* that was reported from Iceland to Angola (in the Atlantic Ocean) and in the Mediterranean, Marmara and Black seas (MolluscaBase eds., 2025). Although other parameters, as temperature, could determine the pea crab distribution and therefore does not need to completely overlap with that of its host (Cuesta *et al.,* 2024). In conclusion, we can argue that *P. bicristatus* is not an exotic species in the Adriatic Sea, maybe it could be considered as unreported or confounded with *P. pisum*.

## ACKNOWLEDGEMENTS

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# DODATNI ZAPIS O POJAVLJANJU STRAŽNE RAKOVICE VRSTE *PINNOTHERES BICRISTATUS* (BRACHYURA: PINNOTHERIDAE) V JADRANSKEM MORJU

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## *POVZETEK*

*Stražna rakovica vrste* Pinnotheres bicristatus *je manjša rakovica, ki sobiva s sedlasto ostrigo* Anomia ephippium. *Prvi zapis o pojavljanju te vrste izvira iz leta 2021, ko je bil v Tržaškem zalivu opažen en samec. Avtorji poročajo o dodatnih primerih pojavljanja te vrste iz vzorcev obrasti, pobrane v tržaškem pristanišču v okviru programa spremljanja Okvirne direktive o morski strategiji. Na podlagi morfoloških značilnosti so identificirali 7 primerkov in to potrdili še z analizo markerjev CoxI DNA, ki so pokazali 100% ujemanje s sekvencami v bazi GenBank. Ta zapis predstavlja četrti primer pojavljanja vrste v Sredozemskem morju in potrjuje njeno prisotnost v Jadranu. Zaradi težav pri določevanju stražnih rakovic, njihovih majhnih velikosti in dejstva, da sedlasta ostriga kot njihov gostitelj nima komercialne vrednosti, je bila vrsta* P. bicristatus *v preteklosti spregledana, njena realna razširjenost pa bi lahko bila večja oziroma podobna razširjenosti njenega gostitelja.*

**Ključne besede:** *Pinnotheres bicristatus*, *Anomia ephippium*, DNA barcoding, CoxI, Tržaški zaliv

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# CONFIRMING THE OCCURRENCE OF THE NON-INDIGENOUS *PTERAGOGUS TRISPILUS* (ACTINOPTERYGII: LABRIDAE) IN MALTESE WATERS

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## *ABSTRACT*

*The comb wrasse* Pteragogus trispilus *Randall, 2013, a species native to the Red Sea and a known Lessepsian migrant, is hereby reported for the second time from Maltese waters. The record is based on a single individual observed and photographed on 25 January 2025 in a Posidonia oceanica seagrass meadow settled on a sandy seabed at a depth of approximately 10 meters. This observation further supports the hypothesized local establishment in the Maltese waters and the ongoing range expansion of this species in the Mediterranean Sea.*

**Key words:** Lessepsian migrant, *Pteragogus trispilus*, Malta, second record, *Posidonia oceanica*, citizen science

## CONFERMA DELLA PRESENZA DEL LABRIDE NON INDIGENO *PTERAGOGUS TRISPILUS* (ACTINOPTERYGII: LABRIDAE) NELLE ACQUE MALTESI

### *SINTESI*

*Il labride* Pteragogus trispilus *Randall, 2013, nativo del Mar Rosso e considerato un migrante Lessepsiano, viene qui segnalato per la seconda volta nelle acque maltesi. La segnalazione è basata su un singolo individuo osservato e fotografato il 25 gennaio 2025 in una prateria di* Posidonia oceanica *su fondale sabbioso a circa 10 m di profondità. Questa osservazione dà sostegno all'ipotesi di un insediamento nelle acque maltesi e di una continua espansione della specie nel Mediterraneo.*

**Parole chiave:** migrante Lessepsiano, *Pteragogus trispilus*, Malta, seconda segnalazione, *Posidonia oceanica*, citizen science

## INTRODUCTION

The occurrence of alien species introduced via the Suez Canal is one of the main concerns within the Mediterranean Sea (Galil, 2009). Therefore, continuous efforts have been made by regional scientists for the early detection of newly introduced species (Azzurro, 2010). Nevertheless, it is difficult for most researchers to monitor their occurrence, primarily due to the limited number of researchers in the field. For this reason, citizen science supported by social media has represented, for decades, a key source of records, with fishers and divers acting as principal contributors (Kousteni *et al.*, 2022). While many examples exist of alien species first being sighted through citizen science, these records have, to date, largely involved species that are highly distinct from indigenous, native fauna.

On the other hand, cryptic species - species that are difficult to distinguish from one another, where an untrained eye would fail to perceive any differences (De Groot *et al.*, 2020) - are also represented within non-indigenous species. As a result, many non-indigenous cryptic species may have already spread widely across the Mediterranean, remaining undetected to date as a result of erroneous identification.

The family Labridae includes a diverse group of reef-associated fishes, with 25 species recorded in the Mediterranean alone (Froese & Pauly, 2025), some of which are already difficult to distinguish, even for the expert eye. Concerning non-indigenous fish species of Red Sea/Indo-Pacific origin, only two species of Labridae have been reported in the Mediterranean so far: *Pteragogus trispilus* Randall, 2013, firstly recorded as *Pteragogus pelycus* Randall, 1981, in Haifa Bay, Israel, in 1991

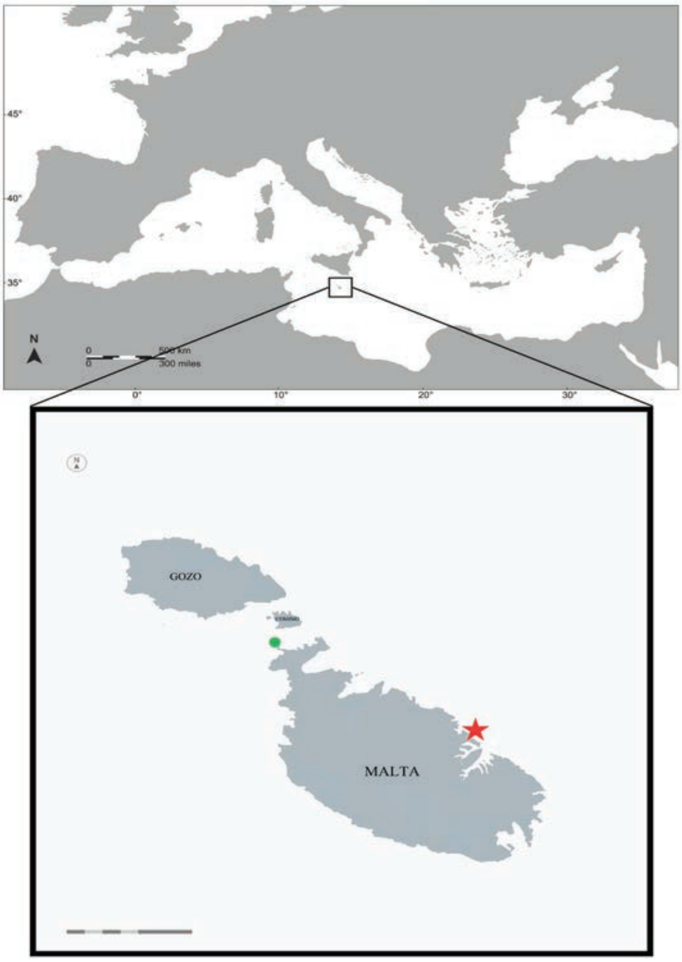

**Fig. 1: Locations for the observations of** *Pteragogus trispilus* **in Maltese waters [green circle, previous record: Borg & Evans (2022); red star, present study].**

**Sl. 1: Lokalitete, na katerih so opazovali primerke vrste** *Pteragogus trispilus* **v malteških vodah [zelen krog, prejšnji zapis: Borg & Evans (2022); rdeča zvezdica, pričujoča študija].**

(Golani & Sonin, 1992), and *Cheilinus lunulatus* (Forsskål, 1775), recorded for the first time in the waters of Gaza Strip, Palestine, in 2022 (Abd Rabou *et al*., 2022). The occurrence of a third NIS labrid, *Iniistius pavo* Valenciennes, 1840 has been excluded due to misidentification (Zenetos *et al*., 2018). Following Randall (2013), the subsequent published records of *P. pelycus* were reclassified as *P. trispilus*.

The native range of *P. trispilus* is the northern Red Sea (Randall, 2013; Golani & Fricke, 2018). After its introduction into the Mediterranean through the Suez Canal, this Lessepsian migrant has progressively expanded its distribution along the Mediterranean coasts and it is well established in the eastern Mediterranean along the coasts of Israel, Lebanon, Syria, Turkey, Cyprus, Greece, Egypt, and Libya (Azzurro *et al*., 2012, 2025; Golani *et al*., 2021). The species has reached the central part of the basin, having been recorded in Tunisia, in 2016 (Hamed *et al*., 2018) and in the Pelagie Islands, Sicilian Channel, Italy, in 2023 (Azzurro *et al*., 2025).

This species was first reported in the Maltese Islands by Borg & Evans (2022), through a photographic record made in the Cirkewwa Marine Park, located off the northernmost coast of the island. This initial record confirmed the occurrence of the species in Maltese waters but was insufficient to speculate on its establishment in the region. This record, together with the most recent one from Italy, inspired further investigation in Maltese waters through the "Spot the Alien" citizen science campaign, which resulted in the reception of a new photographic record from a local recreational diver.

This study reports the second sighting of *P. trispilus* in Malta, contributing to existing knowledge of the species' distribution in the region and reinforcing the importance of citizen science in monitoring the spread and establishment of new Lessepsian migrants within the Mediterranean.

## MATERIAL AND METHODS

For non-experts, it is difficult to distinguish *P. trispilus* from other indigenous Labridae species, especially *Symphodus cinereus*. As mentioned above, the only known report of the species from Maltese waters to date was published in 2022 (Borg & Evans, 2022), with no additional records reported since.

Therefore, on the 17th of February 2025, a targeted Facebook post providing information on the species, accompanied by photographic references, was published on local diving and angling groups to actively elicit potential sightings of the species from local waters. In response, one of the authors (SB), a local recreational diver, submitted a report documenting a single specimen of *P. trispilus* observed during a SCUBA dive on 25 January 2025 at 35°55′9.85″N, 14°29′53.76″E, a site off Sliema, located off the eastern coast of the island of Malta, at a depth of 10 meters (Fig. 1), supported by both video and photographic evidence (Fig. 2; https://www.youtube.com/watch?v=LbHdBC5as7Y; https://www.youtube.com/watch?v=P_JZdbvWT1A). The two video clips hereby were uploaded on YouTube by one of the authors (AG), as they represent original footage.

The seabed at the observation site was characterized by reticulate *Posidonia oceanica* meadows interspersed with sandy patches. The individual was observed sheltering among the seagrass blades, a behaviour similar to that exhibited by many indigenous wrasse species. The water temperature at the time of the sighting was 17° C.

Since the individual was only filmed and photographed *in situ* by the recreational diver, it was not possible to collect the fish for further morphological or genetic analysis.

## RESULTS

Despite the continuous movement of the individual and the absence of artificial illumination, the observed fish was identified by carefully examining the characteristic features of *P. trispilus* visible in the video footage and photographs obtained. In particular, our identification was based on the description provided by Randall (2013) and supported by other publications such as that of Ibrahim *et al*. (2019), focusing on features like the dorsal profile of head, the eye pupil rimmed with orange and the rest of iris having seven spoke-like dark lines, a vertical white streak to each side of the posterior edge of preopercle, a lateral line with black dots and dashes and white dots and finally the presence of a round black spot surrounded by a white ring on the operculum (Fig. 2). Also, three black spots anteriorly on the dorsal fin, one on each of the first three membranes, not visible in the photographic material, were observed during diving.

## DISCUSSION

The occurrence of *P. trispilus* in Malta aligns with the documented westward spread of Lessepsian migrants across the Mediterranean following their first entry into the basin. Similar records from Greece, Turkey, and Italy suggest that the species is gradually adapting to new environments within the region.

The location of this recent sighting (Sliema) lies on the opposite side of the island from the previously-documented Maltese record of the species, suggesting that the species is probably underreported from Maltese waters. Its cryptic appearance may have facilitated its unnoticed spread, as it is likely to be misidentified or overlooked by untrained observers (Kirsch *et al*., 2018).

This finding also raises new ecological concerns. Given the ecological importance of *Posidonia oceanica* meadows as key habitats within the Mediterranean, the potential impacts of *P. trispilus* on local fish communities should be further investigated in the Maltese area, as underlined for the nearby Tunisian region by Hamed *et al*. (2018). In particular, monitoring efforts should assess whether *P. trispilus* has already become established in Maltese waters and whether it may be interacting ecologically with native wrasse species through mechanisms such as competition or niche partitioning. For example, on Rhodes Island, one of the regions of the eastern Mediterranean most affected by biological invasions (Corsini-Foka *et al*., 2015) and invaded at an early stage by *P. trispilus*, this seagrass resident is present in fishery activities since 2002 (Corsini-Foka & Kondylatos, 2015) and its abundance indicates a rearrangement of fish assemblages in *P. oceanica* meadows (Kalogirou *et al*., 2010; Kondylatos *et al*., 2023). In samples collected from *P. oceanica* meadows carried out using the boat-seine method, among labrids, *P. trispilus* ranked second in terms of density after the Mediterranean rainbow wrasse *Coris julis* (L.), followed by the native labrids *Symphodus ocellatus* (Forsskål) and *Symphodus rostratus* (Bloch) (Kalogirou *et al*., 2010). Furthermore, using the same fishing method, *P. trispilus* showed a high frequency of occurrence, while, among alien fish, a not-negligible density was observed after the invasive *Siganus rivulatus*, *Fistularia commersonii*, *Parupeneus forsskali* and *Siganus luridus* (Kondylatos *et al*., 2023).

The sighting described in this note represents the second confirmed record of *P. trispilus* in Maltese waters, indicating a further extension of the species' known distribution. Although a single additional sighting of a species within an invaded area does not constitute definitive evidence of establishment of the same species, the continued sighting of the species at spatially disparate locations within the invaded area does hint at a further dispersal of the species within the same area.

The strategic location of the Maltese archipelago within the central Mediterranean, along the westernmost margins of the Ionian Sea and at the nexus between the western and eastern basins, is probably one of the main drivers behind the high fish biodiversity recorded from the waters around the islands, given the sheer density of shopping traffic and the occurrence of a number of important hydrodynamic phenomena around the same islands. Borg *et al*. (2023) record a total of 412 confirmed fish species from Maltese waters, which represents more than half of all the fish species known from the Mediterranean Basin, with more than 10% (42 species) of the species confirmed for Maltese waters being either range expanding, non-indigenous or cryptogenic. Several studies (e.g. Bartolo *et al*., 2021) have in fact highlighted the importance of the Maltese Islands as an outpost for the monitoring of non-native species in the Mediterranean, given their geographic location within the south-east corner of the Strait of Sicily. A number of studies (e.g. Massi et al., 2021), have in fact postulated the biogeographic role played by the Strait of Sicily in moderating, as

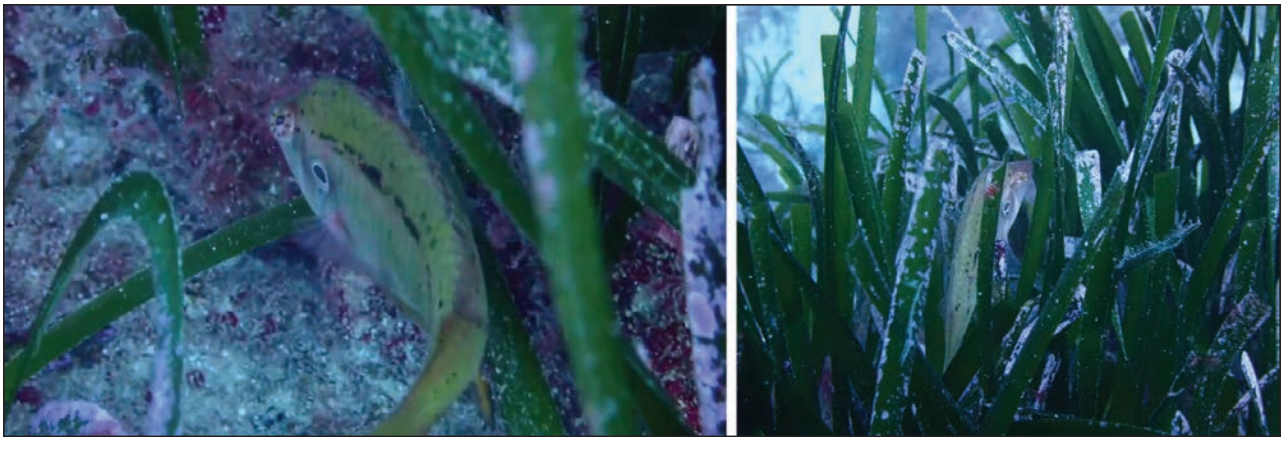

***Fig. 2:*** *Pteragogus trispilus* ***dwelling among the blades of*** *Posidonia oceanica* ***seagrass off Sliema, island of Malta (January 2025; photos by Sarah Baumann).***
***Sl. 2:*** *Pteragogus trispilus****, ki živi med listi morske trave*** *Posidonia oceanica* ***pri Sliemi, otok Malta (januar 2025; foto: Sarah Baumann).***

***Fig. 3:*** *Pteragogus tripsilus* ***photographed within a brown algal assemblage at Mgarr ix-Xini, island of Gozo (May 2025; photo by DiveGozo).***
***Sl. 3:*** *Pteragogus tripsilus* ***slikan med rjavimi algami v Mgarr ix-Xini na otoku Gozo (maj 2025; slika: DiveGozo).***

a 'semi-permeable barrier', the passage of species from the eastern basin of the Mediterranean into the western half.

The present finding supplements the first record of *P. trispilus* from Malta described by Borg & Evans (2022), further contributing to the growing checklist of marine fishes reported for the Maltese archipelago (Borg *et al*., 2023), where a total of fourteen Lessepsian fishes have been recorded, after the recent addition of *Lagocephalus guentheri* Miranda Ribeiro, 1915 (Deidun *et al*., 2024).

Furthermore, through this work, we wish to highlight the crucial role played by citizen science in the monitoring of marine alien species. However, effective citizen science relies on the constant engagement by a local researcher, who can provide knowledge, training, and feedback (Toomey *et al*., 2025). This collaborative approach not only enhances the quality of species records but also contributes to raising a new generation of ocean-literate citizens, fostering a greater awareness and stewardship of marine biodiversity.

## REMARK

On 25th of May 2025, after the acceptance of the present note, a local SCUBA diving club (DiveGozo - https://www.divegozo.co.uk) posted on its social media pages a photo of a fish belonging to an unkown species taken at a depth of approx. 10 m from a brown algal assemblage at Mgarr ix-Xini off the southern shores of the island of Gozo (36.019297°N, 14.273136°E). The fish (Fig. 3) was identified as *P. trispilus*.

ACKNOWLEDGEMENTS

Special thanks go to the Maltese diving communities for their ongoing contributions to marine biodiversity research.

# POTRDITEV POJAVLJANJA TUJERODNE USTNAČE VRSTE *PTERAGOGUS TRISPILUS* (ACTINOPTERYGII: LABRIDAE) ZNOTRAJ MALTEŠKIH VODA

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## *POVZETEK*

*Avtorji poročajo o drugem zapisu o pojavljanju vrste* Pteragogus trispilus *Randall, 2013, ki izvira iz Rdečega morja in je znana lesepska selivka, v malteških vodah. Zapis o pojavljanju temelji na enem posamezniku, opaženem in fotografiranem 25. januarja 2025 na morskem travniku pozejdonke* Posidonia oceanica*, ki se nahaja na peščenem morskem dnu na globini približno 10 metrov. Ta ugotovitev dodatno podpira domnevno lokalno naselitev in stalno širitev areala te vrste v malteških vodah in Sredozemskem morju.*

**Ključne besede:** lesepska selivka, *Pteragogus trispilus*, Malta, drugi zapis o pojavljanju, *Posidonia oceanica*, občanska znanost

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# A NEW ICHTHYOLOGICAL RECORD AND DISTRIBUTIONAL UPDATE FOR *EPIGONUS DENTICULATUS* DIEUZEIDE, 1950 IN TURKISH MEDITERRANEAN WATERS

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## *ABSTRACT*

*In July 2024, a single specimen of* Epigonus denticulatus *was captured off Silifke, Mersin, in the northeastern Mediterranean, Türkiye, at a depth of approximately 555 m. The specimen measured 14.20 cm in total length and weighed 27.8 g. Although* E. denticulatus *is known to occur in the Mediterranean Sea, it remains a rare species in eastern Mediterranean waters. This finding represents the second recorded occurrence of* E. denticulatus *in Türkiye's northeastern Mediterranean waters, contributing to the documentation of its presence in the Turkish Mediterranean region. The record provides valuable data for understanding biodiversity and the distribution of deep-sea fishes in the eastern Mediterranean, offering a foundation for future research in this field.*

**Key words:** Pencil cardinal, Epigonidae, deep-sea fish, ichthyological record, northeastern Mediterranean

# NUOVO RECORD ITTIOLOGICO E AGGIORNAMENTO SULLA DISTRIBUZIONE DI *EPIGONUS DENTICULATUS* DIEUZEIDE, 1950 IN ACQUE MEDITERRANEE TURCHE

## *SINTESI*

*Nel luglio 2024, un singolo esemplare di* Epigonus denticulatus *è stato catturato al largo di Silifke, a Mersin, nel Mediterraneo nord-orientale, in Turchia, a una profondità di circa 555 m. L'esemplare misurava 14,20 cm di lunghezza totale e pesava 27,8 g. Sebbene* E. denticulatus *sia noto per la sua presenza nel Mediterraneo, rimane una specie rara nelle acque della parte orientale. Questo ritrovamento rappresenta la seconda presenza registrata della specie nelle acque del Mediterraneo nord-orientale della Turchia, contribuendo alla documentazione della sua presenza nella regione mediterranea turca. La documentazione fornisce dati preziosi per la comprensione della biodiversità e della distribuzione dei pesci di profondità nel Mediterraneo orientale, offrendo una base per future ricerche in questo campo.*

**Parole chiave:** re di triglie bruno, Epigonidae, pesce di profondità, record ittiologico, Mediterraneo nord-orientale

## INTRODUCTION

The family Epigonidae is comprised of six genera and over 45 valid species (Fricke & Couperus, 2024; Fricke *et al.,* 2025; Okamoto *et al.,* 2024; 2025), distributed across the Atlantic, Pacific, and Indian Oceans (Abramov, 1992; Fricke, 1999; Froese & Pauly, 2025). In the Mediterranean Sea, the genus *Epigonus* is represented by three valid species: the deepwater cardinalfish (*Epigonus constanciae* Giglioli, 1880), the pencil cardinalfish (*Epigonus denticulatus* Dieuzeide, 1950), and the black cardinalfish (*Epigonus telescopus* Risso, 1810) (Froese & Pauly, 2025; IUCN, 2025). All three species have broad geographical distributions and have been recorded in Turkish marine waters (IUCN, 2025). Their presence in the Mediterranean enhances the region's ichthyofaunal diversity while underscoring the need for further studies on their distribution, population dynamics, and ecological roles within deep-sea ecosystems.

In the Mediterranean, the pencil cardinalfish was first documented in the Aegean Sea (Fischer *et al.,* 1987). Subsequent reports have confirmed its presence in various regions, including the eastern Ionian Sea and the Adriatic Sea (Mytilineou *et al.,* 2005), the Catalan Sea (Coll *et al.,* 2006), Turkish Mediterranean waters (Ergüden *et al.,* 2017), and Syrian waters (Ibrahim *et al.,* 2023). These records suggest a wider distribution of *E. denticulatus* in the Mediterranean Basin than previously recognised, emphasising the importance of continued ichthyofaunal surveys to improve the understanding of the species' range and ecological significance.

While the pencil cardinalfish (*E. denticulatus*) has hitherto been recorded along the Mediterranean coast of Türkiye, no prior studies documented its sexual characteristics. Here, we determine, for the first time, the sex of an *E. denticulatus* specimen from Turkish Mediterranean waters – identifying it as male – and provide associated morphological data.

This ichthyological note is significant as it constitutes the second documented occurrence of *E. denticulatus* in the northeastern Mediterranean waters of Türkiye and contributes new distributional data for the species in the region, underscoring the need for further research into its population structure and ecological characteristics.

## MATERIAL AND METHODS

A male specimen of *E. denticulatus* was collected during a trawl survey off Silifke, Mersin, Türkiye (36°12′840″ N, 34°24′315″ E) on 18 July 2024 (Fig. 1). Following capture, the specimen was identified and photographed on board before being transported to the laboratory for further analysis (Fig. 2). Morphometric measurements were recorded to the nearest 0.1 mm using a calliper, with meristic counts conducted under reflected light using a stereomicroscope. Sexual identification and gonadal assessment were completed through binocular microscopy. This specimen was confirmed as *E. denticulatus* based on diagnostic morphological characteristics following Gon (1986), Mayer (1974), Maugé & Mayer (1990), and Froese & Pauly (2025). After the examination, the specimen was preserved in 4% formaldehyde solution and deposited in the Marine Life Museum collection of Mersin University under catalogue number MEUFC-25-11-149.

## RESULTS AND DISCUSSION

The Mediterranean specimen of *E. denticulatus* exhibited distinct morphological features, including the following meristic counts: dorsal fin rays VII, I+10; anal fin rays II+8; ventral fin rays I+5; pectoral fin rays 18; and caudal fin rays 26. The body was elongated, the head moderately sized, with a large mouth and a round to slightly oval eye. The opercular spine was absent; in contrast, the membranous

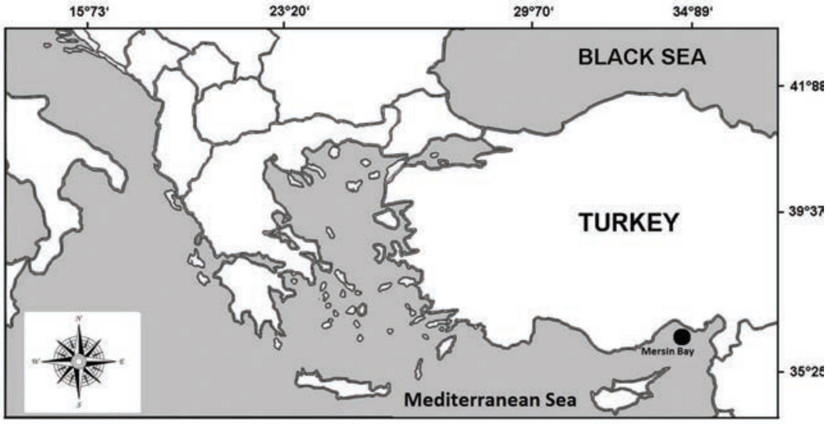

***Fig. 1: Capture site (•) of* E. denticulatus *Dieuzeide, 1950 in Mersin Bay (northeastern Mediterranean Sea, Türkiye).***
***Sl. 1: Lokaliteta ulova primerka vrste (•)* E. denticulatus *Dieuzeide, 1950 v zalivu Mersin (severovzhodno Sredozemsko morje, Turčija).***

***Fig. 2: Specimen of* E. denticulatus *(14.2 cm TL), captured in Mersin Bay, northeastern Mediterranean Sea, Türkiye (Photo: Deniz Ergüden).***
***Sl. 2: Primerek vrste* E. denticulatus *(14,2 cm telesne dolžine), ujet v zalivu Mersin, severovzhodno Sredozemsko morje, Turčija (foto: Deniz Ergüden).***

edge along the upper margin of the gill cover was well-developed. The caudal peduncle was elongated. The body coloration ranged from uniformly brownish to yellowish, with a darker dorsal side and numerous brown-black melanophores visible within the scale pockets and contributing to the specimen's distinct pigmentation pattern.

Relative to standard length (SL), the examined *E. denticulatus* exhibited the following morphometric proportions: head length (HL), 30.33%; pre-dorsal length, 33.88%; pre-anal length, 61.73%; and body depth, 20.33%. Relative to head length (HL), measurements were: eye diameter, 43.05%; pre-orbital length, 23.16%; interorbital distance, 35.42%. All diagnostic meristic and morphometric data for this specimen are presented in Table 1.

Cardinalfish of the genus *Epigonus* exhibit an extensive, near-global distribution, occurring across tropical to cold-temperate latitudes, including subantarctic regions. These bathydemersal fish inhabit continental and insular slopes, at depths ranging from 50 to 1,200 m (Gon, 1994; Okamoto & Gon, 2018). However, studies by Mytilineou *et al.* (2005) and Okamoto *et al.* (2011) indicate that most species within this genus are predominantly found along continental slopes, with recorded depths typically ranging between 100 and 1,000 m.

The pencil cardinalfish (*E. denticulatus*) is a bathydemersal species typically encountered along the upper continental slope, at depths ranging from 75 to 850 m (Abramov, 1992; Okamoto & Gon, 2018). Tortonese (1986) noted that its maximum depth distribution is somewhere between 300 and 600 m. While adults generally occupy deeper waters, juveniles are pelagic, typically found between 130 and 425 m (Maugé & Mayer, 1990; May & Maxell, 1986). The species reaches a maximum total length (TL) of 20 cm in males (Gon, 1986) and feeds predominantly on small fishes and planktonic invertebrates (Tortonese, 1986).

According to Dieuezide (1950) and Matallanas (1982), *E. denticulatus* attains sexual maturity at 12.0 cm TL. Our *E. denticulatus* specimen was a male (14.2 cm TL), with gonads in stage 3 of sexual maturity (maturing phase) (Balbontín & Bravo, 1993; Moyano *et al.,* 2020).

Meristic and morphometric characters of the pencil cardinal specimens are provided in Table 1, with comparative data from Ergüden *et al.* (2007) and Ibrahim *et al.* (2023). Our specimen exceeds the size range previously reported for Mediterranean specimens off Türkiye (Ergüden *et al.,* 2017) but remains slightly smaller than the individual documented from the Syrian coast (Ibrahim *et al.*, 2023).

Deep-sea fisheries in Türkiye's northeastern Mediterranean waters have operated for over two decades, with recent bottom trawling efforts expanding to deeper, newly explored continental slope areas. This has resulted in the capture of numerous rare and previously unrecorded demersal fish species (Ergüden & Bayhan, 2015). Our study confirms the presence of the pencil cardinalfish, *E. denticulatus* – considered exceptionally rare in the easternmost Mediterranean – in these waters, providing further evidence of the species' expanding distribution in the region. This finding underscores the need for continued monitoring and research of deep-sea fish biodiversity.

## CONCLUSIONS

The pencil cardinalfish, *E. denticulatus*, is widely distributed throughout the western and northern Mediterranean, including the Aegean Sea. However, it has rarely been recorded in Turkish Mediterranean waters, except for Mersin Bay, where it has been documented twice. This study represents the second documented record of the species' occurrence along the northeastern Mediterranean coast of Türkiye. The reappearance of *E. denticulatus* along Syrian and Turkish coasts – following an approximate seven-year absence – may indicate an eastward range expansion. This

***Tab. 1: Comparative morphometric and meristic data for the pencil cardinal fish,*** *E. denticulatus*, ***from Turkish marine waters.***
***Tab. 1: Primerjalni morfometrični in meristični podatki za rjavega veleokca,*** *E. denticulatus*, ***iz turških morskih voda.***

| **Reference** | **This study** | **Erguden** *et al.* **(2017)** | **Ibrahim** *et al.* **(2023)** |
|---|---|---|---|
| **Number of Specimen (n)** | **1** | **2** | **1** |
| **Morphometric (cm)** | | | |
| Total length | 14.20 | 8.10-12.90 | 15.40 |
| Standart length | 12.10 | 7.25-11.55 | 12.00 |
| Fork length | 12.70 | 7.44-11.85 | |
| Head length | 3.67 | 2.27-3.62 | 4.50 |
| Pre orbital length | 0.85 | 0.50-0.80 | 0.80 |
| Post-orbital length | 2.22 | 0.65-1.02 | 2.70 |
| Eye diameter | 1.58 | 1.10-1.50 | - |
| Interorbital distance | 1.30 | 0.77-1.22 | - |
| Pre pectoral fin length | 3.34 | 2.44-3.89 | 4.00 |
| Pectoral fin length | 1.90 | 1.20-1.91 | 2.60 |
| Pre pelvic length | 4.10 | 2.40-3.83 | 4.50 |
| Pelvic fin length | 0.50 | 0.40-0.65 | 2.30 |
| Pelvic fin height | 1.60 | 1.01-1.43 | - |
| Body depth | 2.46 | 1.30-2.10 | - |
| 1st Pre dorsal length | 4.10 | 2.42-3.86 | 3.80 |
| 1st Dorsal fin length | 1.79 | 0.99-1.58 | 1.50 |
| 1st Dorsal fin height | 1.63 | 1.16-1.85 | - |
| 2nd Dorsal fin length | 1.19 | 0.67-0.92 | 1.30 |
| 2nd Dorsal fin height | 1.95 | 1.13-1.80 | - |
| Pre anal length | 7.47 | 4.33-6.90 | 7.70 |
| Anal fin length | 1.46 | 0.65-0.97 | 1.20 |
| Anal fin height | 2.03 | 1.14-1.82 | - |
| Caudal peduncle depth | 1.12 | 0.68-1.06 | - |
| Maximum mouth height | 1.68 | 0.95-1.53 | - |
| Maximum mouth width | 0.87 | 0.61-0.81 | - |
| Body weight (g) | 27.80 | 6.10-20.40 | - |
| **Meristic** | | | |
| First dorsal-fin rays | VII | VII | VII |
| Second dorsal-fin rays | 1+10 | 1+10 | 10 |
| Pectoral fin ray | 18 | 18 | 14 |
| Pelvic fin ray | I +5 | I +5 | I +5 |
| Anal fin ray | II +9 | II +8 | II +8 |
| Caudal fin ray | 24 | 26 | 20 |
| Lateral line scales | 47 | 46-48 | - |
| Total gill rakers | 29 | 29-30 | - |
| Opercular membranous spines | 6 | 6-7 | - |
| Pyloric caeca | 11 | 10-11 | - |

observation underscores the need for continued ichthyofaunal surveys to monitor the species' population dynamics and identify the environmental factors potentially influencing its distribution in the eastern Mediterranean.

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# NOV IHTIOLOŠKI ZAPIS IN PODATKI O RAZŠIRJENOSTI RJAVEGA VELEOKCA, *EPIGONUS DENTICULATUS* DIEUZEIDE, 1950 V TURŠKIH SREDOZEMSKIH VODAH

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## *POVZETEK*

*Primerek rjavega veleokca (*Epigonus denticulatus*) so julija 2024 ulovili pri Silifkeju v Mersinu v severovzhodnem Sredozemlju (Turčija) na globini približno 555 m. Primerek je meril v dolžino 14,2 cm in tehtal 27,8 g. Čeprav je znano, da se rjavi veleokec pojavlja v Sredozemskem morju, je v vodah vzhodnega Sredozemlja redka vrsta. Ulov tega primerka predstavlja drugi zabeleženi pojav vrste* E. denticulatus *v severovzhodnih sredozemskih vodah Turčije, kar potrjuje njegovo prisotnosti v turški sredozemski regiji. Zapisi o pojavljanju nudijo dragocene podatke za razumevanje biotske raznovrstnosti in porazdelitve globokomorskih rib v vzhodnem Sredozemlju ter zagotavljajo osnovo za prihodnje raziskave na tem področju.*

**Ključne besede:** rjavi veleokec, Epigonidae, globokomorke ribe, ihtiološki zapis, severovzhodno

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# CONFIRMED OCCURRENCE OF THE CORNISH BLACKFISH *SCHEDOPHILUS MEDUSOPHAGUS* (OSTEICHTHYES: CENTROLOPHIDAE) FROM THE MAGHREB SHORE (SOUTHWESTERN MEDITERRANEAN SEA)

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## *ABSTRACT*

*The authors report additional records of the Cornish blackfish,* Schedophilus medusophagus *(Cocco, 1839), from the western Algerian coast near the Moroccan border. Two specimens were captured off Beni Saf, measuring 600 mm and 630 mm in total length (TL) while their total body weight (TBW) was globally estimated to be more than 5 kg. The third specimen caught off Bouzedjar, measured 650 mm TL, but its TBW was not provided by the fishmonger. These additional records confirm the species' presence off the Algerian coast and throughout the Maghreb shore, with an apparently viable population successfully established. This pattern likely reflects regional abundance of jellyfish. While the origin of* S. medusophagus *in the study area remains obscure, range expansion from the eastern Atlantic through the Strait of Gibraltar remains a feasible hypothesis.*

**Key words:** *Schedophilus medusophagus*, jellyfish, distribution, population, Maghreb shore

## PRESENZA CONFERMATA DEL MANGIAMEDUSE *SCHEDOPHILUS MEDUSOPHAGUS* (OSTEICHTHYES: CENTROLOPHIDAE) LUNGO LA COSTA DEL MAGHREB (MEDITERRANEO SUDOCCIDENTALE)

### *SINTESI*

*Gli autori riportano ulteriori ritrovamenti del mangiameduse,* Schedophilus medusophagus *(Cocco, 1839), lungo la costa occidentale algerina vicino al confine con il Marocco. Al largo di Beni Saf sono stati catturati due esemplari che misuravano 600 mm e 630 mm di lunghezza totale (TL), mentre il loro peso corporeo totale (TBW) è stato stimato globalmente superiore a 5 kg. Il terzo esemplare catturato al largo di Bouzedjar misurava 650 mm di lunghezza totale (TL), ma il suo TBW non è stato fornito dal pescivendolo. Questi ulteriori dati confermano la presenza della specie al largo della costa algerina e in tutto il Maghreb, con una popolazione apparentemente vitale stabilita con successo. Questo modello riflette probabilmente l'abbondanza regionale delle meduse. Sebbene l'origine di* S. medusophagus *nell'area di studio rimanga oscura, l'espansione dell'areale dall'Atlantico orientale attraverso lo Stretto di Gibilterra rimane un'ipotesi fattibile.*

**Parole chiave:** *Schedophilus medusophagus*, meduse, distribuzione, popolazione, costa del Maghreb

## INTRODUCTION

The Cornish blackfish, *Schedophilus medusophagus* Cocco, 1839, is distributed in the eastern Atlantic from the British Isles and the coast of Ireland (Günther, 1882; Quigley, 1984), to the Bay of Biscay (Quéro *et al.*, 2003), the northeastern coast of Spain (Bañón *et al.*, 2012), and southward along the Moroccan coast (Lloris & Rucabado, 1998), as well as around the Azores (Santos *et al.*, 1997) and Madeira Islands (Wirtz *et al.*, 2008).

*S. medusophagus* occurs in the western Mediterranean Basin (Haedrich, 1986), where it was first reported from Sicily (Cocco, 1839) and from broader Italian marine waters (Tortonese, 1975; Garibaldi *et al.*, 2010; Tiralongo *et al.*, 2019). Dulčić (1998) confirmed its presence in the Adriatic Sea, while tentative reports suggest its occurrence in the Hellenic Seas (Papaconstatinou, 2014). Eastward the species remains undocumented in Turkish marine waters (Bilecenoğlu *et al.*, 2014) and absent from the Levant Basin (Ali, 2018; Bariche & Fricke, 2020). Southward, *S. medusophagus* is found in Maltese waters (Mifsud, 2005), but is unreported off Libya (Elbaraasi *et al.*, 2019) or Egypt's Mediterranean coast (El Sayed *et al.*, 2017).

However, two records of the species have been reported from the Tunisian coast – one from the northern Gulf of Tunis (Bradaï, 2000) and another off Salakta, a city on the eastern coast (Hattour & Koched, 2017) – and one from Annaba, an Algerian city near the Tunisian border (Ladoul *et al.*, 2024). Investigations conducted in western Algeria have made it possible to report the capture of three new specimens of *S. medusophagus* described herein, and to provide a few comments on the species' distribution along the Maghreb shore.

## MATERIAL AND METHODS

Three specimens of *Schedophilus medusophagus* were observed at the main fish markets of Algiers, where fish and other marine species caught along the Algerian coast, from the Moroccan to the Tunisian border, are landed. On 28 June 2018, two *S. medusophagus* specimens were captured by trawler at a depth of 200 m over sandy-muddy substrates, off Beni Saf in western Algeria (35°18′08″ N, 1°23′01″ W) (Fig. 1). They were caught along with several specimens of the Norway lobster *Nephrops norvegicus* (Linnaeus, 1758) (Fig. 2). On 16 December 2018, a third specimen was caught by trawler at a depth of 200 m over sandy-muddy substrates, off Bouzedjar, also in western Algeria (35°42′35″ N, 1°22′17″ W) (Fig. 1), along with angler fish *Lophius piscatorius* Linnaeus, 1758 and slender rockfish *Scorpaena elongata* Cadenat, 1943. The three *S. medusophagus* specimens were identified using field guides and ichthyological fauna including Cocco (1839), Günther (1882), Tortonese (1975), Haedrich (1986), Deidun *et al.* (2003), Garibaldi *et al.* (2010), and Ladoul *et al.* (2024). They were photographed and – to the extent possible – measured. Obtaining full morphometric measurements proved challenging as all three specimens were quickly sliced and sold.

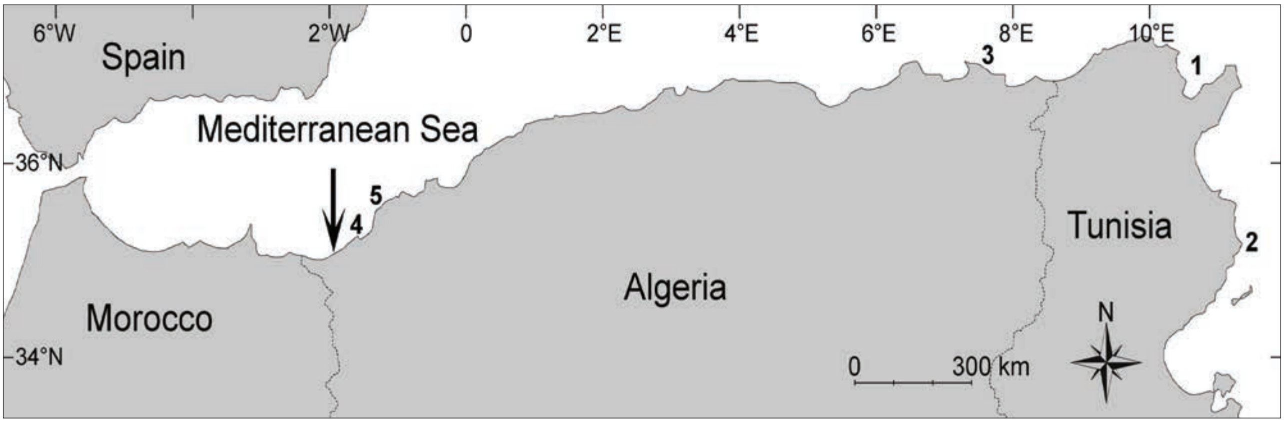

***Fig. 1: Map of the Maghreb shore indicating the capture sites of*** *Schedophilus medusophagus*. ***1. Gulf of Tunis (Bradaï, 2000). 2. Off Salakta (Hattour & Koched, 2017). 3. Off Annaba (Ladoul*** *et al.*, ***2024). 4. Off Beni Saf (this study). 5. Off Bouzedjar (this study). Arrow: collection site of the Portuguese man-of-war jellyfish,*** *Physalia physalis* ***(Linnaeus, 1758), (Boughamou & Ladoul, 2022).***

***Sl. 1: Zemljevid obale Magreba z označenimi lokalitetami ulova vrste*** *Schedophilus medusophagus*. ***1. Tuniški zaliv (Bradaï, 2000). 2. Pri Salakti (Hattour & Koched, 2017). 3. Pri Annabi (Ladoul in sod., 2024). 4. Pri Beni Safu (ta študija). 5. Pri Bouzedjarju (ta študija). Puščica: mesto ulova portugalske ladjice*** *Physalia physalis* ***(Linnaeus, 1758) (Boughamou & Ladoul, 2022).***

***Fig. 2. Specimens of*** *Schedophilus medusophagus* ***captured off Beni Saf. Scale bar = 200 mm (Photo: F. Hemida).***
***Sl. 2: Primerki vrste*** *Schedophilus medusophagus****, ujeti pri Beni Safu. Merilo = 200 mm (Foto: F. Hemida).***

## RESULTS AND DISCUSSION

The two specimens of *Schedophilus medusophagus* captured off Beni Saf measured 630 mm and 600 mm in total length (TL), 510 mm and 490 mm in standard length (SL), respectively (Fig. 2). As confirmed by the fishmonger, their combined total body weight (TBW) exceeded 5.0 kg. The specimen caught off Bouzedjar measured 650 mm TL and 550 mm SL (Fig. 3); however, despite requests from the co-author, its TBW was not provided. The three *S. medusophagus* were large-sized specimens; Haedrich (1986) reported 500 mm as the maximum SL. They were identified *via* a combination of the following morphological characters: body compressed and high; a single long dorsal fin, its origin anterior to pectoral fin origin; snout obtuse and slightly shorter than eye diameter; eyes positioned just below the upper profile of the head; prominent spines on the preoperculum margin; no teeth on the roof of mouth; pectoral and pelvic fins inserted at the same level; caudal fin bilobate, anterior part of lateral line strongly curved over the operculum and the pectoral fin; background body color light blue, with irregular darker grey patches and wavy horizontal stripes along the sides, some extending to the bases of dorsal and anal fins; pectoral and pelvic fins dark; a continuous dark stripe running along the middle of both dorsal and anal fins (Fig. 2).

The general morphology and color of the specimens are consistent with previous descriptions of *S. medusophagus* by the authors cited above. These new findings confirm the presence of the species in the Algerian ichthyofauna and fill the distributional gap along the Algerian coast between the westernmost records off Morocco (Lloris & Rucabado, 1998) to the easternmost off Tunisia (Bradaï, 2000; Hattour & Koched, 2017). Based on these new records, it appears that a viable population of *S. medusophagus* is established along the Maghreb shore and likely throughout the southern Mediterranean coast.

*S. medusophagus* is a pelagic species often associated with floating objects and closely linked to blooms of medusae, which constitute its main prey (Günther, 1882; Battaglia *et al.*, 2014). In

***Fig. 3. Specimen of*** *Schedophilus medusophagus* ***captured off Bouzedjar. Scale bar = 100 mm (Photo: F. Hemida).***
***Sl. 3: Primerek vrste*** *Schedophilus medusophagus****, ujete pri Bouzedjaru. Merilo = 100 mm (Foto: F. Hemida).***

the Ligurian Sea, Garibaldi *et al.* (2010) noted that the abundance of *S. medusophagus* was related to blooms of the jellyfish *Pelagia noctiluca* (Forsskål, 1775) occurring in the western Mediterranean. Similar patterns have been observed by Onofri *et al.* (1986) in the Middle Adriatic Sea. Boughamou & Ladoul (2022) reported the first fully documented records of the Portuguese man-of-war, *Physalia physalis* (Linnaeus, 1758), collected on Al-Wardania Beach west of the cities of Bouzedjar and Beni Saf, where captures of *S. medusophagus* have also been reported. Therefore, the occurrence of a viable population of this species along the Maghreb shore remains a plausible hypothesis likely supported by the regional abundance of medusae, especially *Pelagia noctiluca* in Tunisian waters (Daly Yahia *et al.*, 2003; Aissi *et al.*, 2014) and along the Algerian coast (Kherchouche & Hafferssas, 2019).

Dulčić (1998) suggested that the presence of *S. medusophagu*s in the Adriatic Sea may reflect water column warming. A similar distribution pattern was reported in the central Tyrrhenian Sea by Milana *et al.* (2011). However, trophic changes occur with ontogeny: stomach contents reveal small teleosts, chaetognaths, and crustaceans in larger specimens of this species, which may explain why they are found in deeper waters (Bañon *et al.*, 2012).

The origin of *S. medusophagu*s in the Mediterranean Sea remains unclear, despite attempts to trace it through specimens captured in the western basin (Cocco, 1839; Günther, 1882), where the species appears to be more widely distributed (Haedrich, 1986). Ladoul *et al.* (2024) proposed that larvae and juveniles may have been carried by oceanic currents through the Strait of Gibraltar, finding favorable environmental conditions for growth and reproduction. This hypothesis is supported by captures of specimens along the western coast of Algeria.

Although a range expansion of *S. medusophagus* from the eastern tropical Atlantic through the Strait of Gibraltar is a plausible hypothesis, direct human-mediated introduction (*sensu* Golani *et al.*, 2021), *via* commercial vessel ballast water transport of larvae and juveniles remains equally possible. Specimen records from Tunisian to Algerian and Moroccan waters confirm the species' occurrence in this western Mediterranean region.

One likely reason for the relative rarity of *S. medusophagus* is that it is frequently mistaken for some of its centropholid relatives – particularly the blackfish, *Centrolophus niger* (Gmelin, 1788), and the imperial blackfish, *S. ovalis* (Cuvier, 1829) – although these species can be distinguished by the shape of the lateral line, strongly arched in the anterior part in *S. medusophagus*, but only slightly arched in its congeners. Another factor contributing to the species' apparent scarcity could be its low commercial value. Locally, *S. medusophagus* is not targeted for consumption or other uses, although fish traders offer no further details or information in this respect.

# POTRJENA PRISOTNOST MEDUZOJEDA *SCHEDOPHILUS MEDUSOPHAGUS* (OSTEICHTHYES: CENTROLOPHIDAE) Z MAGREBSKE OBALE (JUGOZAHODNO SREDOZEMSKO MORJE)

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## *POVZETEK*

*Avtorji poročajo o novih najdbah meduzojeda* Schedophilus medusophagus *(Cocco, 1839), iz zahodne alžirske obale blizu meje z Marokom. Pri Beni Safu sta bila ujeta dva primerka, ki sta merila 600 mm in 630 mm totalne dolžine, njuno težo pa so ocenili, da je presegala 5 kg. Tretji primerek, ulovljen pri Bouzedjarju, je meril 650 mm TL, vendar ribič ni navedel njegove teže. Ti dodatni zapisi o pojavljanju potrjujejo prisotnost vrste ob alžirski obali in po celotni obali Magreba, kjer se je uspešno vzpostavila viabilna populacija. Ta vzorec najverjetneje odraža regionalno številčnost meduz. Čeprav izvor meduzojeda na preučevanem območju ostaja nejasen, je hipoteza o razširjanju areala iz vzhodnega Atlantika skozi Gibraltarsko ožino možna.*

**Ključne besede:** *Schedophilus medusophagus*, klobučnjaki, razširjenost, populacija, obala Magreba

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# FIRST OCCURRENCE OF ARIIDAE IN CYPRIOT WATERS – A MAJOR CONTRIBUTION TO BIODIVERSITY

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## *ABSTRACT*

*The Ariidae family (order Siluriformes) comprises over 160 species primarily distributed in tropical and subtropical marine and brackish waters. Herein we report the first occurrence of an Ariidae fish in Cypriot waters and the third record of this family in the Mediterranean. On 7 January 2025, a recreational fisher captured an unidentified fish near Limassol, Cyprus, at a depth of ~4 m. The fish was photographed and filmed before release. Available evidence confirmed its taxonomic classification within the Ariidae family. This record is particularly significant, as it represents the first documentation of an Ariidae and so another alien fish in Cypriot waters, expanding knowledge of Mediterranean ichthyofauna. It underscores the need for continued monitoring and further taxonomic investigations to assess the implications of this presence for local biodiversity and ecosystem dynamics.*

**Key words:** Siluriformes, catfish, alien species, Mediterranean Sea, early detection

# PRIMA COMPARSA DI ARIIDAE NELLE ACQUE CIPRIOTE – UN CONTRIBUTO SIGNIFICATIVO ALLA BIODIVERSITÀ

## *SINTESI*

*La famiglia Ariidae (ordine Siluriformes) comprende oltre 160 specie distribuite principalmente nelle acque marine e salmastre tropicali e subtropicali. Qui riportiamo la prima occorrenza di un pesce della famiglia Ariidae nelle acque cipriote, rappresentando la terza segnalazione per questa famiglia nel Mediterraneo. Il 7 gennaio 2025, un pescatore ricreativo ha catturato un pesce non identificato vicino a Limassol, Cipro, a una profondità di circa 4 m. Il pesce è stato fotografato e filmato prima di essere rilasciato. Le prove disponibili hanno confermato la sua appartenenza alla famiglia Ariidae. Questa segnalazione ha un'importanza significativa, in quanto rappresenta la prima documentazione di un pesce della famiglia Ariidae e quindi di una nuova specie aliena nelle acque cipriote, ampliando le conoscenze sull'ittiofauna mediterranea. Si sottolinea inoltre la necessità di un monitoraggio continuo e di ulteriori indagini tassonomiche per valutare le implicazioni di questa presenza sulla biodiversità locale e sulle dinamiche dell'ecosistema.*

**Parole chiave:** Siluriformes, pesce gatto, specie aliena, Mar Mediterraneo, rilevazione precoce

## INTRODUCTION

The Ariidae family (Siluriformes) encompasses 160 species across 30 genera with global distribution but a notable preference for tropical and subtropical regions (Froese & Pauly, 2023). Though primarily found in marine environments, they can also inhabit brackish waters in estuaries and coastal lagoons (Simier *et al*., 2021). Species in the Ariidae family range from medium to large in size, with some exceeding 1 m in total length (TL). The head is large, rounded to depressed, and covered by a bony shield that is often rugose and visible beneath thin skin, although in certain species it may be obscured by thicker skin and muscles. While paired maxillary and mandibular barbels, totalling four or six, represent a distinctive and consistent feature across the family, the presence of a supraoccipital process extending backward medially to connect with the pre-dorsal plate is an identifying characteristic for many species. Ariid fishes lack scales and have a complete lateral line that branches posteriorly onto the upper and lower lobes of the caudal fin. The dorsal fin is short, with a serrated spine followed by soft rays. An adipose fin is always present opposite the anal fin, and the caudal fin is deeply forked (Nelson *et al*., 2016). The pectoral fins have serrated spines and soft rays, while the pelvic fins are equipped with six soft rays, modified in mature females. Coloration is typically grey, yellow, or brown, sometimes with black patches or a silvery lateral stripe, and the ventral side is paler or white (Acero, 2002).

Within the Mediterranean Sea, only two representatives of this family have been recorded to date. The Guinean Sea catfish, *Carlarius parkii*, was reported only once, in 1983, in the shallow waters of Haifa Bay, Israel (Golani & Ben-Tuvia, 1986). Its natural range includes the eastern Atlantic, from Cape Blanc to Angola, with occasional sightings along the Atlantic coasts of Morocco (Acero & Betancur-R., 2016). While the species was initially thought to have naturally entered the Mediterranean via the Strait of Gibraltar, its prolonged absence from intermediate locations has led some researchers to consider it cryptogenic (Zenetos *et al*., 2022). More recently, in 2022, another species, *Ariopsis felis*, was recorded in Palestinian waters off the Gaza Strip on a single occasion, at a depth of 25 m on a muddy bottom (Salah *et al*., 2024). The natural distribution range of *A. felis* encompasses the western Atlantic coast, from Massachusetts and the northern Gulf of Mexico to southern Florida (USA) and into Mexico (Froese & Pauly, 2023). The detection of this species in the Mediterranean raises questions regarding its introduction pathway and potential for establishment.

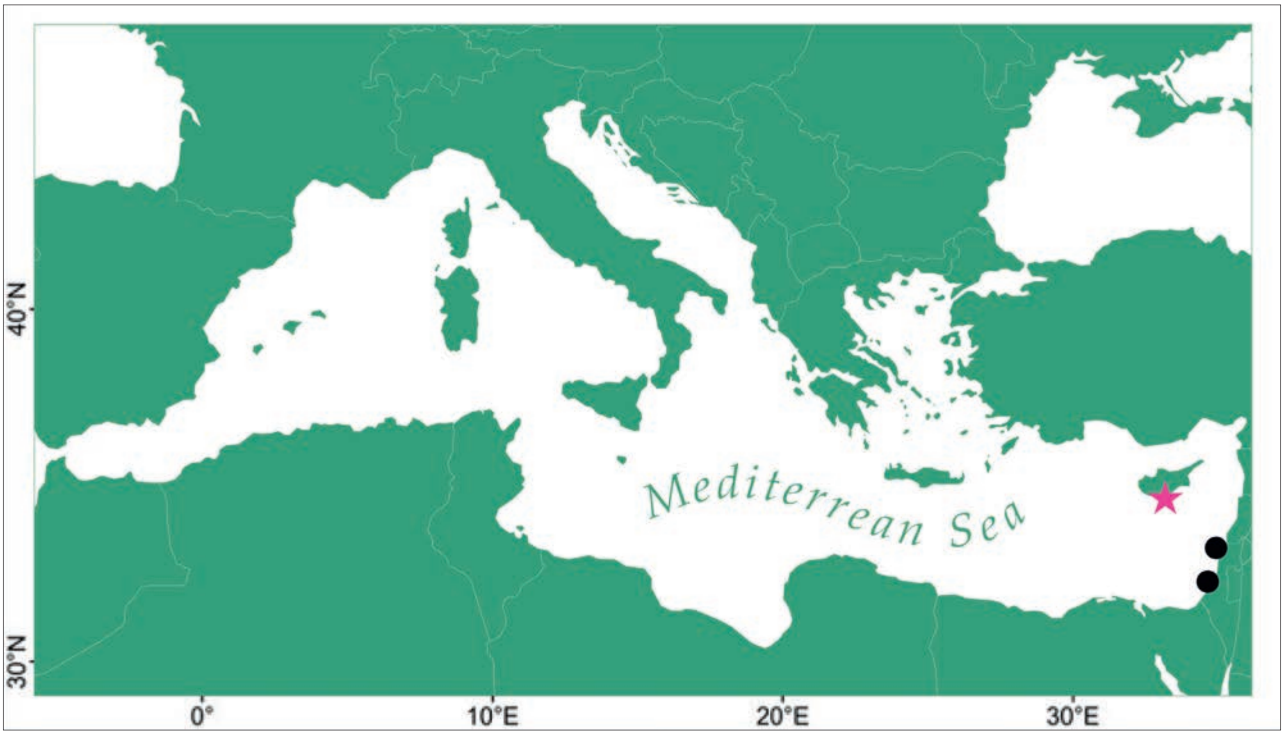

***Fig. 1: Distribution map of Ariidae fish records in the Mediterranean Sea. Black circles indicate historical records, the reddish star denotes the new record.***
***Sl. 1: Zemljevid razširjenosti morskih somov v Sredozemskem morju. Črni krogci kažejo zgodovinske podatke, rdeča zvezdica pa ponazarja novi zapis o pojavljanju.***

***Fig. 2: Ariidae specimen observed in Limassol, Cyprus, on 7 January 2025 (©Antonis Pourgouris). Original video footage available at [link].***
***Sl. 2: Primerek morskega soma pri Limassolu na Cipru, posnet 7 januarja 2025 (Foto: Antonis Pourgouris). Originalni videozapis je razpoložljiv na [link].***

Here, we report for the first time the presence of a member of the Ariidae family in Cyprus, marking the third documented occurrence of this group in the Mediterranean Sea. We also discussion potential introduction pathways and the implications for Mediterranean biodiversity.

## MATERIAL AND METHODS

On 7 January 2025, an individual belonging to the Ariidae family was caught by a recreational fisher using a fishing rod from the shore, in Limassol, Cyprus (34.664056 N, 33.029972 E, Fig. 1), at a depth of ~4 m on a sandy bottom with seagrass patches. The capture site is located between Limassol New Port (~1.5 km away) and Limassol Marina (~0.6 km away). The fisher used fly larvae (*bigattini*) as bait. The fish was photographed and filmed before being released. Despite the lack of a physical specimen, diagnostic features were assessed using available evidence.

## RESULTS AND DISCUSSION

The photographs and video footage depicted a specimen with an estimated total length of about 20 cm displaying general characteristics consistent with the Ariidae family, including body shape, a distinct supraoccipital process, and a dark adipose fin (Fig. 2). However, key diagnostic features required for genus and species-level identification, such as serrated dorsal and pectoral fin spines and close-set nostrils, were neither clearly visible nor adequately evaluable. The absence of a physical specimen precluded examination of other critical taxonomic characters, such as tooth morphology and dorsal bony shield characteristics.

Despite previous Mediterranean reference records of Ariidae species, which include *Ariopsis felis* and *Carlarius parkii*, the possibility that the observed specimen belongs to a third, unreported species of this family cannot be excluded. This taxonomic uncertainty prevents a definitive identification of the specimen and consequently limits speculation about introduction pathways. However, the proximity of the capture site to Limassol's major port suggests potential human-mediated introduction through ballast water discharge.

While this pathway remains unconfirmed, the record is nonetheless significant, as it represents Cyprus's first documented Ariidae occurrence (considered alien in all Mediterranean contexts). Such findings reveal dynamic marine biodiversity patterns in the region, potentially driven by changing environmental conditions, anthropogenic influences, or biogeographic shifts. Given the identification challenges and uncertainties regarding potential establishment, further targeted studies are required to assess the species' population in the area and facilitate a more detailed taxonomic characterisation. Enhanced monitoring efforts combining systematic scientific surveys with citizen science initiatives could be instrumental for detecting additional specimens and acquiring improved morphological and genetic data. The active involvement of local fishers, divers, and other stakeholders in reporting unusual catches or sightings will be essential for enhancing our understanding of the species' distribution and potential ecological impact. Furthermore, strengthening collaboration among researchers, environmental agencies, and maritime authorities will enable a more comprehensive and coordinated response to marine biological invasions, helping to mitigate the potential risks associated with the introduction of non-native species (Tiralongo *et al.*, 2020).

## ACKNOWLEDGEMENTS

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# PRVO POJAVLJANJE PREDSTAVNIKOV IZ DRUŽINE ARIIDAE V CIPRSKIH VODAH – VELIK PRISPEVEK K BIODIVERZITETI

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## *POVZETEK*

*Morski somi (družina Ariidae, red Siluriformes) štejejo 160 vrst, ki so primarno razširjene v tropskih in subtropskih morskih in brakičnih vodah. Avtorja poročata o prvem zapisu o pojavljanju vrste iz družine morskih somov v ciprskih vodah in tretji zapis o pojavljanju vrst iz te družine v Sredozemlju. Sedmega januarja 2025 je rekreativni ribič pri Limassolu na Cipru na globini približno 4 m ujel neidentificirano ribo, ki jo je pred izpustom fotografiral in posnel. Izkazalo se je, da gre za vrsto iz družine Ariidae. Ta zapis o pojavljanju je pomemben, saj gre za prvi primer pojavljanja morskega soma kot tujerodne vrste v ciprskih vodah, in dopolnjuje vedenje o sredozemski ihtiofavni. Hkrati poudarja potrebo po nadaljnjem spremljanju in nadaljnjih taksonomskih preiskavah za oceno posledic prisotnosti te vrste za lokalno biotsko raznovrstnost in dinamiko ekosistemov.*

**Ključne besede:** Siluriformes, morski somi, tujerodne vrste, Sredozemsko morje, zgodnje odkrivanje

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# SREDOZEMSKE HRUSTANČNICE

# *SQUALI E RAZZE MEDITERRANEE*

# *MEDITERRANEAN SHARKS AND RAYS*

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# AN INSIGHT INTO THE DIET OF THE BULL RAY, *AETOMYLAEUS BOVINUS* (GEOFFROY SAINT-HILAIRE, 1817) IN THE NORTHERN ADRIATIC SEA

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## *ABSTRACT*

*This study provides baseline information on the feeding habits of the bull ray, Aetomylaeus bovinus (Geoffroy Saint-Hilaire, 1817), in the Gulf of Venezia. Among 1557 prey items isolated from the stomachs of bull ray specimens, gastropods represented the overwhelming majority (93.8%). Within gastropods,* Aporrhais pespelecani *was the dominant species, followed by* Gibbula magus *and* Bolinus brandaris *– all characteristic elements of the biocoenosis of the muddy detritic bottom. We observed differences in prey structure between juveniles and adults, as well as sexes. Among fishes that proved to be particularly important in terms of biomass, the majority of prey items consisted of small pelagic fish, including pilchard (Sardina pilchardus) and horse mackerel (Trachurus sp.). This paper contributes new data on the feeding ecology of a lesser known and critically endangered batoid species.*

**Key words:** myliobatids, feeding ecology, nursery, Gulf of Venice

# APPROFONDIMENTI SULLE ABITUDINI ALIMENTARI DELLA VACCARELLA, *AETOMYLAEUS BOVINUS* (GEOFFROY SAINT-HILAIRE, 1817) NELL'ADRIATICO SETTENTRIONALE

## *SINTESI*

*Lo studio riporta le abitudini alimentari della vaccarella,* Aetomylaeus bovinus *(Geoffroy Saint-Hilaire, 1817), nel Golfo di Venezia. Tra le 1557 prede isolate dagli stomaci, i gasteropodi costituivano la grande maggioranza (93,8%), dominati dalla specie* Aporrhais pespelecani*, seguita da* Gibbula magus e Bolinus brandaris. *Queste specie sono elementi caratteristici della biocenosi del fondo detritico fangoso. Sono state osservate differenze nella struttura delle prede tra giovani e adulti e tra i sessi. Tra i pesci che sembravano essere particolarmente importanti in termini di biomassa, i piccoli pesci pelagici come la sardina (*Sardina pilchardus*) e il sugarello (*Trachurus *sp.) rappresentavano le prede più grandi. Questo lavoro contribuisce a fornire nuove informazioni sull'ecologia alimentare di una specie di razza meno conosciuta e in pericolo critico.*

**Parole chiave:** vaccarella, ecologia alimentare, nursery, Golfo di Venezia

## INTRODUCTION

The bull ray, *Aetomylaeus bovinus* (Geoffroy Saint-Hilaire, 1817), is a benthopelagic species inhabiting coastal and warm temperate waters, occasionally found offshore, at depths of 10–150 m (Capapé & Quignard, 1975). Bull rays can tolerate greatly reduced salinities (Ebert & Stehmann, 2013) and therefore occasionally enter shallow lagoons (El Kamel *et al.*, 2009) and semi-enclosed bays (Zogaris & Dussling, 2010; Bilgili & Kabasakal, 2023). As a longevous species with late maturity and low reproductive rates – signature traits of a K-selected life history strategy (Stevens *et al.*, 2000) – the bull ray is vulnerable to overfishing, especially in nearshore habitats, where it forms small aggregations to feed (Seck *et al.*, 2002; El Kamel *et al.*, 2010, Zogaris & Dussling, 2010; Akyol *et al.*, 2017). The bull ray is poorly studied in terms of feeding ecology. The only comprehensive study on the feeding habits of *A. bovinus* was conducted by Capapé (1977) in Tunisian waters, based on analyses of 568 specimens at different stages of development.

Bull rays are observed in the northern Adriatic Sea between late spring and early autumn, while in winter they migrate towards southern areas (La Mesa *et al.*, 2017). Due to its longevity, *A. bovinus* was previously considered an indicator species for pollution with heavy metals such as Hg and MeHg (Horvat *et al.*, 2013), arsenic (Šlejkovec *et al.*, 2014), and selenium (Faganeli *et al.*, 2018). Though not commercially targeted, the species is often caught as by-catch and discarded. It is currently considered a critically endangered ray species on the global scale, whose populations suffered substantial depletion in the last years due to overfishing (Jabado *et al.* 2021). Recently, this status was also confirmed by Soldo & Lipej (2022), who evaluated the species as rare in the Adriatic Sea.

The aim of this study is to investigate the feeding habits of the bull ray in the northern Adriatic Sea (the Gulf of Trieste and neighbouring areas along the western Istrian coast). The feeding ecology of this species is significantly understudied, making any data in this regard vital. Such research is also necessary and useful in elucidating the impact of such predation on the structure of epibenthic macrofaunal assemblages.

## MATERIAL AND METHODS

The stomachs of bull rays were collected between 2005 and 2015 from rays caught as by-catch by commercial trawlers. Fishing was conducted at depths of 10 – 50 m in the Gulf of Trieste and along the western Istrian coast (Fig. 1). The sample was comprised of neonates, adult males, and adult females, including several pregnant specimens. After being defrosted in the lab, each individual was sexed. The specimens were measured (disk width – DW) and weighed. Each stomach was weighed full and emptied. Stomach contents were washed on the sieve and conserved in 95% ethanol. Prey items were analysed using an Olympus SZX16 stereomicroscope and photographed using an Olympus camera DP 74.

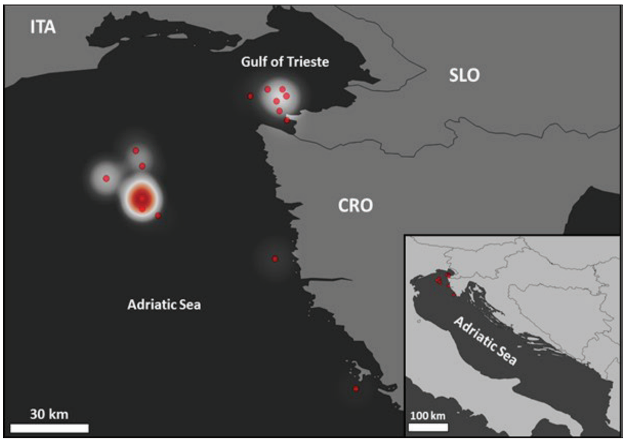

***Fig. 1: Map of the studied area and its position in the Adriatic Sea. Areas where bull rays were caught are depicted as red dots. Catch density is additionally presented as a heat map.***
***Sl. 1: Zemljevid obravnavanega območja in njegov položaj glede na Jadransko morje. Predeli, kjer so ujeli kljunate morske golobe, so označeni z rdečimi krogci. Gostota ulova je prikazana kot kolobarji.***

Prey items were identified to the lowest taxonomic level (species level where possible), using taxonomic keys and field guides (Riedel, 1991; Falciai & Minervini, 1992), and subsequently counted. A reference collection of gastropod opercula preserved at the Marine Biology Station proved extremely valuable for determination, providing additional diagnostic support. The counting of prey items was based on typical anatomical parts: claws and legs for crustaceans, carapaces for decapods, shells and feet for bivalves, opercula for gastropods (Fig. 2), and partial remains (including otoliths) for teleost species.

### Data analysis

Opercula from isolated benthic gastropods were precisely measured (max length and width) and photographed under the microscope. To assess the approximate weight of each gastropod, a correlation length-weight curve obtained from the data of live collected specimens (pulled from the shells) was used. Length-weight correlation curves were calculated for the gastropod species that dominated the bull ray's diet: *Aporrhais pespelecani* (Linnaeus, 1758), *Bolinus*

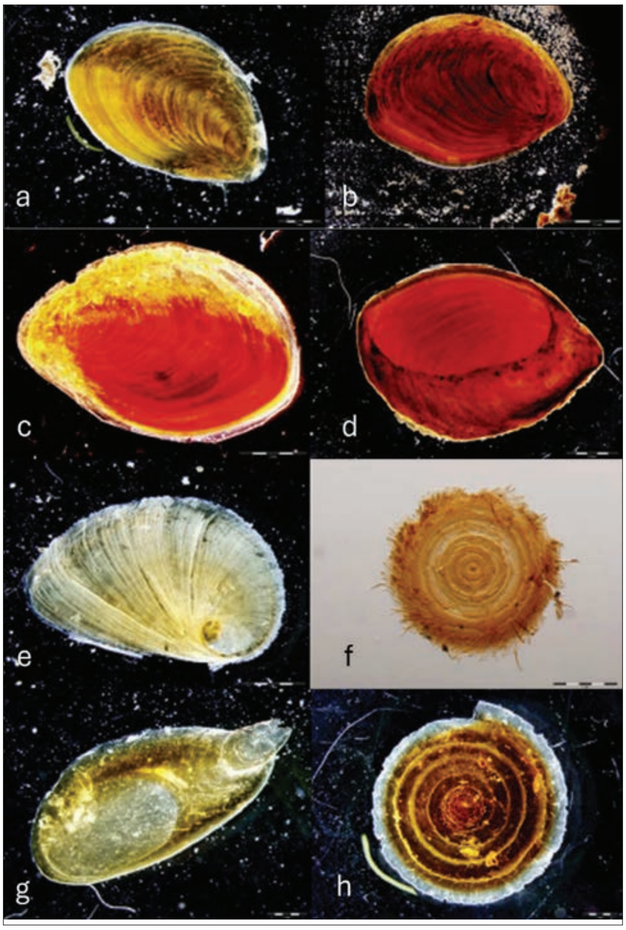

**Fig. 2: Opercula of various gastropods present in the diet of the bull ray. Legend: a and b –** *Bolinus brandaris***, c and d –** *Hexaplex trunculus***, e –** *Cerithium vulgatum***, f –** *Turritella communis***, g –** *Aporrhais pespelecani***, and h –** *Gibbula magus***. Scale bar = 1 mm.**

**Sl. 2: Poklopci (operkuli) različnih polžev, ki se pojavljajo v prehrani kljunatega morskega goloba. Legenda: a in b –** *Bolinus brandaris***, c in d –** *Hexaplex trunculus***, e –** *Cerithium vulgatum***, f –** *Turritella communis***, g –** *Aporrhais pespelecani* **in h –** *Gibbula magus***. Merilo = 1 mm.**

*brandaris* (Linnaeus, 1758), *Gibbula magus* (Linnaeus, 1758), and *Hexaplex trunculus* (Linnaeus, 1758).

The opercula of *B. brandaris* and *H. trunculus* exhibit numerous morphological similarities, making them challenging to distinguish. To ensure accurate identification, every operculum assignable to either species was carefully examined under the microscope and compared against reference specimens collected from the natural environment (those used for the correlation length-weight curves). The majority of muricid opercula were conclusively identified as *B. brandaris.* In addition to opercular shape, the width-to-length ratio proved valuable for species discrimination in ambiguous cases (Fig. 3), as *B. brandaris* and *H. trunculus* have different opercular proportions. For the few specimens that could not be confidently identified, we recorded them as generic *Murex* sp.

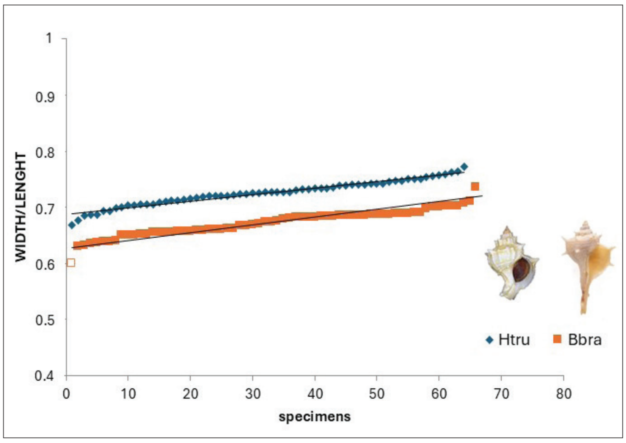

**Fig. 3: Relationship between width and length of opercula of two similar species** *Hexaplex trunculus* **(blue diamonds) and** *Bolinus brandaris* **(orange squares), obtained from specimens as by-catch from the fishermen. This relationship was useful to discriminate the opercula of the two muricid species found in the stomachs of the bull rays.**

**Sl. 3: Odnos med dolžino in širino poklopcev pri dveh sorodnih vrstah volekov** *Hexaplex trunculus* **(modri karo) in** *Bolinus brandaris* **(oranžni kvadratki), na podlagi živih primerkov, ulovljenih kot prilov ribičev. Ta odnos je bil uporaben za razlikovanje poklopcev obeh volekov, najdenih v prehrani kljunatega morskega goloba.**

The feeding habits of the bull ray were described using relative frequency of occurrence (PF = number of stomachs containing prey *i*/total number of full stomachs × 100), relative numerical abundance (PN = number of prey *i*/total number of prey × 100), and relative gravimetric composition (PB = weight of prey *i*/total weight of all prey x 100). To minimise potential errors inherent in individual parameters, all measures were integrated into a single composite Index of Relative Importance (IRI%) calculated as:

$$[IRI = PF \times (PN + PB)]$$ (Pinkas *et al.*, 1971),

which reduces potential misinterpretations from relying on any single given value. Prey biomass was obtained either from species-specific correlation diagrams (length-weight relationships) or literature estimates (Ravara, 2012). According to Capapé & Quignard (1974), we defined sexual maturity at 800 mm disk width (DW) for males and 900–1000 mm for females, classifying individuals below these thresholds (DW< 800 mm in males and DW< 900 mm in females) as juveniles. Dietary diversity was assessed using the Shannon-Wiener diversity index:

$$H' = -\,(\Sigma\, pi{*}\ln pi)$$

Diversity was also assessed separately according to sex and size classes. To evaluate the diet overlap between juveniles and adults and between males and females, we used the Morisita-Horn index (Krebs, 1989):

$$C_H = 2{*}(\sum p_{ij}\, p_{ik}) \,/\, (\sum p^2_{ij} + \sum p^2_{ik})$$

where $C_H$ is the simplified Morisita-Horn index representing the overlap between predators *j* and *k*; $P_{ij}$ is the proportion of prey *i* in the total prey consumed by predator *j*; $P_{ik}$ is the proportion of prey *i* in the total prey consumed by predator *k*; and *n* is the total number of prey categories. The index ranges from 0 (no dietary overlap) to 1 (complete dietary overlap), with values over 0.6 indicating significant resource sharing.

To assess the trophic level of the bull ray, a TROPH index was calculated using TrophLab software (Pauly *et al.*, 2000), available through FishBase (www. fishbase.org):

$$TROPHi = 1 + \Sigma^{G}_{j=1} DCij \times TROPHj$$

*TROPHj* represents the fractional trophic level of prey *j*, and *DCij* denotes the proportion of *j* in the diet of consumer species *i*.

## RESULTS

### Biometry

A total of 42 bull ray specimens were measured and weighed, of which 19 were identified as males and 22 as females, while in one juvenile specimen the sex could not be determined. Maximum recorded disc width (DW) was 222 cm for females and 115 cm for males, with minimum DWs of 27 cm and 37 cm, respectively. The correlation between size and weight was statistically significant ($y=0.0233x^2 + 10.49x-11590$; $r^2=0.92$). Females were larger and heavier than males (Figure 4), with individual weights exceeding 100 kilograms.

### Overall diet

The feeding habits of a total of 41 bull ray specimens were analysed. In one specimen, stomach content analysis was not possible, and 10 stomachs (24.4%) were found to be empty. Of the 1557 prey items isolated from the stomachs, gastropods represented the overwhelming majority (93.8%). Analysis of the opercula against the comparative collection confirmed *Bolinus brandaris* as the highly predominant muricid species. The most preyed upon gastropod was *Aporrhais pespelecani* (PN%=50.61%), present in 75% of all stomachs, followed by *B. brandaris* (PN%=19.33%; PF%=60.71), and *Gibbula magus* (PN%=18.37; PF%=53.57). Other gastropods, including *Hexaplex trunculus, Turritella communis*, and *Cerithium vulgatum*, were negligible in terms of relative abundance and only occurred in a single stomach. In adult bull rays, fish represented a substantial portion of prey biomass (45.30%), second only to gastropods (52.86%), while in juveniles, gastropods prevailed (PB=86.08%).

Among other taxonomic groups, teleosts accounted for 2.70%, hermit crabs 1.99%, and polychaetes 1.16%. Sipunculids and bivalves were negligible in terms of relative abundance (0.19% and 0.13%, respectively). Fish prey mostly consisted of small pelagic species, including pilchard (*Sardina pilchardus*) and horse mackerel (*Trachurus* sp.), and even a few specimens of anchovy (*Engraulis encrasicolus*) and gilt sardine (*Sardinella aurita*). The bull ray's TROPH value was calculated as 3.40±0.58.

### Diet differences between sexes

Both sexes specialise in gastropod predation, with males predominantly catching *Aporrhais pespelecani* (PN – 70.5% *vs.* 36.1%; IRI% – 29.4 *vs.* 3.7%) and females favouring muricids such as *Bolinus brandaris* (PN – 31.9% *vs.* 11%; IRI% – 28.9% *vs.* 4.3%). Notably, fish – a secondary food category – were only preyed on by females (Figs. 5 and 6). Females exhibited greater dietary diversity than males (The Shannon-Wiener diversity index *H′;* 1.73 vs 1.02). However, the Morisita-Horn index showed substantial dietary overlap between sexes (0.79) which indicates shared prey resources. The calculated TROPH values for males were 3.37±0.58 and 3.43±0.58 for females.

### Diet differences between juveniles and adults

Both juveniles and adults primarily consume gastropods, the dominant prey category in their diets. Juveniles mainly feed on *Gibbula magus* (PN – 34.5% *vs.* 5.5%; IRI% – 77.9 *vs.* 32.2%), while adults show preference for *Bolinus brandaris* (PN – 33.4% *vs.* 1.6%; IRI% – 33.4% *vs.* 0.4%). Juveniles prey more heavily upon anomurans (especially *Paguristes eremita*) than adults (Fig. 7), which is evident when we compare the frequency of occurrence. Adults consumed more fish – which are more important in terms of biomass – suggesting an ontogenetic dietary shift (Fig. 7). The pattern mirrors intersexual differences, likely influenced by the fact that females represent the majority of the adult population. In the sample examined, adults had a more diversified diet than juveniles (*H′;* 1.44 *vs.*

***Tab. 1: Diet composition of bull rays in the study area: N – number of prey items of different species, PN – relative abundance (%), PB – relative biomass (%), PF – frequency of occurrence and IRI% – index of relative importance (%). Specimens which we were not able to identify as*** *Hexaplex* ***or*** *Bolinus* ***are grouped under*** *Murex* ***sp. and marked with an asterisk.***

***Tab. 1: Prehrana kljunatega morskega goloba na obravnavanem območju: N – število različnih vrst plena, PN – relativna abundanca (%), PB – relativna biomasa (%), PF – frekvenca pojavljanja in IRI% – indeks relativne pomembnosti plena (%). Primerki, ki jih nismo uspeli določiti kot čokate ali bodičaste voleke, smo združili v kategorijo*** *Murex* ***sp. in jih označili z zvezdico.***

| taxa | | N | PN% | PB% | PF% | IRI% |
|---|---|---|---|---|---|---|
| Mollusca | *Aporrhais pespelecani* | 788 | 50.61 | 20.03 | 75.00 | 53.24 |
| | *Gibbula magus* | 286 | 18.37 | 10.91 | 53.57 | 15.76 |
| | *Hexaplex trunculus* | 13 | 0.83 | 4.86 | 10.71 | 0.61 |
| | *Bolinus brandaris* | 301 | 19.33 | 6.68 | 60.71 | 15.87 |
| | »*Murex*« sp.* | 55 | 3.53 | 17.62 | 39.29 | 8.35 |
| | Muricidae | 1 | 0.06 | 0.32 | 3.57 | 0.01 |
| | *Turitella communis* | 1 | 0.06 | 0.02 | 3.57 | <0.01 |
| | *Cerithium vulgatum* | 1 | 0.06 | 0.06 | 3.57 | <0.01 |
| | Cerithidae/Naticidae | 15 | 0.96 | 0.97 | 14.29 | 0.28 |
| | Bivalvia | 2 | 0.13 | 0.07 | 3.57 | 0.01 |
| Crustacea | Anomura | 3 | 0.19 | 0.32 | 10.71 | 0.05 |
| | *Paguristes eremita* | 19 | 1.22 | 3.09 | 17.86 | 0.77 |
| | *Pagurus anachoretus* | 1 | 0.06 | 0.11 | 3.57 | 0.01 |
| | Paguridea | 8 | 0.51 | 0.73 | 14.29 | 0.18 |
| Annellida | Polychaeta | 18 | 1.16 | 0.07 | 14.29 | 0.18 |
| | Sipunculida | 3 | 0.19 | 0.05 | 7.14 | 0.02 |
| Pisces | *Engraulis encrasicolus* | 2 | 0.13 | 0.95 | 7.14 | 0.08 |
| | *Sardina pilchardus* | 24 | 1.54 | 23.90 | 14.29 | 3.65 |
| | *Sardinella aurita* | 1 | 0.06 | 0.21 | 3.57 | 0.01 |
| | *Trachurus* sp. | 14 | 0.90 | 4.34 | 14.29 | 0.75 |
| | *Solea* sp. | 1 | 0.06 | 4.69 | 3.57 | 0.17 |

1.08). The Morisita-Horn index analysis revealed no significant difference between the diets of juveniles and adults, since the overlap in the diet was 0.74. The calculated TROPH values for juveniles were 3.38±0.58, and 3.42±0.41 for adult specimens.

## DISCUSSION

The feeding habits of the bull ray were assessed on a rather small sample (41), consisting entirely of by-catch specimens occasionally entangled in fishing nets. However, some studies suggest that as few as 15–30 non-empty stomachs may be enough to adequately describe prey diversity in certain shark species (Alonso *et al.,* 2002; Lucifora *et al.,* 2006). Our analysis included 41 stomachs, of which 10 were empty. The empty stomachs belonged to the smallest specimens – DW 27 cm (female) and DW 37 cm (male) – with DWs below the reported size of specimens at birth (Seck *et al.,* 2002). We can therefore presume that pregnant bull rays aborted their pups during fishing interaction, as cases of parturition induced by

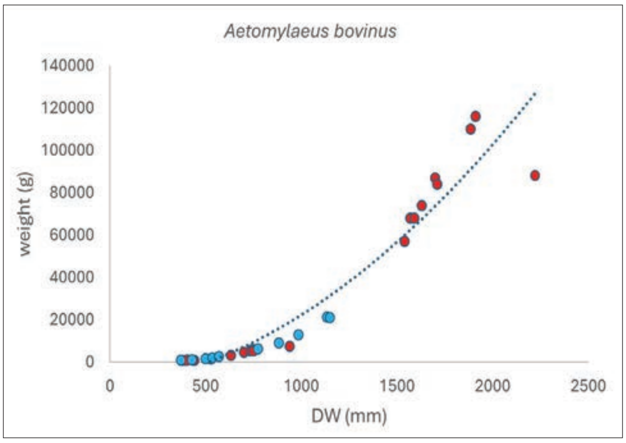

***Fig. 4: Size-weight relationships in the bull rays from the studied area. Legend: DW – disk width (mm), red circles – females, blue circles – males.***
***Sl. 4: Dolžinskomasni odnos kljunatih morskih golobov na obravnavanem območju. Legenda: DW – premer diska (mm), rdeči krogci – samice, modri krogci – samci.***

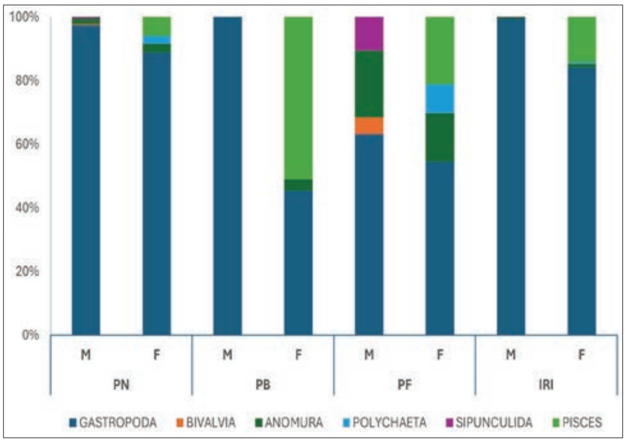

***Fig. 5: Comparison of diet compositions in male (M) and female (F) bull rays from the studied area: PN – relative abundance (%), PB – relative biomass (%), PF – frequency of occurrence, and IRI% – index of relative importance (%).***
***Sl. 5: Primerjava prehrane samcev (M) in samic (F) kljunatega morskega goloba na obravnavanem območju: PN – relativna abundanca (%), PB – relativna biomasa (%), PF – frekvenca pojavljanja in IRI% – indeks relativne pomembnosti plena (%).***

capture are well-documented (Adams *et al.*, 2018; de Sousa Rangel *et al.*, 2020).

The number of stomachs analysed in our study seems to be adequate to provide relevant insight into the feeding habits of the bull ray. Our results show that with 31 full stomachs, 90% of the asymptotic species richness was reached (*see* Fig. 8). Our results are generally consistent with one of the few available studies on the species' diet published by Capapé (1977), who found the bull ray preying mainly on four food categories: bivalves, cephalopods, gastropods, and fish. In his study, which was based on a substantially larger sample of stomachs, additional, even peculiar animal taxa were identified among the prey items of the bull ray, such as polychaetes, sipunculids, and echinoderms.

### Mollusc specialisation

The bull ray consumes gastropods and bivalves by crushing their shells with strong dental plates and can therefore be defined as a batoid specialised in durophagous feeding (Wilga & Motta, 2000). The dominant gastropod species preyed upon by bull rays – *Aporrhais pespelecani, Gibbula magus*, and *Bolinus brandaris* – are characteristic and abundant in the biocoenosis of the muddy detritic bottom, where their shells also represent an essential substrate for the settlement of multi-species biogenic clumps (Stachowitsch & Fuchs, 1995). This biocoenosis geographically corresponds to the area where fishing vessels operated when catching bull rays, so we can assume that the diet of the bull ray reflects the availability of shelled prey species in the environment. *Aporrhais pespelecani,* the most frequently consumed and most abundant prey species, is known for its burrowing behaviour (Yonge, 1937). In a recent study carried out in the Sea of Marmara (Türkiye), hard-shelled molluscs were also identified as the main food items of another, closely related batoidean, *Myliobatis aquila* (Gül & Demirel, 2020). Adult bull rays preyed on more muricids (*Hexaplex trunculus, Bolinus brandaris, Murex* sp.) than juveniles, both in term of relative abundance (PN%=40.8 *vs.* 2.3) and biomass (PB%=37.0 *vs.* 6.3). This may be explained by the fact that adults, having larger and stronger jaws, are better equipped to feed on muricids, which are characterised by their thick shells. Juvenile bull rays showed a preference for other species, such as *A. pespelecani* and *G. magus* (PN%=56.81 *vs.* 34.49, respectively), which were also the overall most frequently consumed prey (PF%=92.86 *vs.* 57.14).

The occurrence of anomurans in the diet of the bull ray is likely related to the frequent use of empty muricid shells as shelters by certain hermit crabs. *Paguristes eremita*, the dominant anomuran found in the diet of the bull rays from the present study, is the largest and most robust anomuran species in the area and is known to inhabit heavier gastropod shells with a wider aperture (family Muricidae) (Manjon-Cabeza & García Raso, 1999). In our study, anomurans were predominantly found in the diet of juveniles; however, it is difficult to assess whether the consumption of *P. eremita* and other anomurans was intentional or incidental. Other related species, such as the bullnose ray (*Myliobatis freminvillei*), have also been reported to occasionally feed on anomurans (Szczepansky & Bengtson, 2014). No data are currently available to

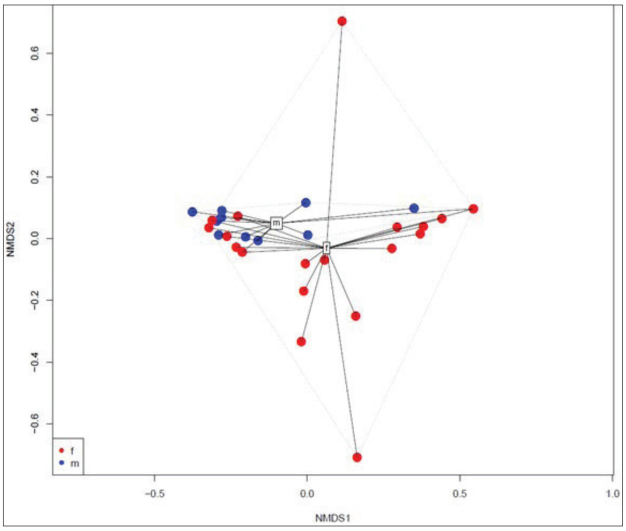

***Fig. 6: Differences/similarities in prey composition and abundance with respect to factor sex (blue circles =males, red circles=females) in the NMDS space.***
***Sl. 6: Razlike/podobnosti v vrstni sestavi in številčnosti plena glede na spol (modri krogci=samci, rdeči krogci=samice).***

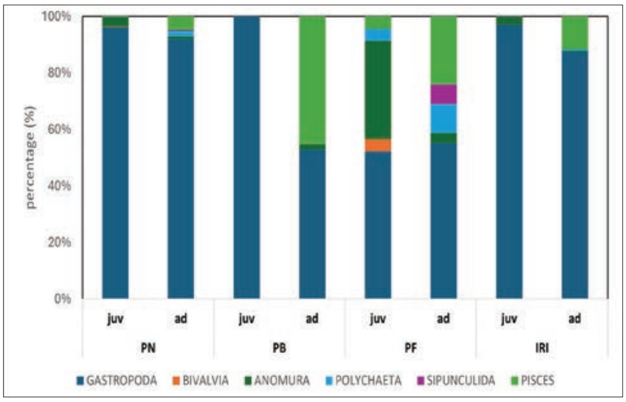

***Fig. 7: Comparison of diet composition between juveniles (juv.) and adult specimens (ad.) of bull rays in the study area: PN – relative abundance (%), PB – relative biomass (%), PF – frequency of occurrence and IRI% – index of relative importance (%).***
***Sl. 7: Primerjava prehrane mladičev (juv.) in odraslih primerkov (ad.) kljunatega morskega goloba na obravnavanem območju: PN – relativna abundanca (%), PB – relativna biomasa (%), PF – frekvenca pojavljanja in IRI% – indeks relativne pomembnosti plena (%).***

determine whether some myliobatids can discriminate between shells occupied by anomurans and those containing gastropods.

The TROPH values for bull rays (3.37-3.43) were higher than those for a related durophagous species, the common eagle ray (*Myliobatis aquila*) (Lipej *et al.*, *in press*) – calculated at 3.20±0.44 to 3.25±0.39 – but lower than the values reported for the blackspotted smoothound *Mustelus punctulatus* (3.70 ±0.6) (Lipej *et al.*, 2012).

The feeding habits of the bull ray are, to some extent, similar to those of its relative, the common eagle ray *Myliobatis aquila*, which is also specialised in hunting molluscs, which represent 75% of its diet (Lipej *et al.*, *in press*). However, while the eagle ray is mainly targeting bivalves, our findings show that the bull ray feeds mainly on gastropods. Among gastropods, eagle rays primarily consume species such as *Cerithium vulgatum* and *Turritella communis* (collectively ~20% of relative abundance), which were rarely preyed on by bull rays (each less than 0.1% of PN%). This dietary divergence between two related species inhabiting the same environment may reduce their competition.

### Fish in the diet

Although fish represented only a small amount in terms of relative abundance, this food category is important in terms of biomass. Our results demonstrate an ontogenetic shift in the diet from gastropods to fish (*sensu* Koen Alonso *et al.*, 2002; Ellis & Musick, 2007).

The species found in the diet of the bull ray are the dominant small pelagic taxa commonly caught in the study area. The only exception is the sole (*Solea sp.*), which is a benthic species. This aligns with findings reported by Capapé (1977) from Tunisian waters, where small pelagic species frequently occurred in the diet of bull rays. Due to size and gape limitations, bull rays and their relatives may only prey on fishes smaller than 50 cm in total length (Wetherbee *et al.*, 2012), meaning small species or larger species at early

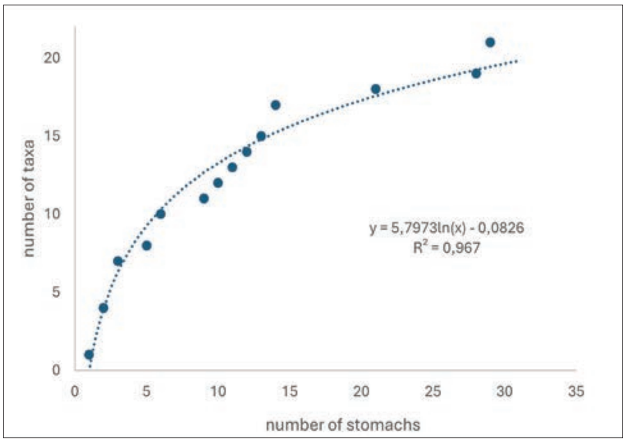

***Fig. 8: The cumulative number of prey types identified with increasing sample size (number of stomachs).***
***Sl. 8: Kumulativno število določenih primerkov plena glede na naraščajoč vzorec (število želodcev).***

life stages. The presence of pelagic species in the diet of predominantly benthic-feeding bull rays may be related to the availability of these species as dead discards abandoned on the sea floor or bull rays feeding on specimens with which they were entangled in the fishing nets during trawling operations. Fish cages are also an important source of food that attracts elasmobranchs (Barash *et al.,* 2018; Akyol *et al.*, 2022; Kurtay *et al.*, 2023). Akyol *et al.* (2022) reported bull rays feeding on dead fish around a sea-cage fish farm in Iskenderun Bay (Türkiye), noting that the rays showed no interest in the pellets used to feed cultured fish. In the study area, discards of small pelagic fish from pelagic trawlers occurred regularly and may represent a significant food source for bull rays.

### The importance of the Gulf of Trieste and adjacent areas as bull ray habitat

While the bull ray was once considered a relatively rare batoid species in the Adriatic Sea (Jardas, 1985), subsequent studies based on the capture of numerous specimens confirmed its presence in the Gulf of Trieste (Dulčić *et al.*, 2008; Lipej *et al.,* 2009) and throughout the broader northern Adriatic region (La Mesa *et al.*, 2017). Dulčić *et al.* (2008) confirmed regular bull ray occurrence in the area, though like other elasmobranch species of low or no commercial value, specimens are typically discarded at sea (Mavrič *et al.*, 2004). The presence of several gravid females with developed embryos and numerous juvenile specimens indicates the area's importance for the reproduction of the species. Further investigation is needed to evaluate its potential nursery function, as speculated by some authors (Dulčić *et al.*, 2008; Lipej *et al.*, 2009). This speculation gains support from Capapé & Quignard's (1975) findings that the species reproduces from March till October, with gestation lasting six months. Notably, the study area hosted some record-sized individuals (1540–2220 mm DW, 68–116 kg), the largest ever documented (Dulčić *et al.* 2008; Lipej *et al.,* 2009).

Over the recent years, increasing myliobatid sightings have been reported through social media, including observations of bull rays in shallow waters. The Gulf of Trieste – a rather shallow basin with many riverine inflows enhancing its productivity – appears to attract bull rays to brackish areas such as lagoons, river mouths, and estuaries. This behaviour aligns with reports by Zogaris & Dussling (2010) of two occurrences of bull rays in the Amvrakikos Gulf (Greece) in August 2000 (two dead specimens found, probably discarded by fishermen) and August 2004 (12 live specimens sighted). This giant shallow lagoon-like gulf supports a rich and abundant mollusc community that evidently attracts bull rays. Similarly, El Kamel *et al.* (2009, 2010) reported the captures of juvenile and adult *A. bovinus* in the Tunisian Lagoon of Bizerte, associating them with the local presence of abundant mollusc populations (Zaouali, 1979) – a known prey preference for the bull ray. Higher occurrences of bull rays have also been observed off the estuaries of three main river systems in northern Italy (the Po, Adige, and Brenta Rivers) (La Mesa *et al.*, 2017) – areas productive due to riverine nutrient input and characterised by a high abundance of molluscs, crustaceans, and small pelagics (e.g., anchovies), which constitute major components of the bull ray's diet. Recently, sightings of bull rays have also been reported by local media in the marine protected area of Miramare (Ciriaco, 2020; Anonymous, 2023) and at Punta Madona in Piran (2023–2025), where divers observed individual bull rays as well as "cemeteries" of broken mollusc shells close to the shore (*pers. observations*).

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# VPOGLED V PREHRANJEVALNE NAVADE KLJUNATEGA MORSKEGA GOLOBA, *AETOMYLAEUS BOVINUS* (GEOFFROY SAINT-HILAIRE, 1817) V SEVERNEM JADRANU

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## *POVZETEK*

*Raziskava poroča o osnovnih podatkih o prehranjevalnih navadah kljunatega morskega goloba* Aetomylaeus bovinus *(Geoffroy Saint-Hilaire, 1817) v Beneškem zalivu. Med 1557 primerki plena, izoliranimi iz želodcev, so veliko večino predstavljali polži (93,8 %). Med njimi je prevladovala vrsta* Aporrhais pespelecani*, sledili sta ji* Gibbula magus *in* Bolinus brandaris. *Te vrste so značilni elementi biocenoze muljastega detritnega dna. Opazili smo razlike v strukturi plena med mladimi in odraslimi primerki ter med spoloma. Med ribami, ki so se izkazale za pomembne predvsem z vidika biomase, so največ plena predstavljale male pelagične ribe, kot sta sardela (*Sardina pilchardus*) in šur (*Trachurus *sp.). Članek prispeva nove podatke o prehranjevalni ekologiji manj znane in kritično ogrožene vrste skatov.*

**Ključne besede:** morski golobi, prehranjevalna ekologija, jaslice, Beneški zaliv

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# A NEW CAPTURE RECORD OF *ALOPIAS SUPERCILIOSUS* LOWE, 1841 FROM THE TURKISH COAST (NORTHEASTERN MEDITERRANEAN)

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## *ABSTRACT*

*A single male bigeye thresher,* Alopias *superciliosus, was incidentally captured by a commercial trawler. The specimen measured 310 cm in total length and weighed 156.0 kg. The capture occurred on 16 January 2025 in the coastal region of Akyatan, at a depth of 30 m. Prior to this study, 15 records of* A. superciliosus *had been documented along the northeastern Mediterranean coast of Türkiye. This study contributes to the existing body of knowledge and marks a notable milestone by documenting the first recorded occurrence of an adult male bigeye thresher in the northeastern Mediterranean, specifically along the Akyatan coast of Türkiye. It also presents a comprehensive analysis of the specimen's morphometric measurements in comparison with existing Mediterranean records.*

**Key words:** bigeye thresher, Alopiidae, record, Akyatan coast, Turkiye

# NUOVA CATTURA DI *ALOPIAS SUPERCILIOSUS* LOWE, 1841 LUNGO LA COSTA TURCA (MEDITERRANEO NORD-ORIENTALE)

## *SINTESI*

*Un singolo esemplare maschio di* Alopias superciliosus *è stato catturato accidentalmente da un peschereccio commerciale. L'esemplare misurava 310 cm di lunghezza totale e pesava 156,0 kg. La cattura è avvenuta il 16 gennaio 2025 nella regione costiera di Akyatan, a una profondità di 30 m. Prima d'ora erano stati documentati 15 esemplari di* A. superciliosus *lungo la costa mediterranea nord-orientale della Turchia. Questo studio contribuisce alle conoscenze esistenti e segna una pietra miliare notevole, documentando la prima presenza registrata di un maschio adulto di squalo volpe occhione nel Mediterraneo nord-orientale, in particolare lungo la costa di Akyatan in Turchia. Viene inoltre presentata un'analisi completa delle misure morfometriche dell'esemplare rispetto ai dati esistenti nel Mediterraneo.*

**Parole chiave:** squalo volpe occhione, Alopiidae, cattura, costa di Akyatan, Turchia

## INTRODUCTION

The family Alopiidae comprises three globally distributed species: the bigeye thresher (*Alopias superciliosus*), the common thresher (*Alopias vulpinus*), and the pelagic thresher (*Alopias pelagicus*) (Ebert *et al.*, 2021; Froese & Pauly, 2025). Of these shark species, *A. superciliosus* and *A. vulpinus* have been recorded in the Mediterranean Sea and along the Turkish coastline, while *A. pelagicus* is distributed in the Indo-Pacific Ocean (Ebert *et al.*, 2021).

***Fig. 1: Map showing the capture site (•) of the* A. superciliosus *along the Akyatan coast, Türkiye.***
***Sl. 1: Zemljevid obravnavanega območja z lokaliteto ulova (•) primerka vrste* A. superciliosus *vzdolž obale Akyatan, Turčija.***

The bigeye thresher, *A. superciliosus*, is a large shark from the order Lamniformes. It is highly migratory and widely distributed in warm temperate and tropical waters (Compagno, 2001). This species occurs both in the pelagic and benthopelagic zones of the continental shelf at depths ranging from 0 to 955 m, with a higher prevalence in the 0–100 m range (Compagno, 2001; Coelho *et al.*, 2015). *A. superciliosus* primarily feeds on teleost fishes (lancetfish, herring, mackerel, etc.) and small billfishes in the pelagic zone, as well as on bottom fish such as the European hake and squid in the benthic zone (Compagno, 1984).

In the Mediterranean Sea, the bigeye thresher shark was first reported from Italian waters (Cigala-Fulgosi, 1983), with subsequent records extending from the west to the east of the Basin (Corsini-Foka & Sioulas, 2009; Kabasakal *et al.*, 2011; Farrag *et al.*, 2017; Kabasakal *et al.*, 2017; Kleitou *et al.*, 2017; Lanteri *et al.*, 2017; Ergüden *et al.*, 2020).

The first documented sighting of the bigeye thresher in Turkish waters occurred along the Marmaris and Gökova coasts in 2005 (Mater, 2005; Clo *et al.*, 2008), followed by a recorded capture in Silivri (Kabasakal & Karhan, 2008). Subsequent reports include records from Silivri, Sivrice, and Fethiye in 2011 and 2016 (Kabasakal *et al.*, 2011), from the Gulf of Antalya in 2015 and 2016 (Gökoğlu *et al.*, 2017; Kabasakal, 2017; Lanteri *et al.*, 2017), as well as from Tasucu and off Fethiye (Ayas *et al.*, 2020; Akyol *et al.*, 2020). The most recent documented capture in Turkish waters was an adult female incidentally caught off the coast of Çevlik in Iskenderun Bay (Ergüden *et al.*, 2020).

The present paper reports the first incidental capture of an adult male bigeye thresher, *A. superciliosus*, along the Akyatan coast (northeastern Mediterranean, Türkiye) and the morphometric measurements of the specimen.

## MATERIAL AND METHODS

The bigeye thresher was captured at night by a commercial trawler at a depth of 30 m on the sandy-muddy bottom of the Akyatan coast (at

***Fig. 2: The* A. superciliosus *recorded along the Akyatan coast, northeastern Mediterranean Sea (scale bar: 0.3 cm).***
***Sl. 2: Primerek vrste* A. superciliosus*, ujet vzdolž obale Akyatan, severovzhodno Sredozemsko morje (merilo: 0,3 cm).***

***Tab. 1: Comparison of selected morphometric measurements of the captured** A. superciliosus **with six previously reported specimens from the Mediterranean Sea. Abbrevations; TL (total length), FDFL (first dorsal fin length), FDFBL (first dorsal fin base length), PFL (pectoral fin length), PFBL (pectoral fin base length), VFL (ventral fin length), VFBL (ventral fin base length), DFVF (distance between dorsal-fin origin and ventral fin origin), PFVF (distance between pectoral fin origin and ventral fin origin), PDL (predorsal length), PVL (preventral length), PPL (pre pectoral length), IOS (Inter orbital space), EY (Eye length), EH (Eye height), MW (mouth width, ML (Mouth length), TailL (tail length), CL (Clasper length). *Lanteri et al. (2017) did not provide percentage TL values in their records on the collected head and pectoral fins of the studied specimen.***

**Tab. 1: Primerjava izbranih morfometričnih meritev ujetega primerka vrste** A. superciliosus **s šestimi predhodno ugotovljenimi primerki iz Sredozemskega morja. Okrajšave; TL (totalna dolžina), FDFL (dolžina prve hrbtne plavuti), FDFBL (dolžina korena prve hrbtne plavuti), PFL (dolžina prsne plavuti), PFBL (dolžina korena prsne plavuti), VFL (dolžina trebušne plavuti), VFBL (dolžina osnove trebušne plavuti), DFVF (razdalja med začetkom hrbtne plavuti in začetkom trebušne plavuti), PFVF (razdalja med začetkom prsne plavuti in začetkom trebušne plavuti), PDL (predorzalna dolžina), PVL (preventralna dolžina), PPL (prepektoralna dolžina), IOS (medočesni prostor), EY (dolžina oči), EH (višina oči), MW (širina ust), ML (dolžina ust), TailL (dolžina repa), CL (dolžina klasperja). *Lanteri in sod. (2017) v svojih zapisih niso navedli vrednosti TL v odstotkih za glavo in prsne plavuti proučevanega osebka.**

| **Character (cm)** | **This study** | **Corsini-Foka & Sioulas (2009)** | **Kabasakal** *et al.* **(2011)** | ***Lanteri** *et al.* **(2017)** | **Farrag** *et al.* **(2017)** | **Ayas** *et al.* **(2020)** | **Ergüden** *et al.* **(2020)** |
|---|---|---|---|---|---|---|---|
| **Location** | Karataş coast | Dodocenase waters | Fethiye coast | Ligurian Sea | Egyptian coast | Tasucu coast | Çevlik coast |
| **Sex** | Male | Male | Female | Female | - | Female | Female |
| **TL** | 310.0 | 310.0 | 450.0 | - | 180.0 | 240.0 | 472.0 |
| **FDFL** | 25.0 (8.06 %TL) | 27.0 (8.7 %TL) | 41.0 (9.1 %TL) | - | - | 17.9 (7.4 %TL) | 40.0 (8.5 %TL) |
| **FDFBL** | 22.0 (7.9 %TL) | 21.0 (6.8 %TL) | 32.0 (7.1 % TL) | - | - | 13.6 (5.6 %TL) | 32.0 (6.8 %TL) |
| **PFL** | 60.0 (19.3 %TL) | 62.0 (20.0 %TL) | 82.0 (18.2 %TL) | 25.4 | 35.0 (19.4 %TL) | 51.5 (21.4 %TL) | 83.0 (17.5 %TL) |
| **PFBL** | 25.0 (8.06 %TL) | 21.0 (6.8 %TL) | 30.0 (6.7 %TL) | - | - | 20.1 (8.4 % TL) | 40.0 (8.5 % TL) |
| **VFL** | 26.0 (8.04 %TL) | 26.0 (8.4 %TL) | 39.0 (8.7 %TL) | - | - | 20,6 (8.6 %TL) | 37.0 (7.8 % TL) |
| **VFBL** | 25.0 (8.06 %TL) | 21.0 (6.8 %TL) | 30.0 (6.7 %TL) | - |  | 15.4 (6.4 %TL) | 30.0 (6.4 %TL) |
| **DFVF** | 36.0 (11.6 %TL) | 23.0 (7.4 %TL) | - | - | - | 17.8 (7.4 %TL) | - |
| **PFVF** | 57.0 (18.4 %TL) | 77.0 (24.8 %TL) | - | - | - | 68.9 (28.7 %TL) | 204.0 (43.2 %TL) |
| **PDL** | 97.0 (31.3 %TL) | 94.0 (30.3 %TL) | 128.0 (28.4 %TL) | - | 57.0 (31.6 %TL) | 87.7 (36.5 %TL) | - |
| **PVL** | 124.0 (40.0 %TL) | 118.0 (38.1 %TL) | 165.0 (36.7 %TL) | - | 70.0 (38.8 %TL) | 105.3 (43.9 %TL) | - |
| **PPL** | 52.0 (16.7 %TL) | 45.0 (14.5 %TL) | 55.0 (12.2 %TL) | 47.7 | 29.0 (16.1 %TL) | 43.7 (18.2 %TL) | - |
| **IOS** | 13.1 (4.2 %TL) | - | - | 7.4 | - | - | - |
| **EL** | 7.6 (2.4 %TL) | - | - | 7.4 | - | - | - |
| **EH** | 5.4 (1.7 %TL) | - | - | 4.7 | - | - | - |
| **MW** | 11.0 (3.5 %TL) | - | - | 10.4 | - | - | 20.0 (4.2 %TL) |
| **ML** | 8.0 (2.6 %TL) | - | - | 7.3 | - | - | - |
| **TailL** | 160.0 (51.6 %TL) | 143.0 (46.1 %TL) | 217.0 (48.2 %TL) | 54.4 | - | 103.8 (43.3 %TL) | 240.0 (50.5 %TL) |
| **CL** | 30.2 | - | - | - | - | - | - |

36°28′20.52″ N, 34°55′20.99″ E) on 16 January 2025 (Fig. 1). Upon being brought aboard, the specimen was found deceased. Since the capture occurred nocturnally, the individual was stored in a refrigerated vessel by the crew until its delivery to the laboratory the following day. Upon arrival at the laboratory, the specimen was immediately examined and identified. It was then preserved at the Museum of the Faculty of Fisheries, Cukurova University, registered under catalogue number CSFM-PIS/18.01.2025 (see Figs. 2 and 3).

The morphometric measurements of the captured *A. superciliosus* were recorded to the nearest 0.01 mm using a calliper. All subsequent morphological descriptions and coloration of the specimen were consistent with those previously documented for this species by Gruber & Compagno (1981) and Compagno (2001).

Nineteen morphometric measurements were taken, including total length (TL), first dorsal fin length (FDFL), first dorsal fin base length (FDFBL), pectoral fin length (PFL), pectoral fin base length (PFBL), ventral fin length (VFL), ventral fin base length (VFBL), distance between dorsal fin origin and ventral fin origin (DFVF), distance between pectoral fin origin and ventral fin origin (PFVF), predorsal length (PDL), preventral length (PVL), prepectoral length (PPL), interorbital space (IOS), eye length (EYL), eye height (EYH), mouth width (MOW), mouth length (MOL), tail length (TAIL), and clasper length (CL). The complete list of morphometric measurements can be found in Table 1.

## RESULTS AND DISCUSSION

The male bigeye thresher specimen measured 310 cm in total length (TL) and weighed 156.0 kg. Several morphometric measurements (expressed as percentages of TL) were recorded as follows: first dorsal fin length (FDFL), 8.06%; first dorsal fin base length (FDFBL), 7.90%; pectoral fin length (PFL), 19.30%; pectoral fin base length (PFBL), 8.06%; ventral fin length (VFL), 8.04%; ventral fin base length (VFBL), 8.06%; distance between dorsal fin origin and ventral fin origin (DFVF), 11.60%; distance between pectoral fin origin and ventral fin origin (PFVF), 18.40%, predorsal length (PDL), 31.3%, preventral length (PVL), 40.00%, prepectoral length (PPL), 16.70%; and tail length (TAIL), 16.00% (Tab. 1).

A comparison of morphometric measurements was made between the male specimen from this study and available Mediterranean records of both male and female bigeye thresher specimens (Tab. 1). Table

***Fig. 3: Head view of the captured** A. superciliosus.*
***Sl. 3: Glava ujetega primerka vrste** A. superciliosus.*

***Tab. 2: Historical capture records of*** *A. superciliosus* ***in Turkish Mediterranean waters.***
***Tab. 2: Zgodovinski podatki o pojavljanju vrste*** *A. superciliosus* ***v sredozemskih vodah Turčije.***

| **References** | **Locality** | **Date** | **Number of Specimen** | **Depth** | **Fishing Gear** | **Sex** | **Length (cm) /Weight (kg)** |
|---|---|---|---|---|---|---|---|
| Mater (2005) | Gökova | 23 May 2005 | 1 | 12 | Shrimp net | - | 350/150.0 |
| Clo *et al.* (2009) | Marmaris | April 2004 | 1 | - | Gill net | - | -/160.0 |
| Kabasakal & Karhan (2008) | Silivri | 23 February 2007 | 1 | - | Purse-seine | - | 450/- |
| Kabasakal *et al.* (2011) | Fethiye | 28 February 2011 | 1 | 110 | Trammel net | Female | 430/300.0 |
| Kabasakal *et al.* (2011) | Silivri | 02 July 2011 | 1 | - | Purse-seine | - | 250/65.0 |
| Kabasakal *et al.* (2011) | Sivrice | 21 May 2016 | 1 | 100 | Stationary net | - | 400/- |
| Gökoglu *et al.* (2017) | Antalya | 19 March 2015-15 July 2015<br>19 March 2015-12 April 2015 | 2<br>2 | 600-700 | Bottom trawl-<br>Long-line | Female<br>Male | 180-299/19.0-65.0<br>180-293/15.5-57.0 |
| Kabasakal (2017) | Antalya | 22 December 2017 | 1 | | Pelagic swordfish longline | Female | 342.4/- |
| Lanteri *et al.* (2017) | - | 25 February 2013 | 1 | - | - | - | 370/250.0 |
| Lanteri *et al.* (2017) | Yeşilköy | 13 March 2013 | 1 | - | - | - | 200/110.0 |
| Lanteri *et al.* (2017) | Yediburunlar | 15 July 2013 | 1 | - | - | - | 500/395.0 |
| Lanteri *et al.* (2017) | Antalya | 15 April 2015 | 1 | - | - | - | - |
| Akyol *et al.* (2020) | off Fethiye | 23 September 2012 | 1 | 1100 | Pelagic longline | Female | 150/30.2 |
| Ergüden *et al.* (2020) | Çevlik | 9 April 2019 | 1 | 20 | Purse seine | Female | 472/400.0 |
| Ayas *et al.* (2020) | Taşucu | 2 January 2020 | 1 | 25 | Trammel net | Female | 240/48.0 |
| This study | Akyatan | 16 January 2025 | 1 | 30 | Bottom trawl | Male | 310/156.0 |

2 presents detailed capture data for the incidentally caught specimen, including: locality, capture date, depth, region, fishing gear, sex, length, and weight, along with comparable data from previous records in Mediterranean waters.

The following characteristics are diagnostic for this shark species: head flattened dorsally and ventrally; lateral grooves situated above the branchial region; snout bulbous; eyes large and extending into the dorsal part of the head; first dorsal fin positioned more posteriorly, with the midpoint of its origin markedly closer to pelvic fin origin; dorsal extension of caudal fin approximates precaudal length; pectoral fins notably pointed; upper lobe of the caudal fin characterised by elongated, strap-like appearance nearly equalling the length of the remainder of the body; lower lobe comparatively short but well-developed (Compagno, 1998).

In terms of coloration, the dorsolateral region of the specimen exhibited a brownish-grey hue and the ventral side a whitish tone with greyish undertones. The posterior margins of the pectoral, pelvic, and first dorsal fin showed dusky pigmentation.

The bigeye thresher is readily distinguishable from the other two thresher shark species by its notably large eyes and the prominent lateral groove that originates behind the eyes and extends along both sides of the head above the gill openings (Ebert *et al.*, 2021). The specimen examined in this study was consistent with the descriptions of *A. superciliosus* reported in the existing literature (Gruber & Compagno, 1981; Compagno, 1984; Compagno, 2001).

In previous studies, maximum total length (TL) values for bigeye thresher sharks have been reported as 484 and 488 cm (Ebert & Stehmann, 2013; Froese & Pauly, 2025), with Lanteri *et al.* (2017) documenting specimens reaching up to 500 cm TL. Sexual maturity is reported to occur at 245–300 cm TL in males and 282–355 cm TL in females (Chen *et al.*, 1997). Size at birth ranges from 64 to 140 cm TL (Bauchot, 1987; Golani, 1996). The gestation period of *A. superciliousus* is 12 months, with an average litter size of 2–4 pups, typically two. The species is believed to have an annual reproductive cycle (Compagno, 1984; Compagno, 2001). Fernandez-Carvalho *et al.* (2011) report the maximum age at 22 years for females and 17 years for males. Based on its size and developmental characteristics, the specimen presented herein was likely a newly matured adult male.

Table 1 presents a comparative analysis of morphometric measurements from six selected Mediterranean studies alongside our findings. While our Akyatan male specimen shares identical TL (310 cm) with the male specimen from the Dodecanese region reported by Corsini-Foka & Sioulas (2009), it shows slightly lower values for FDFL, PFL, and PFVF, but exceeds the Dodecanese specimen in other measured parameters. These observed variations may reflect various ecological and biological factors, including feeding ability, habitat, environmental conditions, gonadal maturity, etc.

In the Mediterranean Sea, *A. superciliosus* is considered particularly susceptible to overfishing. In 2014 and 2016, thresher sharks were listed in Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS), reflecting the Parties' commitment to regional conservation efforts. Additionally, thresher sharks were included in Appendix II of the Convention on International Trade in Endangered Species Wild Fauna and Flora (CITES), requiring exports from CITES Parties to be accompanied by permits demonstrating legal and sustainable sourcing.

The 2018 IUCN Red List classified *A. superciliosus* as vulnerable (VU) globally under criteria A2bd (Rigby *et al.*, 2019) and endangered (EN) in the Mediterranean and European regions (Walls & Soldo, 2016). In the Mediterranean Sea, the thresher shark is both targeted and caught as bycatch in a variety of commercial fishing practices, including longline, bottom trawl, purse seine, and gillnet fisheries (Serena, 2005; Bariche, 2012). While Serena (2005) considers *A. superciliosus* to be an uncommon species in the Mediterranean – captured only sporadically and poorly documented – De Maddalena & Baensch (2005), Clo *et al.* (2008), and Corsini-Foka & Sioulas (2009) argue that the species is not rare in the region and is, in fact, abundant in the eastern Mediterranean Basin.

Incidental captures of sharks – apex predators in the marine food chain – have the potential to disrupt the ecosystem balance and threaten the sustainability of shark populations in the wild (Nurastri *et al.*, 2024). According to Serena (2005), the sharks' limited restocking capacity and slow population recovery following overfishing are consequences of their late sexual maturity and low fecundity.

Recent years have seen growing emphasis on researching sharks environmental preferences, developing methods to reduce their incidental catch in commercial fisheries, and implementing sustainable conservation measures for shark species.

A more comprehensive dataset is essential for accurately assessing the scale of shark bycatch mortality in Turkish fisheries. Current evidence suggests that *A. superciliosus* and other shark populations in the Eastern Mediterranean face significant threats. Thus, targeted investigation is necessary to ascertain these species' conservation status specifically within the context of Turkish fisheries.

While *A. superciliosus* was classified as endangered in the Mediterranean region during its most recent IUCN Red List assessment in 2018 (Rigby *et al.*, 2019), its current conservation status remains uncertain. The morphometric data obtained from an incidentally captured male specimen in this study therefore contribute valuable new information to the scientific literature on this protected species, which maintains a limited population in Mediterranean waters.

## ACKNOWLEDGMENTS

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# NOV ULOV VELIKOOKE MORSKE LISICE *ALOPIAS SUPERCILIOSUS* LOWE, 1841 IZ TURŠKE OBALE (SEVEROVZHODNO SREDOZEMLJE)

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## *POVZETEK*

*Samec velikooke morske lisice se je po naključju ujel v vlečno mrežo komercialnega plovila. Meril je 310 cm v skupno dolžino in tehtal 156,0 kg. Ulov se je zgodil 16. januarja 2025 v obalni regiji Akyatan, na globini 30 m. Pred pričujočo študijo je bilo vzdolž severovzhodne sredozemske obale Turčije dokumentiranih 15 zapisov o pojavljanju vrste* A. superciliosus. *Ta študija dopolnjuje obstoječe znanje in pomeni pomemben mejnik z dokumentiranjem prvega zabeleženega pojava odraslega samca velikooke morske lisice v severovzhodnem Sredozemlju, natančneje ob obali Akyatan v Turčiji. Predstavlja tudi celovito analizo morfometričnih meritev osebka v primerjavi z obstoječimi sredozemskimi zapisi o pojavljanju.*

**Ključne besede:** velikooka morska lisica, Alopiidae, zapis o pojavljanju, obala Akyatant, Turkiye

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# NO LONGER AS COMMON AS ITS NAME: A REVIEW OF THE OCCURRENCE OF *TORPEDO TORPEDO* (LINNAEUS, 1758) (CHONDRICHTHYES: ELASMOBRANCHII) IN TURKISH WATERS, WITH PHOTOGRAPHIC EVIDENCE

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## *ABSTRACT*

*On 26 August 2010, a common torpedo (*Torpedo torpedo*), was incidentally captured in bottom-trawl fishery off the coast of Samandag (northeastern Mediterranean Sea). The specimen was a male measuring 295 mm in TL, 152 mm in DW, and weighing 327 g. A systematic review of available data revealed that there have been at least 12 specimens of* T. torpedo *captured in Turkish waters. However, contemporary catch records from the investigated area show that the common torpedo is no longer as common in Turkish seas as its name might suggest – a fact further corroborated by the sporadic nature of these records. To develop and implement an effective management plan for the conservation of* T. torpedo*, systematic data collection is essential.*

**Key words:** Common torpedo, Turkish seas, status, occurrence

# NON PIÙ COSÌ COMUNE COME IL SUO NOME: REVISIONE DELLA PRESENZA DI *TORPEDO TORPEDO* (LINNAEUS, 1758) (CHONDRICHTHYES: ELASMOBRANCHII) IN ACQUE TURCHE, CON PROVE FOTOGRAFICHE

## *SINTESI*

*Il 26 agosto 2010, una torpedine comune (*Torpedo torpedo*), è stata catturata accidentalmente durante la pesca a strascico al largo delle coste di Samandag (Mediterraneo nord-orientale). L'esemplare era un maschio di 295 mm di lunghezza totale, 152 mm di larghezza del disco e pesava 327 g. Una revisione sistematica dei dati disponibili ha rivelato che ci sono stati almeno 12 esemplari di* T. torpedo *catturati nelle acque turche. Tuttavia, le registrazioni contemporanee delle catture nell'area indagata mostrano che la specie non è più così comune nei mari turchi come il suo nome potrebbe suggerire - un fatto ulteriormente corroborato dalla natura sporadica di queste registrazioni. Per sviluppare e implementare un piano di gestione efficace per la conservazione di* T. torpedo*, è essenziale una raccolta sistematica di dati.*

**Parole chiave**: torpedine comune, mari turchi, status, presenza

## INTRODUCTION

Electric rays, also known as torpedo rays, belong to the family Torpedinidae (Elasmobranchii: Torpedinidae) (Froese & Pauly, 2024). In the Mediterranean Sea, this family is represented by two genera – *Tetronarce* and *Torpedo* – and four species: *Tetronarce nobiliana* (Bonaparte, 1835), *Torpedo marmorata* Risso, 1810, *T. sinuspersici* Olfers, 1831, and *T. torpedo* (Linnaeus, 1758) (Serena *et al*., 2020; Barone *et al*., 2022). Despite the established presence of *T. nobiliana*, *T. marmorata*, and *T. torpedo* throughout the Mediterranean Sea – although with varying frequencies across its subregions (Follesa *et al*., 2019) – the Lessepsian immigrant *T. sinuspersici* is considered a species whose occurrence in the region still needs to be confirmed (Barone *et al*., 2022). Among the four Mediterranean torpedinids, the common torpedo, *T. torpedo*, is the most distinctive taxon characterized by its ocellated dorsal pattern, which allows for quick and reliable species identification (Serena *et al*., 2020; Barone *et al*., 2022). Besides the Mediterranean Sea, *T. torpedo* is also found in the eastern Atlantic, where its distribution range extends from Angola to the southern Bay of Biscay (Ebert & Stehmann, 2013).

The presence of *T. torpedo* in Turkish seas has been documented since one of the earliest ichthyological inventories of the region, where it was referred to as *T. ocellata* Rafinesque, 1810 (Ninni, 1923). However, subsequent studies from the Turkish Aegean and Mediterranean waters have reported extremely low numbers of examined specimens (≤ 4 specimens per study) (e.g., Geldiay, 1969; Kabasakal, 2002; Eryılmaz, 2003; Torcu Koç *et al*., 2012; Yemişken *et al*., 2014; Yağlıoğlu *et al*., 2015). As a result, the common torpedo is now considered an uncommon species in the region, a pattern also noted for the broader Mediterranean Sea (Tsikliras & Dimarchopoulou, 2021). According to Tsikliras and Dimarchopoulou (2021), *T. torpedo* is among the Mediterranean rays with significant knowledge gaps that require further study. This article analyses photographs of an individual reported by Yemisken *et al*. (2014) and provides a review of the species' occurrence in Turkish waters.

***Fig. 1: Maps showing approximate capture locations for* T. torpedo *in Turkish seas.***
***Sl. 1: Zemljevid obravnavanega območja s približnimi lokalitetami ulova vrste* T. torpedo *v turških morjih.***

## MATERIAL AND METHODS

Geographical subarea (GSA) designations follow the framework of the General Fisheries Council for the Mediterranean (GFCM, 2018). The present specimen of *T. torpedo* was incidentally captured off the coast of Samandag, in the northeastern Mediterranean Sea (GSA 24; Fig. 1). The sampling survey was conducted aboard a 21 m commercial stern-trawler *FV Azaklar*, towing a bottom trawl with a 44 mm knot-to-knot cod-end mesh opening. Due to the influence of upwelling currents and terrestrial nutrient inputs, Iskenderun Bay, where the coast of Samandag is located, exhibits high primary productivity and is therefore considered one of the most important bottom-trawling zones in the entire Mediterranean Sea (Yemişken *et al.*, 2014). The examined common torpedo individual, which was originally documented by Yemisken *et al.* (2014), was collected in commercial bottom-trawling fishery. The haul, conducted over a mixed bottom of mud and sand at an average depth of 51 m, started at 36.065550° N, 35.540060° E and ended at 36.020070° N, 35.570200° E. Species identification was performed following Barone *et al.* (2022), with taxonomic nomenclature according to Froese and Pauly (2024). Unfortunately, the captured individual could not be preserved after biometric measurements. Total length (TL) and disc width (DW) were measured to the nearest millimeter using a measurement tape, while mass (W) was recorded to the nearest gram. These data will be made available upon request.

Data on the occurrence of *T. torpedo* in Turkish waters were compiled from two main sources: (1) published scientific literature (including both general ichthyological studies and elasmobranch-specific articles) reporting records of this species, and (2) grey literature including unpublished data from ichthyological surveys conducted by the former Hydrobiological Research Institute of Istanbul University and the former Fishery Research Center under the Meat and Fish Office of the Republic of Türkiye. Each record was assessed for data quality based on the scoring criteria proposed by Kovačić *et al.* (2020).

## RESULTS AND DISCUSSION

On 26 August 2010, a male common torpedo was captured (Fig. 2), measuring 295 mm in total length (TL), 152 mm in disc width (DW), and weighing 327 g (W). The following description outlined the outer morphology and coloration of the examined specimen: body disc fairly circular with a broadly truncated front margin; tail stout and massive, bearing two distinct dorsal fins, with the first being larger than the second; spiracles rimmed by knob-like papillae of varying lengths; dorsal surface light reddish-brown, featuring three blue-centered eye-spots encircled by black and yellowish outer rings, ventral surface creamy white; claspers hard and calcified, with tips reaching well beyond pelvic fins tips; eyes smaller than spiracles. A dorsal view and close-up of the spiracles of the examined common torpedo are shown in Figure 2.

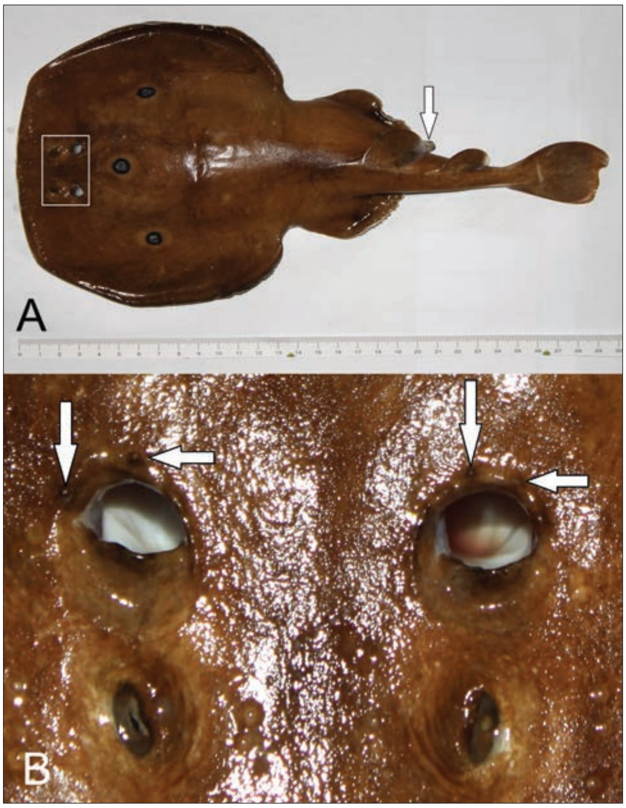

***Fig. 2: (A) Dorsal view of the examined* T. torpedo *specimen, with the white rectangle outlining the spiracle region (shown in detail below) and (↓) indicating the clasper tip; (B) close-up of spiracles, with the arrows indicating knob-like papillae along the spiracular margins.***

***Sl. 2: (A) Dorzalni pogled na pregledani primerek* T. torpedo*, z belim pravokotnikom, ki označuje strčnice (spirakla) (podrobno prikazano spodaj) in (↓), ki označuje konico klasperja; (B) bližnji posnetek spirakla s puščicami, ki označujejo gumbaste papile vzdolž spiralnih robov.***

The basic literature on elasmobranch taxonomy describes *T. torpedo* as a torpedinid species characterized by a dorsal surface patterned with 1 to 7 blue-centered eye-spots (or ocelli), each encircled by black and orangeish-yellow rings (Ebert & Stehmann, 2013; Barone *et al.*, 2022). The spiracles, which are larger than the eyes, are rimmed with small knob-like papillae (Ebert & Stehmann, 2013; Barone *et al.*, 2022). These descriptive characters are the main dichotomous

***Tab. 1: Historical and contemporary records of*** *Torpedo torpedo* ***from Turkish waters. *Confirmed presence criteria (adapted from Kovačić et al., 2020; pp. 2–3, Table 1) are defined as follows: (1) Collection: verified presence, (2) Publication: evidence from photograph, (3) Publication: evidence based on morphological or genetic data, (4) Publication: expert providing individual collection data, (5) Publication: expert conducting a broad study, and (12) Unpublished: record supported by a photograph and/or morphological data, but still unpublished or only mentioned in grey literature. SoM: Sea of Marmara (GSA 28); AS: Aegean Sea (GSA 22); NLS: Northern Levant Sea (GSA 24). N/A: Data not available.***

***Tab. 1: Zgodovinski in recentni zapisi o pojavljanju vrste*** *Torpedo torpedo* ***iz turških voda. *Kriteriji potrjene prisotnosti (prirejeno po Kovačić in sod., 2020; str. 2–3, tabela 1) so opredeljeni takole: (1) Zbirka: preverjena prisotnost, (2) Objava: dokaz s fotografije, (3) Objava: dokaz, ki temelji na morfoloških ali genetskih podatkih, (4) Objava: strokovnjak, ki zagotavlja podatke o posamezni zbirki, (5) Objava: strokovnjak, ki izvaja obsežno študijo, in (12) Neobjavljeno: zapis o pojavljanju podprt s fotografijo in/ali morfološkimi podatki, vendar še neobjavljena ali pa je omenjena le v sivi literaturi. SoM: Marmarsko morje (GSA 28); AS: Egejsko morje (GSA 22); NLS: Severno Levantsko morje (GSA 24). N/A: podatki niso na voljo.***

| No | Date | Locality | Depth (m) | Criteria* | References and remarks |
|---|---|---|---|---|---|
| 1 | Before 1923 | SoM | N/A | 4 | Ninni (1923); although in the majority of the general ichthyological (Bilecenoğlu *et al.*, 2002, 2014; Bilecenoğlu, 2024) or elasmobrabchii spesific (Artüz & Fricke, 2024) checklists referred to Ninni (1923) as the first record reference of *T. torpedo* in the SoM, author was not specified the exact locality where the examined specimen(s) captured; however, Ninni (1923) positively identified the species and gave the description of ocellated pattern (5 in the reference) of dorsal surface, and considered the species as ‘common’. |
| 2 | Before 1926 | SoM | N/A | 4 | Deveciyan (1926); although the author only reported the presence of *T. marmorata* in the region based on the findings of his visits to Istanbul Fish Market, he also provided the description of the ocellated pattern (5 in the reference) of dorsal surface of an electric ray that he encountered in the same fish market but did not specify it as *T. torpedo*. |
| 3 | 23 Sept. 1960 | SoM | N/A | 12 | Unpublished data. A male specimen (TL 290 mm and W 300 g) has been captured in scientific bottom-trawl survey conducted by former Fishery Research Center, Meat and Fish Office of Republic of Türkiye. No photo of the examined specimen is available but the species was recorded as *T. torpedo* in the species list of the survey. |
| 4 | Before 1968 | AS | N/A | 4 | Geldiay (1969); captured in waters of Bay of Izmir in bottom long-line fishery. |
| 5 | 1974 | SoM | N/A | 12 | Unpublished data. Several specimens have been either captured or sighted in the ‘Biological Information for Sewage Disposal in the Bosphorus’ project conducted by former Hydrobiological Research Institute of Istanbul University. Observed specimens specified as *T. narke* Risso, 1810 in the ichthyological inventory of the survey, and while it has been considered as ‘rare’ in the Black Sea opening of the Bosphorus Strait, it has been considered as ‘frequently found’ in the SoM. |
| 6-9 | 1995-1999 | SoM, AS, NLS | N/A | 4 | Kabasakal (2002). Examined number of specimens (n=2) is mistyped in the reference and the actual number is 4 (one specimen per station specified in table 1 of the reference). |
| 10 | Sept. 2000 | AS | 60 | 4 | Eryılmaz (2003). One specimen (520 mm TL) was captured in bottom-trawl fishery and coordinates of locality of capture are as follows: 39°44′32″ N, 25°53′48″ E. The order of the coordinates is given incorrectly in the reference. |
| 11 | 2009-2010 | NLS | ≤50 | 4 | Yağlıoğlu *et al.* (2015). *T. torpedo* consisted 0.12% of the total biomass of the elasmobranch in Iskenderun Bay bottom-trawl fishery |
| 12 | 2010-2011 | NLS | 51 | 4 | Yemişken *et al.* (2014). One specimen has been captured in Iskenderun Bay. *T. torpedo* formed 0.07% of the total biomass of discarded bycatch in bottom-trawl fishery conducted in the region. |

keys used to identify northeastern Atlantic (Ebert & Stehmann, 2013) and Mediterranean torpedinid species (Barone *et al.*, 2022). Since the external morphology of the examined specimen – as outlined above – matched the descriptions provided by Ebert and Stehmann (2013) and Barone *et al.* (2022), the individual was positively identified as *Torpedo torpedo* (Linnaeus, 1758).

According to Bilecenoğlu (2024), *T. torpedo* occurs in the Sea of Marmara (SoM) and in Turkish Aegean and Mediterranean waters. Although the species is considered very rare in Turkish waters, its occurrence has been confirmed in contemporary studies (e.g., Kabasakal, 2002; Eryılmaz, 2003; Torcu Koç *et al.*, 2012; Yemişken *et al.*, 2014; Yağlıoğlu *et al.*, 2015). A critical retrospective review of ichthyological checklists of Turkish seas, published roughly a decade apart (Bilecenoğlu *et al.*, 2002, 2014; Bilecenoğlu, 2024), reveals that all these studies cite the occurrence of *T. torpedo* in the SoM based on a century-old reference: Ninni (1923). Beyond the checklists compiled by Bilecenoğlu (and colleagues), the species' occurrence in the SoM is also mentioned in a much earlier ichthyological catalogue of Turkish seas by Mater & Meriç (1996), which – however – provides no information on the localities and depths of capture for the examined specimen(s) nor does it indicate where voucher specimen(s) are deposited. Notably, Mater and Meriç (1996) do not specify their source for the species' reported presence in the SoM either. A summary of historical and contemporary records of *T. torpedo* in Turkish seas is presented in Table 1.

In the International Mediterranean Trawl Survey (MEDITS), conducted to collect data on the distribution and demographic structure of demersal species inhabiting the continental shelf and upper slope, the frequency of *T. torpedo* occurrence (%) within the 10–200 m depth range varied from 0.8% in Sardinian waters (GSA 11) to 3.7% in the western Ionian Sea (GSA 19) (Follesa *et al.*, 2019). According to Damalas and Vassilopoulou (2011), 29 specimens of *T. torpedo* were incidentally captured in bottom-trawl fisheries in the central Aegean Sea (GSA 22) between 2003 and 2006, corresponding to a median catch of 0.13 per unit of effort (CPUE kg/h). Despite recent sporadic records of the common torpedo in the SoM (Kabasakal, 2002; Torcu Koç *et al.*, 2012) as well as in Turkish Aegean (Eryılmaz, 2003) and Mediterranean waters (Yemişken *et al.*, 2014; Yağlıoğlu *et al.*, 2015), the species' consistent absence from recent large-scale demersal surveys (e.g., Filiz *et al.*, 2018; Gül & Demirel, 2020; Daban *et al.*, 2021; Deval & Mutlu, 2024; Karadurmuş & Sarı, 2024) strongly suggests that *T. torpedo* is not a common batoid in the region and may indeed be extremely rare. According to Bengil and Başusta (2018), *T. torpedo* accounts for merely 0.01% of total elasmobranch bycatch biomass in Turkish waters. In contrast, Tiralongo *et al.* (2019) reported *T. torpedo* to be a common electric ray in Sicilian Ionian waters (GSA 19), an observation consistent with the 5.2% frequency of occurrence recorded for this species in the western Mediterranean (GSA 9) by Follesa *et al.* (2019).

Based on the available data, it is reasonable to conclude that *T. torpedo* is no longer as common in Turkish seas as its name might suggest. The scarcity of contemporary catch records from the study area and their sporadic nature supports the species' declining presence in the region. According to Tiralongo *et al.* (2019), *T. torpedo* is a k-selected batoid species and is currently classified as Vulnerable on the IUCN Red List (Jabado *et al.*, 2021). Its biological traits – including low ovarian fecundity (ranging from 3 to 20 eggs; Tiralongo *et al.*, 2019), a moderately long generation length (10 years; Jabado *et al.*, 2021), and its occurrence in habitats overlapping with demersal fisheries – make it particularly vulnerable to the impacts of untargeted capture. To develop and implement an effective management plan for the conservation of *T. torpedo*, systematic data collection is essential, as emphasized by both GFCM (2018) and Tsikliras & Dimarchopoulou (2021).

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# NI VEČ TAKO POGOST KOT NJEGOVO IME: PREGLED POJAVLJANJA OKATEGA ELEKTRIČNEGA SKATA *TORPEDO TORPEDO* (LINNAEUS, 1758) (CHONDRICHTHYES: ELASMOBRANCHII) V TURŠKIH VODAH S FOTOGRAFSKIMI DOKAZI

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## *POVZETEK*

*26. avgusta 2010 so pri ribolovu s pridneno vlečno mrežo ob obali Samandaga (severovzhodno Sredozemsko morje) slučajno ujeli okatega električnega skata (*Torpedo torpedo*). Bil je samec, ki je v telesno dolžino meril 295 mm, v premeru diska 152 mm in tehtal 327 g. Na podlagi sistematičnega pregleda razpoložljivih podatkov se je izkazalo, da je bilo v turških vodah doslej ujetih vsaj 12 primerkov okatega električnega skata. Sodobni zapisi z raziskovanega območja kažejo, da okati električni skat ni več pogosta vrsta v turških vodah kot bi sklepali iz angleškega imena (Common electric ray) – dejstvo, ki ga dodatno potrjuje občasna narava teh zapisov. Za razvoj in izvajanje učinkovitega načrta upravljanja za ohranitev vrste* T. torpedo *je bistveno sistematično zbiranje podatkov.*

**Ključne besede:** okati električni skat, turška morja, status, pojavljanje

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# DISC DEFORMITY IN A JUVENILE FEMALE BROWN RAY, *RAJA MIRALETUS* (FAMILY: RAJIDAE), FROM NORTHEASTERN MEDITERRANEAN (TÜRKİYE)

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## *ABSTRACT*

*This study describes a female specimen of the brown ray* Raja miraletus *Linnaeus, 1758, found along the coast of the city of Aydıncık (Mersin Bay, Turkey) in the northeastern Mediterranean Sea, exhibiting disk deformities. The deformation is located on the right disk portion of the specimen, with no other deformities observed on the rest of the body. The juvenile female specimen measures 22 centimeters in disk diameter, 31.7 centimeters in total length, and weighs 186 grams. This specimen represents the first recorded abnormality of the species* R. miraletus *in Turkish Mediterranean waters, and this report provides the first information on the presence of abnormalities in female specimens of the species* R. miraletus.

**Key words:** Rajiformes, abnormality, pectoral disc deformity, Mersin Bay, Eastern Mediterranean

# DEFORMITÀ DISCALE IN UNA GIOVANE FEMMINA DI RAZZA QUATTROCCHI, *RAJA MIRALETUS* (FAMIGLIA: RAJIDAE), PROVENIENTE DAL MEDITERRANEO NORD-ORIENTALE (TURCHIA)

## *SINTESI*

*Lo studio descrive un esemplare femmina di razza quattrocchi* Raja miraletus *Linnaeus, 1758, trovato lungo la costa della città di Aydıncık (Baia di Mersin, Turchia) nel Mediterraneo nord-orientale, che presenta deformazioni del disco. La deformazione è localizzata sulla parte destra del disco dell'esemplare, senza altre deformazioni osservate sul resto del corpo. Il giovane esemplare femmina misura 22 centimetri di diametro del disco, 31,7 centimetri di lunghezza totale e pesa 186 grammi. Questo esemplare rappresenta la prima anomalia registrata della specie* R. miraletus *nelle acque turche del Mediterraneo e questa relazione fornisce le prime informazioni sulla presenza di anomalie negli esemplari femmina della specie* R. miraletus.

**Parole chiave:** Rajiformes, anormalità, deformità del disco pettorale, Baia di Mersin, Mediterraneo orientale

## INTRODUCTION

In the Mediterranean Sea, there are 15 skate and ray species belonging to the family Rajidae (Froese & Pauly, 2025; IUCN, 2025). Of these, 14 species are reported from Turkish waters, and 13 are distributed in Mersin Bay, Northeastern Mediterranean (Turan *et al.,* 2025).

The brown ray, *Raja miraletus* Linnaeus, 1758, is distributed along the Atlantic coast from northern Spain to Morocco and is also widely reported throughout the Mediterranean Sea, including its eastern regions (Golani *et al.,* 2006; Froese & Pauly, 2025). This species has been observed to inhabit depths ranging from 17 to 462 meters (Mytilineou *et al.,* 2005), with a common occurrence between 50 and 150 meters (Bianchi *et al.,* 1999).

A review of the extant literature reveals a preponderance of documented studies concerning morphological abnormalities in adult skate individuals. These abnormalities include albinism, leucism, and other atypical colorations. Examples of such studies can be found in the works of Quigley *et al.* (2018a,b; 2019a,b), Lara-Mendoza & Guerra-Jiménez (2020), and Capape *et al.* (2015a). Furthermore, missing or additional fins (Williams, 1935; Ellis, 2005; Antoni *et al*., 2012; Moore, 2015) and anophthalmia (Ehemann *et al*., 2022) were reported. In some studies (Hoenig & Walsh, 1983; Heupel *et al*., 1999), deformed skeletons and other physical deformities to the body (Ramírez-Amaro *et al*., 2013; Moore, 2015; Capape *et al*., 2015b; Capapé *et al*., 2018) were also observed.

In the Mediterranean Sea, there have been documented cases of morphological abnormalities in skates, primarily characterized by the absence of fusion between the pectoral fins and the head region (Metin *et al.,* 2009; Akyol & Aydin, 2018) and in the anterior region of the disc deformities (reduced snout and a notch on each side of the rostrum) (Capapé *et al.,* 2018). Additionally, there have been reports of tail abnormalities (Capapé *et al.,* 2015b; Mnasri *et al.,* 2010; Capapé *et al.,* 2018; Marouani *et al.,* 2019). As demonstrated in the study by Capapé *et al.* (2018), aberrant coloration patterns are infrequent. Furthermore, Gajic *et al.* (2023) stated that a single ocellus is present on the dorsal surface of the left pectoral fin.

This study presents the first documented instance of a morphological abnormality characterized by a distinct deformity on the surface of the right pectoral fin disk in a female specimen of the species *R. miraletus* in the Mediterranean Sea. It is noteworthy that no additional structural deformities were identified in the remaining anatomical structures of the specimen, suggesting that this is not a systemic developmental concern but rather a localized anomaly.

## MATERIAL AND METHODS

A female specimen of *R. miraletus* exhibiting morphological abnormalities (Fig. 1) was collected during routine bottom trawling operations conducted on January 9, 2018, off the coast of Aydıncık in the Mersin Bay (36° 06 ′N, 33° 18 ′E) at depths ranging from 65 to 80 meters. Standard biometric procedures

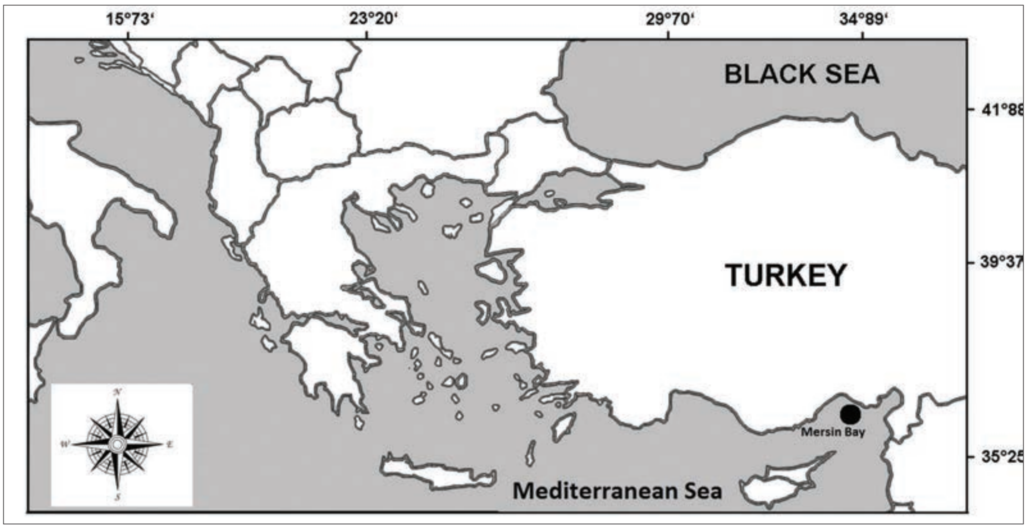

***Fig. 1: The capture site (•) of** Raja miraletus* ***Linnaeus, 1758 from Aydıncık coast (Mersin Bay, Türkiye).***

***Sl. 1: Zemljevid obravnavanega območja z lokaliteto ulova (•) vrste** Raja miraletus* ***Linnaeus, 1758 ob obali mesta Aydıncık (Mersin Bay, Turčija).***

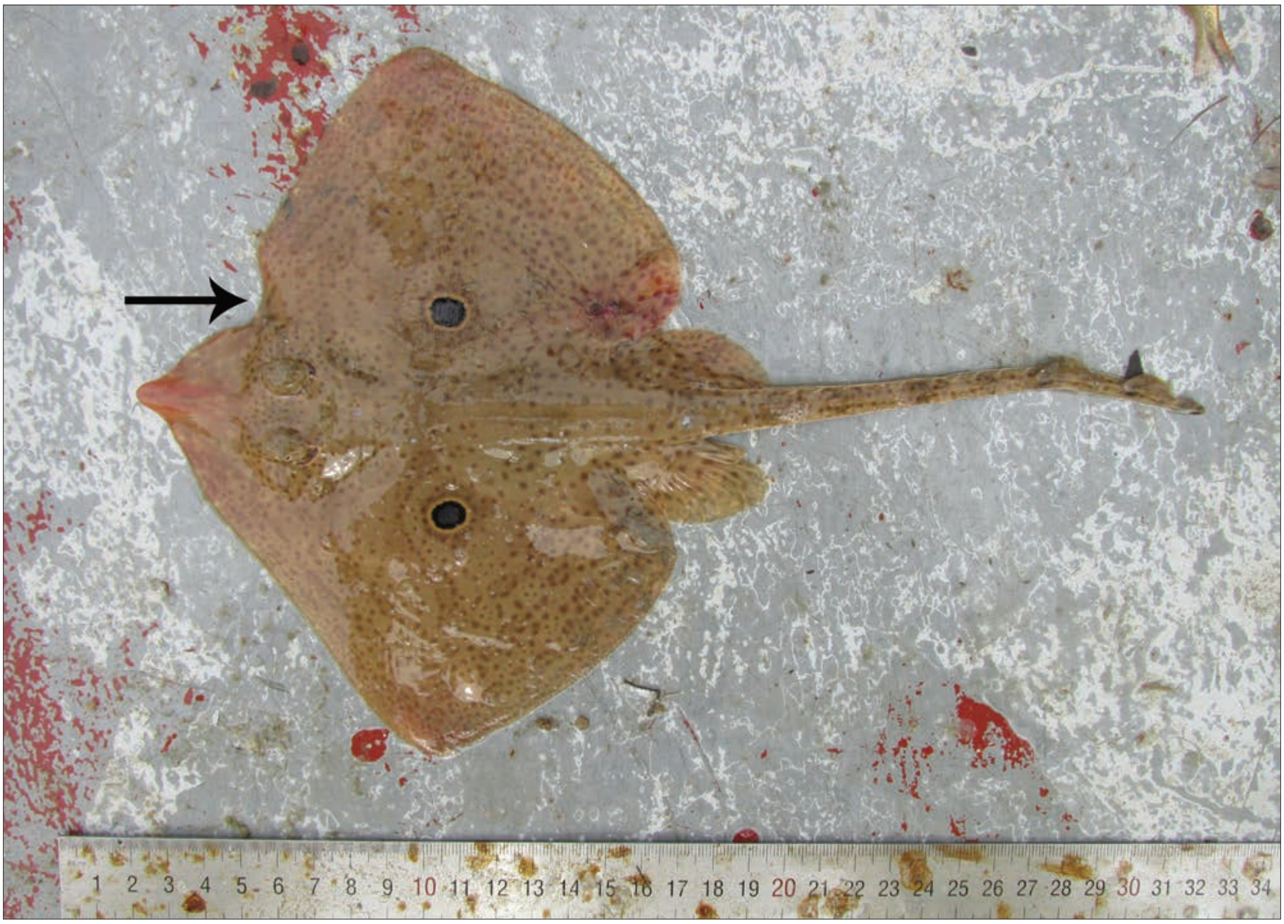

***Fig. 2: The deformity of the disc part (right pectoral fin part) of*** *R. miraletus* ***caught in the Mersin Bay, Türkiye (black Arrow showing the anterior region of the disc).***
***Sl. 2: Deformacija dela diska (desni del prsne plavuti) primerka vrste*** *R. miraletus****, ujetega ob obali mesta Aydıncık (Mersin Bay, Turčija) (črna puščica označuje anteriorni predel diska).***

were applied, and all linear morphometric measurements were recorded to the nearest millimeter. Total body weight was recorded to the nearest gram. Taxonomic identification was based on diagnostic criteria defined by McEachran & Dunn (1998), Compagno *et al*. (1989), and Schneider (1990). The abnormal specimen has been preserved and archived at the Mersin University Marine Life Museum under catalog number MEUFC-24-11-150 (see Fig. 2). This ensures that the specimen will be available for future morphological and genetic studies.

## RESULTS AND DISCUSSION

During a commercial bottom trawl operation in Mersin Bay (Northeastern Mediterranean, Türkiye), between 65-80 m depth contours, two specimens of *R. miraletus* were captured. Among these, only one individual exhibited a notable disc deformation, while the other specimen appeared morphologically normal, with no observable anomalies (Fig. 2 and Fig. 3). *R. miraletus* is a relatively diminutive species within the family Rajidae, and it is characterized by a distinctly angular disc. The body is generally circular in outline, with pectoral fins that are broader than they are long, forming a sinuous margin along the lateral edges. The snout is notably short and rounded, and the pectoral fins exhibit well-defined angular extensions on their lateral extremities, contributing to the species' distinctive morphology.

The brown ray (*R. miraletus*) can be readily distinguished from other sympatric skate species inhabiting the Eastern Mediterranean by the presence of two prominent, symmetrical ocelli located on the anterior dorsal surface of its pectoral fins. Each ocellus is composed of a central light blue spot, encircled by a narrow black or dark blue ring, which is bordered by a broader outer ring of yellow-orange coloration. These distinctive markings are not only

***Fig. 3: The normal specimen of** R. miraletus **in Mersin Bay, Türkiye.***
***Sl. 3: Normalni primerek vrste** R. miraletus **iz zaliva Mersin, Turčija.***

visually striking but may also play a role in species recognition, camouflage, or predator deterrence (Barone *et al.,* 2022).

*R. miraletus* is an oviparous elasmobranch species, meaning it reproduces by laying eggs. According to Mendez *et al.* (2022), sexual maturity is attained at a total length (TL) of 39.0–44.0 cm in females and 36.0–40.0 cm in males, corresponding to disc widths (DW) of approximately 24 cm and 22 cm, respectively. The species undergoes embryonic development within the egg capsule over a period of approximately five months before hatching. At birth, the total length of neonates ranges from 5 to 11 centimeters. Noteworthy disparities in size at maturity have been documented among different regions. For instance, in northwestern European populations, McCully *et al.* (2012) documented considerably elevated size thresholds, with minimum maturity sizes recorded at 55.0 centimeters total length (TL) for males and 60.0 centimeters TL for females. Furthermore, the estimated mean size at 50% maturity was 78.2 centimeters for males and 85.6 centimeters for females. The maximum recorded size of immature individuals was 91.0 centimeters for males and 93.0 centimeters for females, suggesting the potential influence of geographical or ecological factors on growth and reproductive parameters.

The juvenile female specimen of *R. miraletus* exhibiting disc deformity was measured at a total length (TL) of 31.7 centimeters, with a disc width (DW) of 22 centimeters, and a total weight of 186 grams (Fig. 2). For comparison, a morphologically normal female specimen of the same species, collected from the same locality off the coast of the city of Mersin (Aydıncık Bay, Türkiye), measured 43.0 centimeters in total length (TL), 29.0 centimeters in body width (DW), and weighed 249 grams. This specimen is depicted in Fig. 3. Table 1 presents detailed morphometric comparisons between the abnormal and normal individuals. Despite the evident external disc abnormality, no differences were seen in the morphometric proportions between the two specimens, suggesting that this deformity had a limited impact on external body morphology.

***Tab. 1: Morphometric measurements (mm) of one abnormal and one normal female specimen of*** *Raja miraletus* ***in the Northeastern Mediterranean.***
***Tab. 1: Morfometrične meritve (mm) nenormalne in normalne samice vrste*** *Raja miraletus* ***v severovzhodnem Sredozemskem morju.***

| **Measurements** | **Value (mm) Abnormal Specimen** | **% (DW)** | **Value (mm) Normal Specimen** | **% (DW)** |
|---|---|---|---|---|
| Total length | 317 | - | 430 | - |
| Disc width | 220 | - | 290 | - |
| Disc length | 174 | 79.1 | 236 | 81.4 |
| Snout length | 18 | 8.2 | 24 | 10.1 |
| Interorbital width | 13 | 5.9 | 17 | 7.2 |
| Spiracle length | 7 | 3.2 | 9 | 3.8 |
| Anterior pectoral length | 21 | 9.5 | 28 | 11.8 |
| Posterior pectoral length | 14 | 6.4 | 19 | 8.1 |
| 1st Dorsal fin base | 31 | 14.1 | 42 | 17.8 |
| 2nd Dorsal fin base | 28 | 12.7 | 38 | 16.1 |
| Tail length | 118 | 53.6 | 160 | 67.8 |
| Tail base width | 22 | 10.0 | 30 | 12.7 |
| Total weight (g) | 186 | - | 249 | - |

Ribeiro-Prado *et al.* (2008) documented that, among all recorded morphological abnormalities in skates and rays, deformities are most frequently observed in the disc region and pectoral fins. Bigelow and Schroeder (1953), as well as Mansri *et al.* (2010), attributed such anomalies to developmental defects during embryogenesis, particularly the failure of the pectoral fins to fuse anteriorly with the head, a condition frequently reported in batoid fishes. Marouani *et al.* (2019) also emphasized that the most prevalent morphological malformations in both skates (Order Rajiformes) and rays (Order Myliobatiformes) involve the incomplete fusion of pectoral fins to the cranial region. Although our specimen did not exhibit this specific condition, the precise etiology of the localized deformation observed in the anterior portion of the right pectoral fin remains undetermined. Of particular note is the absence of any discernible scarring or lesions, suggesting that the observed abnormality is unlikely to have been caused by trauma or injury. Injury or trauma are well-documented etiological factors contributing to morphological defects in elasmobranchs (Moore, 2015; Montero-Hernandez *et al.,* 2024).

According to Capapé *et al.* (2018), pectoral fins play a vital role in the locomotion of skates and rays, serving as the primary means of propulsion and maneuvering. Despite their functional importance, abnormalities affecting the head and anterior pectoral fin regions remain exceedingly rare among batoid species. However, the prevalence of such deformities in skates (e.g., Ellis, 2005; Metin *et al.,* 2019; Clarke, 2021) and stingrays (e.g., Yoshiharu & Sugihara, 1971; Escobar-Sánchez *et al.,* 2009) remains limited. The present study documents, for the first time, a deformity localized in the anterior region of the pectoral fin in a specimen of *R. miraletus* from the Turkish Mediterranean Sea. A comparable morphological anomaly affecting the anterior pectoral region was previously documented by Metin *et al.* (2009) in another species of skate, *R. polystigma*. These observations underscore the rarity of such conditions and highlight the importance of documenting even isolated cases to better understand the developmental and ecological implications of these abnormalities.

Another important category of morphological abnormalities in batoids involves malformations of the tail, often characterized by partial or complete absence of dorsal and caudal fins. Templeman (1965), Mnasri *et al.* (2009), and Orlov (2011) noted that while such injuries are relatively common in stingrays, typically as a result of physical trauma,

***Tab. 2: Records of abnormal cases of skate and ray species in Mediterranean regions.***
***Tab. 2: Zapisi o pojavljanju nenormalnih primerkov skatov v sredozemskih regijah.***

| Species | Number of Samples | Sex | Abnormal deformity | Capture site | Capture date | Reference |
|---|---|---|---|---|---|---|
| *Raja polystigma* | 1 | Male | Head part | Izmir Bay, Aegean Sea, Türkiye | October 2005 | Metin *et al.* (2009) |
| *Raja polystigma* | 1 | Juvenile Female | The shape of the end of the tail is forked | Northern Tunisian waters (Central Mediterranean) | May 2010 | Mnasri *et al.* (2010) |
| *Raja clavata* | 2 | Male (Juvenile and Adult) | Reduced tail, abnormality at the distal end of the tail | Syria coast, Eastern Mediterranean | April 2013-July 2014 | Capapé *et al.* (2015b) |
|  | 1 | Female | On the tail lack of dorsal and caudal fins |  | September 2014 |  |
| *Raja clavata* | 2 | Female | Snout, rostrum and tail<br>Snout and caudal fin | Izmir, Aegean Sea, Türkiye | September 2016<br>February 2017 | Capapé *et al.* (2018) |
| *Raja clavata* | 1 | Female | Absence of tail and asymmetric pectoral fin | Gulf of Gabes (Tunisia, Central Mediterranean Sea) | Early 2016 | Marouani *et al.* (2019) |
| *Raja clavata* | 2 | Female | Absence of caudal and dorsal fin |  |  |  |
| *Raja radula* | 1 | Female | Absence of caudal and dorsal fin |  |  |  |
| *Raja miraletus* | 1 | Juvenile Female | Pectoral fin abnormality | Mersin Bay, Northeastern Mediterranean | January 2018 | This study |

they remain rare in skates. Orlov (2011) emphasized the scarcity of documented tail abnormalities in skates and highlighted the limited number of studies addressing such cases (Mnasri *et al.,* 2010; Capapé *et al.,* 2015a,b). Capapé *et al.* (2015b), for example, documented abnormal tail structures in both male and female specimens of *R. clavata* collected from Syrian coastal waters. Furthermore, Capapé *et al.* (2018) reported snout, rostrum, and caudal fin anomalies in *R. clavata* from the Aegean Sea, Türkiye. Similarly, Marouani *et al.* (2019) described the complete absence of caudal and dorsal fins in female specimens of *R. clavata* and *R. radula*, as well as an instance of asymmetric pectoral fin formation in a female *R. clavata* from the Gulf of Gabès, Tunisia. In addition, Mnasri *et al.* (2010) observed a fork-shaped tail tip in a juvenile female specimen from northern Tunisian waters. A comparative overview of the present case with previously reported deformities in Mediterranean skates and rays is provided in Tab. 2, illustrating the rarity and morphological diversity of such abnormalities.

According to Bensam (1965), members of the family Rajidae are oviparous, with embryonic development occurring within the yolk sac of the egg capsule deposited by the female. He proposed that congenital deformities may have their origins in mutations or developmental disruptions that occur during the process of early embryogenesis. In support of this assertion, Ribeiro-Prado *et al.* (2008) underscored the potential impact of environmental stressors on the emergence of such abnormalities. In particular, chronic exposure to pollutants, chemical contaminants, or other unfavorable ecological conditions may interfere with normal developmental processes, thereby increasing the likelihood of morphological anomalies in both wild and captive elasmobranch populations.

Although there have been sporadic reports of morphological abnormalities affecting the snout and disc regions in various skate and ray species inhabiting the Mediterranean Sea, the present study documents the first instance of a pectoral fin deformity in a juvenile female *R. miraletus*. To date, no such anomaly has been recorded in this species within Turkish territorial waters. In conclusion, this observation constitutes the first documented instance of a morphological abnormality in *R. miraletus* from the Mediterranean coast of Turkey. This finding contributes novel data to the extant literature on elasmobranch developmental anomalies in the region.

## CONCLUSIONS

Consequently, this study documents the first known instance of a pectoral fin deformity in a juvenile female *R. miraletus* from the Mediterranean coast of Türkiye, thereby contributing valuable new data to the limited literature on morphological abnormalities in skates and rays. The absence of scarring or injury lends support to the hypothesis that deformity is congenital, potentially resulting from developmental irregularities or environmental stressors. This case underscores the importance of ongoing biological monitoring and morphological assessments of elasmobranch populations in the Eastern Mediterranean. Future research should aim to determine the prevalence, causative factors, and ecological implications of such abnormalities, particularly in the face of increasing anthropogenic pressures on marine ecosystems.

## ACKNOWLEDGMENTS

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# DEFORMACIJA DISKA PRI JUVENILNI SAMICI MODROPEGE RAŽE, *RAJA MIRALETUS* (DRUŽINA: RAJIDAE), IZ SEVEROVZHODNEGA SREDOZEMSKEGA MORJA (TURČIJA)

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## *POVZETEK*

*Avtorji poročajo o samici modropege raže,* Raja miraletus *Linnaeus, 1758, najdene ob obali mesta Aydıncık (Mersin Bay, Turčija) v severovzhodnem Sredozemskem morju, ki kaže deformacije diska. Deformacija se nahaja na desnem delu diska, drugi del telesa pa je brez deformacij. Juvenilna samica je v premeru diska merila 22 centimetrov in v dolžino 31,7 cm ter tehtala 186 gramov. Ta primerek predstavlja prvi primer o ugotovljeni nenormalnosti vrste* R. miraletus *v turških sredozemskih vodah, pričujoč prispevek pa podaja prve informacije o prisotnosti nenormalnosti pri samicah vrste* R. miraletus.

**Ključne besede:** Rajiformes, nenormalnost, deformacija prsnega diska, zaliv Mersin, vzhodno Sredozemsko morje

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# ON AN OLD RECORD OF THE SMALLTOOTH SAND TIGER SHARK *ODONTASPIS FEROX* (CHONDRICHTHYES: ODONTASPIDIDAE) FROM THE ALGERIAN COAST (SOUTHWESTERN MEDITERRANEAN SEA)

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## *ABSTRACT*

*The paper reports the capture of smalltooth sandtiger shark,* Odontaspis ferox *(Risso, 1810), from the eastern region of the Algerian coast (GSA 04). It was probably an adult female specimen, with an estimated total length of 3 m and a total body weight of 200 kg. This finding constitutes the second record of* O. ferox *in Algerian ichthyofauna. The origin of this specimen remains uncertain and the presence of a viable population in the area needs further documentation. However, a management plan is needed to preserve this species and prevent its extinction – not only in Algerian waters but throughout the Mediterranean Sea.*

**Key words:** Odontaspididae, *Odontaspis ferox*, distribution, Algerian coast, Mediterranean Sea, origin, management plan

# VECCHIO RITROVAMENTO DEL CAGNACCIO *ODONTASPIS FEROX* (CHONDRICHTHYES: ODONTASPIDIDAE) LUNGO LA COSTA ALGERINA (MEDITERRANEO SUDOCCIDENTALE)

## *SINTESI*

*L'articolo riporta la cattura di un esemplare di cagnaccio,* Odontaspis ferox *(Risso, 1810), proveniente dalla regione orientale della costa algerina (GSA 04). Si tratta probabilmente di un esemplare femmina adulto, con una lunghezza totale stimata di 3 m e un peso corporeo totale di 200 kg. Questo ritrovamento costituisce il secondo dato di* O. ferox *nell'ittiofauna algerina. L'origine di questo esemplare rimane incerta e la presenza di una popolazione vitale nell'area necessita di ulteriore documentazione. Tuttavia, è necessario un piano di gestione per preservare questa specie e prevenirne l'estinzione, non solo nelle acque algerine ma in tutto il Mediterraneo.*

**Parole chiave:** Odontaspididae, *Odontaspis ferox*, distribuzione, costa algerina, piano di gestione

## INTRODUCTION

The smalltooth sandtiger shark, *Odontaspis ferox* (Risso, 1810), has a cosmopolitan distribution in warm temperate and tropical waters. Although essentially demersal, it has also been captured pelagically in the open ocean (Compagno, 1984) and caught by trawl on the continental slope at depths of up to 880 m (Fergusson *et al.*, 2008). The species has been recorded in the Pacific Ocean (Long *et al.*, 2014) and sporadically along the western Atlantic coast, from North America (Sheehan, 1998) to Brazil (Menni *et al.*, 1995). Along the eastern Atlantic coast, *O. ferox* has been reported from the Bay of Biscay (Quéro *et al.*, 2003), Portugal (Carneiro *et al.*, 2014), Morocco (Collignon & Aloncle, 1972), and as far south as Mauritania (Ebert & Stehmann, 2013). In addition, *O. ferox* is known to occur around the Azores (Barcelos *et al.*, 2018), Madeira (Maul, 1955), the Canary Islands (Barría *et al.* (2018), and Cabo Verde (Wirtz *et al.*, 2013).

In the Mediterranean Sea, *O. ferox* was first recorded on the coast of France, off Nice, by Risso (1810), and areas nearby by Bougis (1959) and Granier (1964), but was observed to be absent from the coast of Languedoc (Capapé *et al.*, 2000). Barrull & Mate (2002) reported the species occurring off the Spanish coast. Tortonese (1956) documented the capture of a large female in the Gulf of Genoa, and two more specimens were reported southward by Vanni (1992). To the east, Soldo & Jardas (2000) reported sporadic captures of *O. ferox* in the Adriatic Sea. Kabasakal & Bayri (2019) and Kabasakal *et al.* (2023) summarised several captures of the species in Turkish waters, while Akbora *et al.* (2019) reported further captures around Cyprus. The species has also been recorded in the Levant Basin (Golani, 2005; Bariche & Fricke, 2020).

In the central Mediterranean Sea, specifically, captures of *O. ferox* in the Strait of Sicily have been reported by Vacchi & Serena (1997), and Sperone *et al.* (2012). Schembri *et al.* (2003) noted annual aggregations of specimens in small groups around the Maltese Islands, including adult females of up to 360 cm TL, as observed during 1998–1999. The species was first reported in the Gulf of Tunis by Capapé (1975), followed by a second specimen documented by Ben Amor *et al.* (2020) from the same area, which was landed at the fish harbour of Kelibia.

Dieuzeide *et al.* (1953) reported the presence of *O. ferox* in Algeria based on a specimen collected by Dr Bourjot at the end of the 19th century from an unspecified site along the Algerian coast. The specimen, described by Moreau (1881), is preserved at the Muséum d'Histoire Naturelle de Paris. Hemida & Labidi (2001) referred to Dieuzeide *et al.* (1953) to support a potential occurrence of *O. ferox* off the Algerian coast and suggested its likely future capture in the region. This hypothesis was later confirmed by the capture of a specimen in the eastern area some years ago. The details of this capture are presented here to determine the presence of this shark species both locally and in the wider the Mediterranean Sea.

## MATERIAL AND METHODS

The specimen of *O. ferox* was observed by one of the authors (F. H.) at Algiers' main fish market, which receives catches from across Algeria's entire coast, spanning from the Moroccan to the Tunisian borders. According to the information provided *in situ* by fishermen and fishmongers, the specimen was caught by commercial trawler on 18 November 1998 off Annaba, a city located in the eastern Algerian coast, 37°06′10″ N and 7°51′02″ E (Fig. 1). The specimen was captured within the boundaries of GFCM geographical subarea

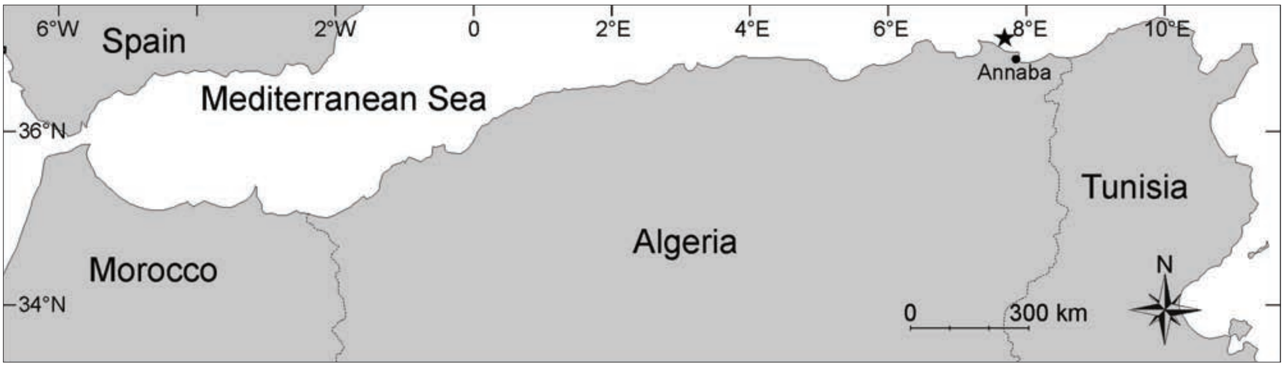

**Fig. 1. Map of the Algerian coast indicating the capture site of** *Odontaspis ferox* **(black star) in the eastern region off Annaba.**
**Sl. 1: Zemljevid alžirske obale z označeno lokaliteto ulova vrste** *Odontaspis ferox* **(črna zvezdica) v vzhodni regiji ob Annabi.**

***Fig. 2. Jaws of the*** *Odontaspis ferox* ***specimen captured off Annaba (Photo: F. Hemida).***
***Sl. 2: Čeljusti primerka vrste*** *Odontaspis ferox* ***ujetega ob Annabi (Foto: F. Hemida).***

(GSA) 04 (GFCM, 2018), at a depth of 120 m over sandy-muddy bottom, along with several specimens of Norway lobster *Nephrops norvegicus* (Linnaeus, 1758), as well as scorpaenid, lophiid and mullid species. Although the specimen had already been sliced, identification was possible based on the remaining portions that preserved key morphological features, particularly the jaws, which were photographed (Fig. 2, 3).

## RESULTS AND DISCUSSION

Despite the fact that the shark was rapidly sectioned and sold, it could still be identified based on the teeth and several available morphological characters, including: a large, bulky body with a long conical snout; eyes more than four times smaller than snout length, without nictitating eyelids; mouth long, extending behind the eyes; teeth moderately large with a prominent narrow cusp and two or more pairs of lateral cusplets (Fig. 2, 3); caudal fin asymmetrical, with a stronger lower lobe; colour medium grey with darker reddish spots scattered over the body, lower edge of caudal fin almost black. These morphological characters are consistent with those described in Compagno (1984) and Ebert & Stehmann (2013).

According to the estimations of the fishermen and the fishmongers, the shark measured 3 m in total length and weighed 200 kg. Both estimations are consistent with previous records reported by Fergusson *et al.* (2008) and Higgs *et al.* (2021), as shown in Table 1. There appears to be a considerable difference in weight between large specimens and medium-sized or small-sized specimens, suggesting that the weight likely increases exponentially as the species reaches large sizes.

Ebert & Stehmann (2013) reported size at first sexual maturity for *O. ferox* as 200–250 cm in males (maximum 344 cm) and 300–350 in females (maximum 450 cm). This specimen, identifiable as female by the absence of claspers among the remains, appeared near adult size. The largest *O. ferox* known to date remains a 520 cm female captured near Walvis Ridge, southeastern Atlantic (Kukuev & Batal'yants, 2019).

***Fig. 3. Median teeth of the lower jaw in the specimen of*** *Odontaspis ferox* ***captured off Annaba (Photo: F. Hemida).***
***Sl. 3: Sredinski zob v spodnji čeljustnici primerka vrste*** *Odontaspis ferox* ***ujetega ob Annabi (Foto: F. Hemida).***

The present specimen constitutes the second documented record of *O. ferox* from the Algerian coast in over a century, highlighting the species' extreme rarity in the region, as is the case throughout the Mediterranean (Fergusson *et al.*, 2008; Kabasakal *et al.*, 2023), as well as various oceans and seas (Higgs *et al.*, 2021). Since 1998, no specimen has been observed in Algerian waters despite regular investigations carried out by local researchers. As stated before, the first record was reported from nearby Tunisian waters by Capapé (1975), followed by a second specimen documented several years later (Ben Amor *et al.*, 2020).

*O. ferox* had not been recorded along the Mediterranean coast of France for decades (Capapé, 1977; Capapé *et al.*, 2000; Ziani, pers. com., 2025). Then, on 21 September 2013, a specimen was found stranded dead at Pénestin beach, Morbihan (northern Bay of Biscay). This specimen measured 3.24 m and weighed 220 kg, and was subsequently preserved (APECS, 2013). The earliest record of *O. ferox* in the Bay of Biscay dates back to January 1930, when a male *O. ferox* measuring 1.40 m in total length was captured by trawl, at approximately 46° N and 4° W, at a depth of about 250 m. More recently, a live specimen was found stranded off the western Cotentin Peninsula (English Channel) in August 2012 but was urgently discarded at sea. No further records have been confirmed in the region to date (Stephan, pers. comm., 2025).

According to the global ichthyological literature, *O. ferox* is only sporadically caught and there are no records of the species occurring in large numbers. Fergusson *et al.* (2008) reported a drastic decline in shark captures from south-eastern Australian trawl grounds. To date, no shoal of this species has been observed; unlike the bluntnose sixgill shark *Hexanchus griseus* (Bonnaterre, 1788), which has been reported in aggregations from Tunisian waters – the same region where the large specimen of *O. ferox* reported by Ben Amor *et al.* (2020) was found.

Barcelos *et al.* (2018) noted that *O. ferox* is globally captured in warm temperate waters. This may explain why more records occurred in the eastern Mediterranean Basin (Capapé, 1989; Kabasakal *et al.*, 2023) and the eastern tropical Atlantic (Quéro, 1984). In an impor-

***Tab. 1: Total length (TL, cm) versus total body weight (TWB, kg) measurements of*** *Odontaspis ferox* ***specimens from various marine areas around the world.***
***Tab. 1: Podatki o meritvah celotne dolžine (TL, cm) in celokupne telesne mase (TWB, kg) primerkov vrste*** *Odontaspis ferox* ***iz različnih predelov sveta.***

| **Areas of capture** | **TL (cm)** | **TBW (kg)** | **Authors** |
|---|---|---|---|
| Gulf of Tunis, northern Tunisia | 247 | 70 | Capapé (1975) |
| Cayo Nuevo, Mexico | 366 | 289 | Bonfil (1995) |
| Cape Hatteras, USA | 340 | 250 | Sheenan (1998) |
| Blake Plateau | 200 | 47 | Ross & Quatrini (2007) |
| Jacksonville, Florida, USA | 250 | 96 | Ross & Quatrini (2007) |
| Viosca Knoll 826, USA | 300-400 | 170-430 | Sulak *et al.* (2007) *in* Higgs *et al.* (2022) |
| South Cat Cay, Bahamas | 314 | 191 | Castro, 2011 *in* Higgs *et al.* (2022) |
| South Cat Cay, Bahamas | 309 | 165 | Castro, 2011 *in* Higgs *et al.* (2022) |
| Bay of Biscay | 324 | 220 | APECS (2013) |
| Colombia | 212 | 90 | Anguila *et al.* (2016) |
| Salvo, New Columbia, USA | 237 | 81 | VIMS 35382 *in* Higgs *et al.* (2022) |
| Cape Codera, Venezuela | 180 | 30 | Tavares *et al.* (2019) |
| Bermuda | 275 | 130 | Higgs *et al.* (2022) |
| Miami Terrace, USA | 200 | 47 | Higgs *et al.* (2022) |
| MC 109, USA | 225 | 115 | Higgs *et al.* (2022) |
| MC 401, USA | 250 | 87 | Higgs *et al.* (2022) |
| Off Annaba, eastern Algeria | 300 | 200 | This study |

tant study on the presence of *O. ferox* in Turkish waters, Kabasakal *et al.* (2023) confirmed that the species is not completely extinct, as shown by the recent captures of four specimens in the region. However, while the establishment of a viable population cannot be totally ruled out, further records are needed to corroborate this hypothesis – particularly through the monitoring of social media posts and the use of local ecological knowledge, with the assistance of fishermen familiar with Turkish fishing grounds (Kabasakal *et al.*, 2023).

Large-sized sharks such as *O. ferox* are highly sensitive to fishing pressure, which has contributed to their decline throughout the Mediterranean Sea (Ferretti *et al.*, 2008). This pattern is further exacerbated by the *k*-selected life-history characteristics of *O. ferox* – as it is generally the case for all elasmobranch species (Mellinger, 1989) – making recruitment from regions where the species is captured in relative abundance highly uncertain. *O. ferox* inhabits deep waters, down to at least 520 m, and does not seem prone to large latitudinal migrations. It is likely a good swimmer, like many other shark species, and may occasionally be affected by environmental disturbances such as high tides, strong currents or storms – factors which could explain why it is sometimes found stranded on beaches.

Over a period of more than a century, only two specimens of *O. ferox* were recorded on the Algerian and two on the Tunisian coast, amounting to just four specimens from the Maghreb shore. These findings highlight the extreme rarity of the species in the region, approaching total disappearance. In full accordance with previous reports, such as Kabasakal *et al.* (2023), a management plan involving the collaboration of local fisheries needs to be implemented to prevent the species' total extinction in this region.

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# O STAREM ZAPISU O DROBNOZOBEM MORSKEM BIKU O*DONTASPIS FEROX* (CHONDRICHTHYES: ODONTASPIDIDAE) Z ALŽIRSKE OBALE (JUGOZAHODNO SREDOZEMSKO MORJE)

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## *POVZETEK*

*Avtorji poročajo o ulovu drobnozobega morskega bika,* Odontaspis ferox *(Risso, 1810), na vzhodnem predelu alžirske obale (GSA 04). Verjetno je šlo za odraslo samico z ocenjeno velikostjo 3 m in celokupno maso 200 kg. Ta najdba predstavlja drugi zapis o pojavljanju vrste* O. ferox *v alžirski ihtiofavni. Od kod je primerek prišel, ostaja nejasno, obstoj viabilne populacije po potrebuje dodatne dokumentirane vire. Za ohranitev te vrste in preprečitev njenega izumrtja je potreben načrt upravljanja – ne samo v alžirskih vodah, ampak po vsem Sredozemskem morju.*

**Ključne besede:** Odontaspididae, *Odontaspis ferox*, razširjenost, alžirska obala, Sredozemsko morje, izvor, načrt upravljanja

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# PLASTIC DEBRIS-INDUCED FIN DAMAGE IN THE SMOOTHHOUND, *MUSTELUS MUSTELUS*

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## *ABSTRACT*

*Marine debris is considered a serious threat to the survival of sharks and rays worldwide. Although entanglement with floating plastic debris has been reported in several shark species, this is the first report of this threat and the resulting mechanical trauma in the triakid shark* Mustelus mustelus *from the Sea of Marmara.*

**Key words:** Plastic, entanglement, smoothhound, trauma, Sea of Marmara

# DANNI ALLE PINNE INDOTTI DA DETRITI PLASTICI IN PALOMBO LISCIO, *MUSTELUS MUSTELUS*

## *SINTESI*

*I detriti marini sono considerati una grave minaccia per la sopravvivenza di squali e razze in tutto il mondo. Sebbene l'impigliamento con detriti di plastica galleggianti sia stato segnalato in diverse specie di squali, questa è la prima segnalazione di questa minaccia e del conseguente trauma meccanico nel palombo liscio* Mustelus mustelus *nel Mar di Marmara.*

**Parole chiave:** plastica, impigliamento, palombo liscio, trauma, Mar di Marmara

## INTRODUCTION

The Anthropocene has been defined as an epoch in which the most fundamental biochemical processes and biodiversity on Earth have undergone dramatic changes due to anthropogenic activities (Lewis & Maslin, 2015; Lipej *et al.*, 2022). During this epoch, species comprising the megafauna in particular have suffered major losses in terrestrial and marine ecosystems (Lewis & Maslin, 2015; Lipej *et al.*, 2022). According to Lewis and Maslin (2015), Anthropocene is also characterized by the unavoidable and increasingly severe pollution of all ecosystems. Among the pollutants that pose a serious threat to the health and sustainability of marine life are marine plastics (MaPs) (Gündoğdu *et al.*, 2020). According to Aytan *et al.* (2022) the impact of MaPs on ecosystems and organisms has increased rapidly in recent decades and is expected to increase in the future. Pollution caused by MaPs is now considered a global environmental problem that negatively affects marine biodiversity (Bottari *et al.*, 2024), and this hazardous situation is known to affect many different taxa in the sea via a plethora of different mechanisms (e.g., entanglement, ingestion, intoxication, etc.) (Lipej *et al.*, 2022). In a recent study, Gündoğdu *et al.*, (2020) reported that 2249 marine taxa are threatened by plastic pollution, including sharks and rays (Lipej *et al.*, 2022).

Here we report the first documented case of plastic strap entanglement causing fin damage in the smoothhound, *Mustelus mustelus* (Linnaeus, 1758) (Carcharhiniformes: Triakidae).

## MATERIAL AND METHODS

A specimen of smoothhound shark was incidentally captured in a commercial trammel-net fishery with a stretched mesh size of 120 mm deployed for demersal bony fishes in the northern Sea of Marmara (Fig. 1). Although the smoothhound does not currently have protection status in Turkish seas, the present specimen was released back into the sea after being photographed and measured. Identification of the present specimen was based on the photographs sent by the fisherman and follows Ebert *et al.* (2021) and Barone *et al.* (2022). Photographs of the present specimen are preserved in the archive of the first author and can be made available upon receiving permission from the fisherman.

## RESULTS AND DISCUSSION

A female specimen with a total length of 120 cm and weighing 8,000 g (Fig. 2), was caught during commercial trammel-net fishing at a depth of approximately 100 m off the coast of Silivri (40°57.494′ N, 28°19.190′ E) in the northern Sea of Marmara (SoM).

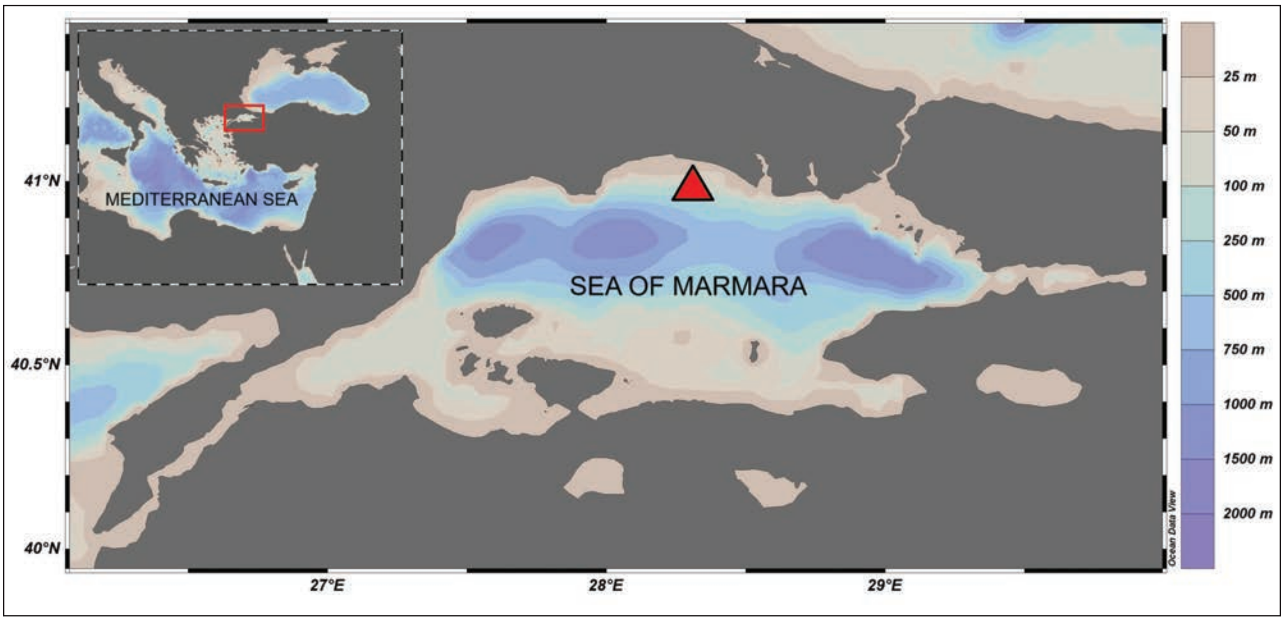

***Fig. 1: Map showing the approximate locality (red triangle) of the capture of the specimen of smoothhound. Red rectangle in the small map shows the geographical position of the Sea of Marmara in the Mediterranean ecosystem.***
***Sl. 1: Zemljevid, ki prikazuje približno lokacijo (rdeči trikotnik) ujetega osebka navadnega morskega. Rdeči pravokotnik na majhnem zemljevidu prikazuje geografski položaj Marmarskega morja v sredozemskem ekosistemu.***

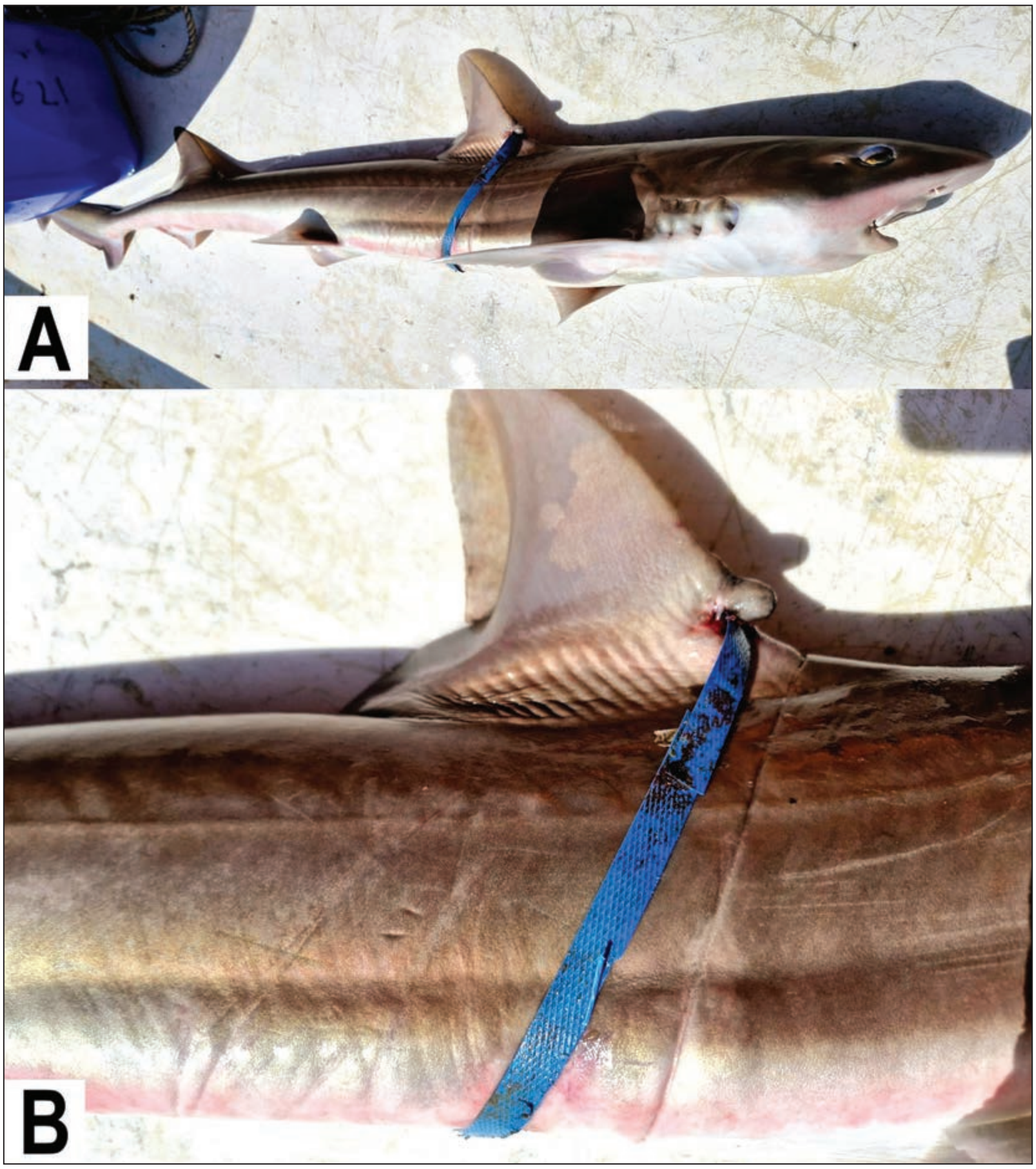

***Fig. 2: A: The smoothhound (*Mustelus mustelus*) entangled in a plastic strap, and B: Close-up of the deep laceration on the anterior edge of the shark's first dorsal fin. (Photo: B. Köksalan)***
***Sl. 2: Navadni morski pes (*Mustelus mustelus*), zapleten v plastični trak (A), in B: bližnji pogled na globoke raztrganine na sprednjem robu prve hrbtne plavuti morskega psa. (Foto: B. Köksalan)***

It was a medium to moderately large-sized shark with a short head and snout. The posterior edges of the dorsal fins, which were large and almost equal in height, were not fringed. The pectoral and pelvic fins were moderately large. The dorsal colouration was uniformly grey to grey-brown and lighter below, without any dark or bright spots on flanks. This brief description of the present specimen is consistent with those provided by Ebert *et al.* (2021) and Barone *et al.* (2022), thus the present specimen was identified as *Mustelus mustelus*.

The specimen was entangled in a plastic strap. According to the fisherman's statement, the plastic strap was tightly wrapped around the shark's trunk, damaging the main cartilaginous skeletal elements at the anterior margin of the first dorsal fin and causing haemorrhagic trauma in this area. Abnormal tissue growth occurred where the plastic strap had damaged the anterior margin of the first dorsal fin. It was also observed that the upper part of the dorsal fin was permanently bent due to the pressure exerted by the plastic strap. The tight fit of the plastic strap on the first dorsal fin and tissue damage suggest that the entanglement occurred a considerable time ago.

According to Afonso and Fidelis (2023), long-term (≥9 months) entanglement of sharks in plastic straps can increase their post-release mortality, even following strap removal, indicating that freeing sharks from such entanglements may often prove ineffective in ensuring their survival. The trauma caused by the mechanical stress of the plastic strap tightly wrapping the shark's body, causing deep lacerations in the dermis and underlying muscle mass, compromises the health and fitness of the shark in the short to medium term (Afonso & Fidelis, 2023). Therefore, although the shark in this case was released alive, the deep haemorrhagic laceration on its first dorsal fin strongly suggests it would have subsequently died.

The majority of the research on the effects of marine plastics on sharks and rays (elasmobranchs) has focused on microplastic ingestion and its aftereffects; however, entanglement in marine debris has also received attention as an important cause of morbidity and mortality in these vulnerable meso- and megapredators (Lipej *et al.*, 2022). Parton *et al.* (2019) reviewed 26 scientific articles related to 47 entanglement events involving 34 elasmobranch species in different marine regions, but the smoothhound was not among them. Although there has been a significant increase in the number of studies on the effects of plastic debris on elasmobranchs, which include some of the flagship species of marine ecosystems, in recent years (reviewed in Lipej *et al.*, 2022), studies on the effects of MaPs on marine organisms in Turkish seas have mostly focused on commercial fish species (Gündoğdu *et al.*, 2020; Aytan *et al.*, 2022). Pollution is now considered one of the main threats contributing to the extinction crisis of one third of all sharks and rays worldwide (Dulvy *et al.*, 2021), which have an evolutionary history of at least 400 million years and play crucial roles in the marine ecosystem (Compagno, 1990). It is therefore necessary to regularly monitor the effects of MaPs on sharks and rays in Turkish waters. Despite being a small marine basin, the SoM is severely affected by pollution and anthropogenic impacts, which threaten the biodiversity of the region (İşinibilir *et al.*, 2024). Due to the frequent occurrence of mega-spawning individuals of *M. mustelus* in the coastal waters of the SoM (Kabasakal *et al.*, 2025), monitoring the potential impacts of MaPs represents a critical consideration for regional conservation strategies targeting vulnerable species such as sharks. In line with this, the incident described in this study – photographed by a commercial fisherman and reported to the researchers with related information – highlights the value of cooperation between citizen scientists and professional researchers in tracking the effects of MaPs on sharks and rays in Turkish seas.

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# POŠKODBE PLAVUTI PRI NAVADNEM MORSKEM PSU, *MUSTELUS MUSTELUS*, ZARADI PLASTIČNIH ODPADKOV

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## *POVZETEK*

*Morski odpadki resno ogrožajo preživetje morskih psov in raž po vsem svetu. O zapletanju s plavajočimi plastičnimi odpadki so poročali že pri več vrstah morskih psov, pričujoči prispevek pa prvo poročilo o tej grožnji in posledični mehanski poškodbi pri navadnemu morskemu psu,* Mustelus mustelus *(družina Triakidae) iz Marmarskega morja.*

**Ključne besede:** plastika, zapletanje, navadni morski pes, travma, Marmarsko morje

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# BITE MARKS OBSERVED ON A LARGE FEMALE WHITE SHARK *CARCHARODON CARCHARIAS* OFF CAMARGUE, FRANCE PROVIDE POTENTIAL INSIGHTS INTO THE REPRODUCTION OF THE MEDITERRANEAN POPULATION

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## *ABSTRACT*

*The ecology of the great white shark* Carcharodon carcharias *in the Mediterranean remains largely unknown due to its rarity and population decline, despite its role as the region's apex predator. In September 2022, we documented a rare adult female displaying distinct bite marks, swimming off the coast of the Camargue. From spring to autumn, the Gulf of Lion, particularly in the adjacent waters of the protected area of the Parc Naturel Régional de Camargue, experiences a significant increase in biodiversity. Our observations suggest that this region may serve as a key late-summer feeding area for female great white sharks following copulation.*

**Key words:** white shark, Gulf of Lion, reproduction, bite marks, conservation

# SEGNI DI MORSI OSSERVATI SU UNA GRANDE FEMMINA DI SQUALO BIANCO *CARCHARODON CARCHARIAS* AL LARGO DELLA CAMARGUE, IN FRANCIA, FORNISCONO POTENZIALI INDICAZIONI SULLA RIPRODUZIONE DELLA POPOLAZIONE MEDITERRANEA

## *SINTESI*

*L'ecologia del grande squalo bianco* Carcharodon carcharias *nel Mediterraneo rimane in gran parte sconosciuta a causa della sua rarità e del declino della popolazione, nonostante il suo ruolo di superpredatore nella regione. Nel settembre 2022, gli autori hanno documentato una rara femmina adulta che mostrava segni di morsi distinti, nuotando al largo della costa della Camargue. Dalla primavera all'autunno, il Golfo del Leone, in particolare nelle acque adiacenti all'area protetta del Parc Naturel Régional de Camargue, registra un significativo aumento della biodiversità. Queste osservazioni suggeriscono che la regione può servire come area di alimentazione tardo-estiva per le femmine di squalo bianco dopo l'accoppiamento.*

**Parole chiave:** squalo bianco, Golfo del Leone, riproduzione, segni di morsi, conservazione

## INTRODUCTION

*Carcharodon carcharias* (Linnaeus, 1758) (Lamniformes: Lamnidae) is one of the largest coastal and oceanic macro-predators (Ebert & Dando, 2020; Ebert *et al.*, 2021). Six genetically distinct and geographically isolated philopatric populations have been identified worldwide: Australia, South Africa, the Northwest Atlantic, the North-East Pacific, Japan, and the Mediterranean (Huveeners *et al.*, 2018; Villafaña *et al.*, 2020; Ebert *et al.*, 2021). The migrations of *C. carcharias* are influenced by environmental conditions, reproduction, and prey availability (Milankovic et *al.*, 2021).

The Mediterranean population has been identified as genetically distinct (Gubili *et al.*, 2012). The species is classified as critically endangered by the IUCN Red List (Soldo *et al.*, 2016). As a top predator, it preys on large pelagic fish such as bluefin tuna *Thunnus thynnus* and swordfish *Xiphias gladius*, as well as elasmobranchs and marine mammals in its Mediterranean area (Fergusson, 1996; De Maddalena & Heim, 2012; Boldrocchi *et al.*, 2017). Since the 1600s, most of our knowledge about the species has relied on rare opportunistic observations of live individuals, historical surveys, and bycatch data (Morey *et al.*, 2003; De Maddalena & Heim, 2012; Maliet et *al.*, 2013; Kabasakal, 2014; Boldrocchi *et al.*, 2017; Moro *et al.*, 2020; Deysson *et al.*, 2024; Jambura *et al.*, 2025).

In the Mediterranean, the research to improve understanding of the life history of the Mediterranean population and especially its reproduction remains a huge challenge currently producing very few results even if involving long term indepth monitoring (Micarelli *et al.*, 2023; Ferretti *et al.*, 2024). This is likely due to a critical decline of over 90% and the marked fragmentation of the original population (Moro *et al.*, 2020; Ferretti *et al.*, 2024).

Regarding the reproduction of the species, the central basin of the Mediterranean Sea is well known as a parturition and nursery area for *C. carcharias* (Saïdi *et al.*, 2005; by Kabasakal, 2014; Boldrochi *et al.*, 2017; Zaouali *et al.*, 2020; Jambura *et al.*, 2025). It is established that females reach maturity at a total length of 450 to 500 cm and males reach maturity at a total length of 350 to 400 cm (Francis, 1996; Ebert & Dando, 2020).

In this context, we report an extremely rare observation of an alive adult female great white shark exhibiting bite marks, suggesting recent mating. This observation contributes valuable insight into timing and dynamics of the poorly known reproductive cycle of the Mediterranean *C. carcharias* population.

## MATERIAL AND METHODS

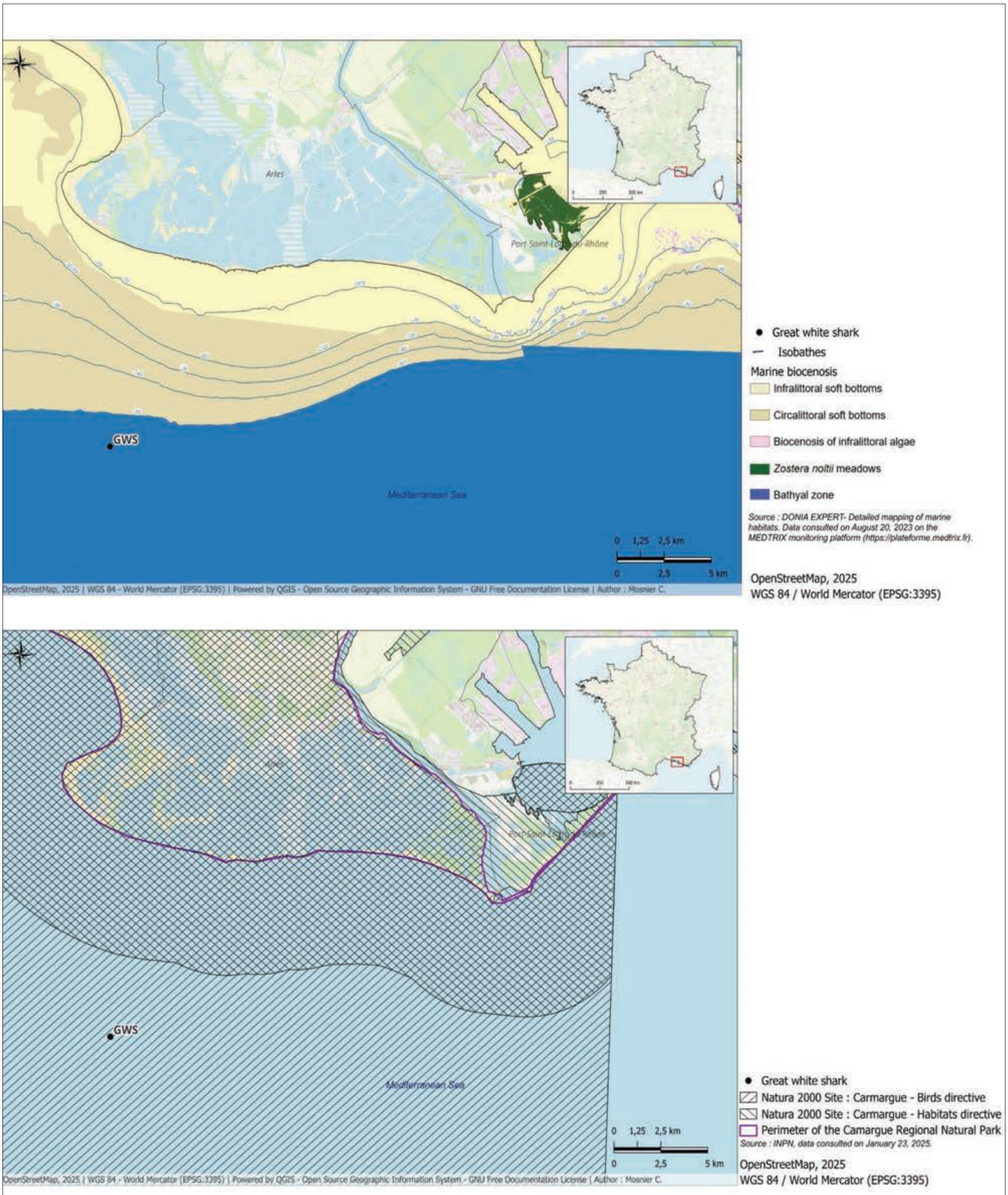
The data presented here concerns a large shark sighted by three anglers in Camargue waters (NW Mediterranean), recorded on video and reported to the Groupe Phocéen d'Étude des Requins (GPER), Marseille, France, along with all sighting details and precise GPS coordinates. No GPER researchers were on board. The animal was observed on September 22, 2022, at 8 AM (GMT+1), 6 NM from the coast (43°16′05.6 "N 4°35′04.1 "E), using the Beauduc lighthouse as a reference. None of the three anglers were fishing, and no bait was in the water. No other boats were in the observation area at the time, according to the sighters. The boat was cruising at moderate speed when it came across the large shark, which surfaced at the same time. With the boat stopped, the shark turned for five minutes at a distance of 10 m before diving towards the coast in the direction of the Parc Naturel Régional de Camargue (PNRC). The observers reported to the GPER, Marseille, France an estimated total length (TL) of the shark exceeding 500 cm when the tip of the animal's snout was at bow level when swimming parallel to the boat. It was a 683 cm long recreational fishing vessel BOSTON WHALER 220 OUTRAGE. The sky was clear at sunrise, the sea was calm, and visibility was good. The surface water temperature was 25 °C. The animal circled the boat during five minutes before disappearing, swimming 10 m below the surface. A juvenile swordfish *X. gladius* was observed in the area just before the shark appeared to the surface near the vessel. The boat's depth sounder detected numerous large fish. It swims in the direction of the coastal area of the PNRC (Fig. 1).

## RESULTS

The large shark was estimated to measure between 500 cm and 600 cm in total length (TL). According to the reported observations (Fig. 2) the individual has a massive, fusiform body with a dark grey dorsal coloration, interspersed with shades of brown, sharply contrasting with its marked white belly. The pectoral fins are large and curved (Figs. 2B, C). The left gill area is wide but bare, lacking protective tegument (Figs. 2A, B). The first dorsal fin is large, triangular, and curved backward (Figs. 2D, E, F). Its posterior margin is clearly concave (Fig. 2F). The absence of claspers was also noted (Fig. 2F). The large, sighted shark has thus been identified as an adult female great white shark (GWS) (Ebert & Dando, 2020; Barone *et al.*, 2022).

## DISCUSSION AND CONCLUSIONS

We identified an adult female great white shark *Carcharodon carcharias* "GWS", estimated to be between 500 cm and 600 cm in total length



Source : DONIA EXPERT- Detailed mapping of marine habitats. Data consulted on August 20, 2023 on the MEDTRIX monitoring platform (https://plateforme.medtrix.fr).

OpenStreetMap, 2025 | WGS 84 - World Mercator (EPSG:3395) | Powered by QGIS - Open Source Geographic Information System - GNU Free Documentation License | Author : Mosnier C.

OpenStreetMap, 2025
WGS 84 / World Mercator (EPSG:3395)

Source : INPN, data consulted on January 23, 2025.

OpenStreetMap, 2025 | WGS 84 - World Mercator (EPSG:3395) | Powered by QGIS - Open Source Geographic Information System - GNU Free Documentation License | Author : Mosnier C.

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***Fig. 1: Geolocation of the shark in Camargue waters. Seabed composition off coastal areas (above). Identification of Natura 2000 protected sites (below).***
***Sl. 1: Geolokacija morskega volka v vodah okoli Camargua. Sestava morskega dna ob obalnih območjih (zgoraj). Identifikacija zavarovanih območij Natura 2000 (spodaj).***

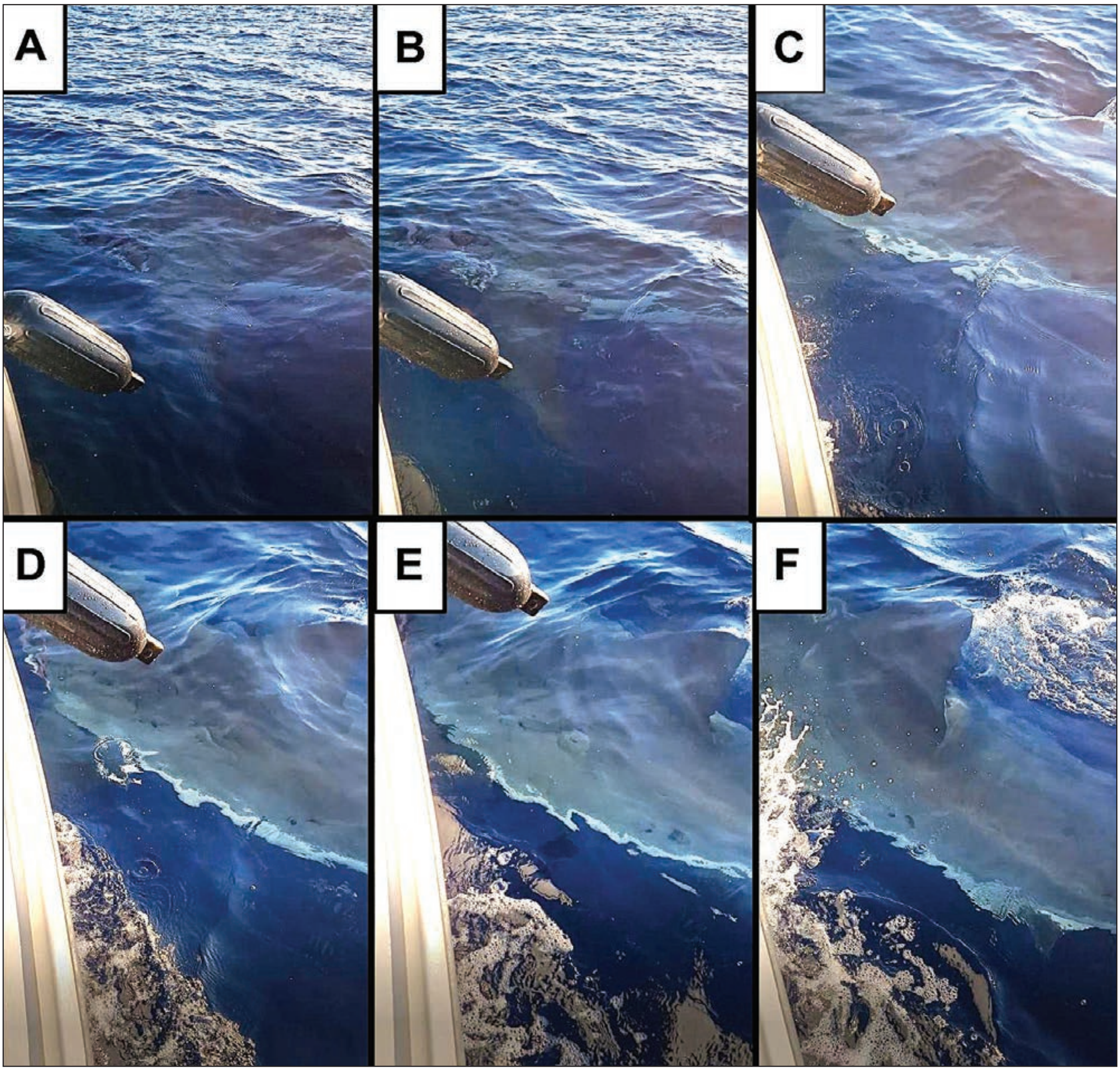

***Fig. 2. Species identification of the great white shark (GWS). The visible absence of claspers confirms it is a female (F).***
***Sl. 2: Identifikacija vrste velikega belega morskega volka (GWS). Vidna odsotnost klasperjev potrjuje, da gre za samico (F).***

(TL). The shark was observed swimming along the continental shelf (Fig.1). Furthermore, the shark was geolocated swimming in the direction of the coastal areas of the Rhone Delta (Fig. 1), the wildest most protected and most nutrient-rich area of the PNRC in terms of alluvial discharge (Monaco *et al.*, 2009; Parc National Regional de Camargue, 2012).

We noted numerous deep and well-defined lesions all over the body of GWS (Figs. 2, 3). The shape of these lesions suggests injuries due to bites by a large macropredatory shark that have wide homodont jaws and large sharp teeth, given their well-defined elliptical shape (Fig. 3), exhibiting bite marks on its flank and on its left ventral area (Figs. 2, 3A, B, C, D). Notably, the left gills appeared to be devoured (Figs. 2A, B, D, 3E). The most plausible explanation for these observations is that another adult conspecific repeatedly bit or gripped the gills with its jaws.

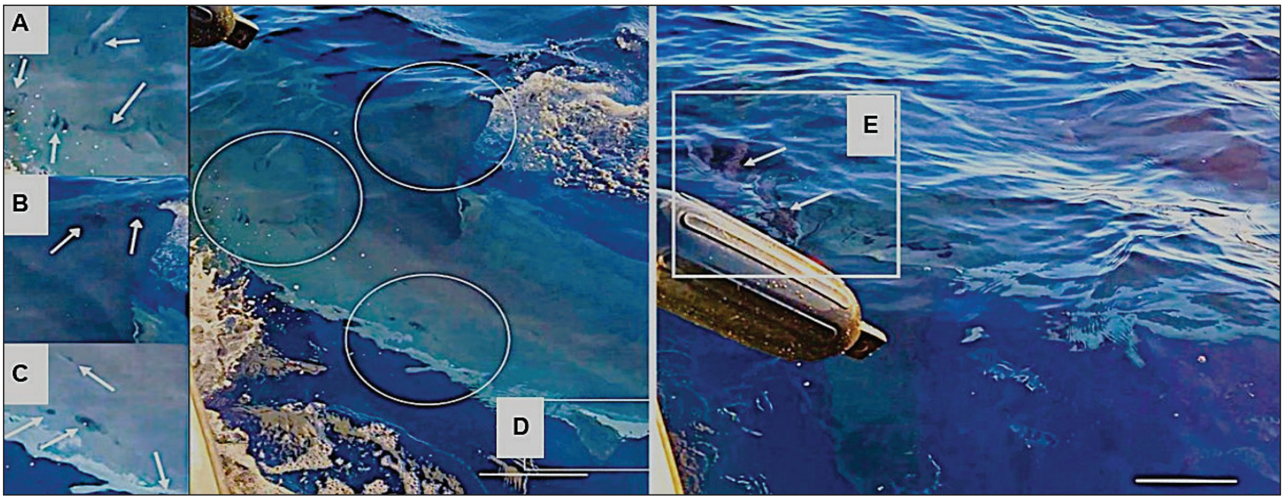

***Fig. 3. Presence of large elliptic and deep isolated lesions (white arrows) visible on the left flank (Figs. 3A, B, C, D) of GWS. Damaged first dorsal fin (Fig. 3B). Fig. 3E: Focus on the devoured GWS's left gills. Scale bar indicates 40 cm.***

***Sl. 3: Prisotnost velikih eliptičnih in globokih izoliranih poškodb (bele puščice), vidnih na levem boku (slike 3A, B, C, D) samice. Poškodovana prva hrbtna plavut (slika 3B). Slika 3E: Osredotočite se na požrte leve škrge samice. Merilna vrstica kaže 40 cm.***

The presence of these fresh, non-healing bite scars further supports the hypothesis that these wounds were sustained recently. These bite marks were observed in late September, a period that coincides with the breeding season for the species in the Mediterranean (De Maddalena & Heim, 2012; Boldrocchi *et al.*, 2017). These bite marks are consistent with the so-called "love bites" or «mating scars» observed in other shark species during copulation attempts (Celona *et al.*, 2005; Ritter & Amin, 2018; De Maddalena *et al.*, 2023; Rangel *et al.*, 2023; Barry *et al.*, 2025). Thus, one adult male conspecific grips the body of a female to permit the copulation (Pratt & Carrier, 2001; Hibbit *et al.*, 2017; Santos *et al.*, 2022). Some of the bites can be inflicted by the male on or around the ventral area of the female's cloaca (Rangel *et al.*, 2023). These are suggested to stimulate the ovulation before the copulation in macropredatory sharks (Rangel *et al.*, 2023). During the copulation the male penetrates and inseminates the female by the cloaca using only single one erected of its two claspers (Pratt & Carrier, 2001; Hibbit *et al.*, 2017; Santos *et al.*, 2022). At the end of mating, the male releases the female from his jaws. This is the post-copulatory state for the female.

September aligns with the peak of adult great white shark occurrence in the Mediterranean (Boldrocchi *et al.*, 2017). This suggests that the wounds may be indicative of a recent mating event. The observation of bite marks serves not only as an indicator of reproductive behaviour but also offers an opportunity to better understand the timing of mating events through the study of skin regeneration and healing patterns (Borucinska *et al.*, 2020).

A large proportion of the GWS female's tissues are damaged (Figs. 2A, B, 3E). Its presence swimming close to the PNRC may be explained by a potential foraging behaviour after a possible post copulatory state. Late September in the Rhone Delta is the peak productivity period of the year in the Gulf of Lion (Monaco *et al.*, 2009). The PNRC serves as nursery, foraging and breeding site for many marine species (Parc Naturel Régional de Camargue, 2012). The favorite preys of the Mediterranean great whites: *T. thynnus*, *X. gladius* and the Delphinidae are mainly abundant at the end of summer in the area (Fromentin & Lopuzanski, 2014; Di-Méglio *et al.*, 2015; Rouyer *et al.*, 2021). This late September 2022, a high abundance of juvenile bluefin tunas were present throughout the Gulf of Lion, notably in the Gulf of Aigues-Mortes (France Bleu Gard Lozère, 2022). The presence of Mediterranean *C. carcharias* is highly correlated with that of *T. thynnus* (Boldrocchi *et al.*, 2017).

The Gulf of Lion may also constitute a key area for the foraging of the species in late summer due to its high productivity (Monaco *et al.*, 2009; Roos, 2012; Stambler, 2013; Strady *et al.*, 2015) and high prey abundance (De Maddalena & Heim, 2012; Rouyer *et al.*, 2021).

This study presents the first footage from the Mediterranean of an adult female *C. carcharias* with possible «mating scars» or so-called «love bites» as the bite marks caused during pre-copulation. Such mating scars are critical for understanding the reproductive dynamics of the species (Rangel *et al.* 2023, Barry *et al.*, 2025). Future observations will be crucial in confirming our preliminary hypotheses. Firstly, the sighting of other females with obvious bites from the ventral pelvic region to the cloacal region would support our hypothesis that the Northwestern Mediterranean could be a mating site for *C. carcharias*. Then, the coastal waters of the Gulf of Lion could be feeding grounds for females in their post-copulatory state.

Given the critically endangered status of the Mediterranean great white shark and the pressure they face from fishing, a deeper understanding of the species' life history is essential to ensuring their conservation. Our study also higlights the value of citizen as a tool for uncovering new, albeit preliminary, knowledge to improve protection of such large elusive critically endangered species.

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# SLEDOVI UGRIZOV NA VELIKI SAMICI BELEGA MORSKEGA VOLKA *CARCHARODON CARCHARIAS* PRI CAMARGU (FRANCIJA) KAŽEJO NA MOŽNO RAZMNOŽEVANJE SREDOZEMSKE POPULACIJE

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## *POVZETEK*

*Ekologija belega morskega volka (*Carcharodon carcharias*) v Sredozemskem morju kljub vlogi te vrste kot največjega plenilca v regiji ostaja slabo poznana zaradi njegove redkosti in upada populacije. Septembra 2022 so avtorji popisali primer redke odrasle samice z izrazitimi sledovi ugrizov ob obali Camargue. Od pomladi do jeseni se v Lyonskem zalivu, zlasti v vodah okoli zavarovanega območja Parc Naturel Régional de Camargue, znatno poveča biodiverziteta. Na podlagi lastnih opazovanj domnevajo, da bi lahko ta regija pozno poleti služila kot pomembno prehranjevalno okolje za samice belega morskega volka po kopulaciji.*

**Ključne besede:** beli morski volk, Lyonski zaliv, razmnoževanje, sledovi ugrizov, varovanje

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# MORPHOLOGICAL DEFORMITIES IN A COMMON TWO-BANDED SEA BREAM, *DIPLODUS VULGARIS* (OSTEICHTHYES: SPARIDAE), FROM NORTHERN TUNISIAN WATERS (CENTRAL MEDITERRANEAN SEA)

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## *ABSTRACT*

*In a sample of common two-banded sea bream,* Diplodus vulgaris*, collected from the northern coast of Tunisia, one specimen displayed abnormal morphology. This individual presented a prominently developed upper margin, arched into a hump, a pointed upper head profile, and a strongly curved lateral line. X-ray imaging revealed abnormal curvatures in the vertebral column, such as hyperkyphosis and lordosis. A length-weight relationship analysis based on 49 normal specimens and the abnormal specimen showed a slightly negative allometry, suggesting that such specimens are capable of living alongside normal population in the wild.*

**Key words:** *Diplodus vulgaris*, hyperkyphosis, lordosis, environmental pollution, length-weight

# DEFORMAZIONI MORFOLOGICHE IN SARAGO COMUNE, *DIPLODUS VULGARIS* (OSTEICHTHYES: SPARIDAE), PROVENIENTE DALLE ACQUE DELLA TUNISIA SETTENTRIONALE (MEDITERRANEO CENTRALE)

## *SINTESI*

*In un campione di sarago comune,* Diplodus vulgaris*, pescato lungo la costa settentrionale della Tunisia, un esemplare presentava una morfologia anomala. Questo pesce esibiva un margine superiore molto sviluppato, arcuato in una gobba, un profilo superiore della testa appuntito e una linea laterale fortemente incurvata. Le immagini radiografiche hanno rivelato curvature anomale della colonna vertebrale, come ipercifosi e lordosi. Un'analisi del rapporto lunghezza-peso basata su 49 esemplari normali e sull'esemplare anormale ha mostrato un'allometria leggermente negativa, suggerendo che questi esemplari sono in grado di vivere insieme alla popolazione normale in natura.*

**Parole chiave:** *Diplodus vulgaris*, ipercifosi, lordosi, inquinamento ambientale, lunghezza-peso

## INTRODUCTION

The common two-banded sea bream *Diplodus vulgaris* (E. Geoffroy Saint-Hilaire, 1817) inhabits the eastern Atlantic from Brittany and the Bay of Biscay to northern Spain and Portugal (Quéro *et al.*, 2003). South of the Strait of Gibraltar, the species is widely distributed from the coast of Morocco to Angola and South Africa, including the archipelagos of Madeira (Wirtz *et al.*, 2008), the Canary Islands (Bauchot & Hureau, 1990), and Cape Verde (Wirtz *et al.*, 2013). *D. vulgaris* is caught throughout the Mediterranean Sea and has also been recorded in the Black Sea, off the Bulgarian coast (Bauchot & Hureau, 1986).

*D. vulgaris* is one of the 21 sparid species of commercial value that are commonly caught along the entire Tunisian coast. It is is particularly abundant in the Gulf of Gabès, where it has been the subject of several studies (Bradaï, 2000; Hadj Taïeb, 2012). The species is also found in northern areas such as the Gulf of Tunis, where its age structure and growth rates have been studied by Mouine *et al.* (2010).

Investigations conducted in northern Tunisia over the two decades since 2000 – initially focused on elasmobranch species (El Kamel et *al.*, 2009a,b) and later encompassing all fish species (Rafrafi-Nouira, 2016) – led to the collection of multiple *D. vulgaris* specimens. One individual among them displayed morphological deformities involving both external (body shape, lateral line) and internal anatomical features.

Comprehensive published scientific references on abnormalities in teleost species document no recorded cases of morphological anomalies in *D. vulgaris* (see Dawson, 1964, 1966, 1971; Dawson & Heal 1971; Dulčić & Soldo, 2005; Jawad *et al.*, 2010; Jawad & Ibrahim, 2018). This paper describes an abnormal specimen and suggests potential causes of similar abnormalities observed in other teleost species.

## MATERIAL AND METHODS

Between 2016 and 2023, a total of 50 specimens of *D. vulgaris* were collected, along with other sparid and labrid species (Fig. 1), using commercial gill-nets with a 26 mm stretched mesh size, on sandy substrates off Ras Jebel, northern Tunisia (37°14′57.53″ N, 10°11′52.85″ E). Three fresh specimens – including one abnormal and two normal ones – were measured for total length (TL) to the nearest centimetre and total body weight (TBW) to the nearest decigram. Morphometric measurements and meristic counts were performed following Tortonese (1975), Bauchot & Hureau (1986), and Quéro *et al.* (2003), with the results summarised in Table 1. The three specimens were then fixed in 10% buffered formalin, preserved in 75%

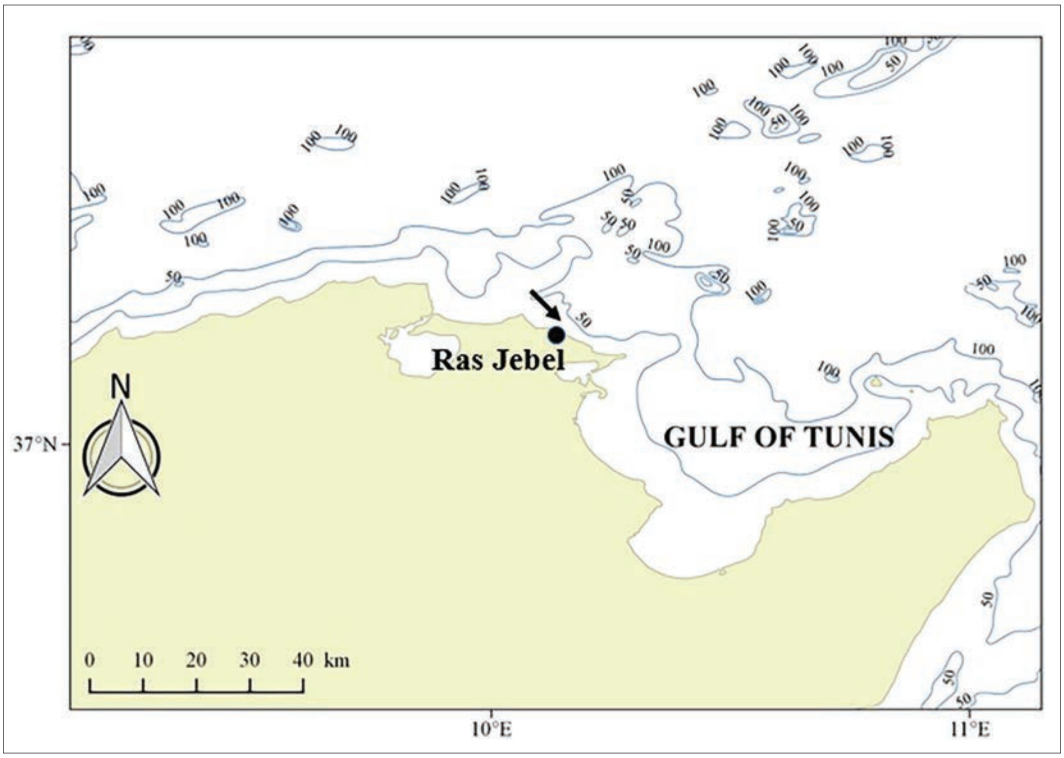

***Fig. 1: Map of northern Tunisia indicating the capture sites of* D. vulgaris *(black arrow).***
***Sl. 1: Zemljevid severne Tunizije z označeno lokaliteto ulova vrste* D. vulgaris *(črna puščica).***

***Tab. 1: Morphometric measurements (expressed as percentages of standard length, %SL), meristic counts, and total body weight (in grams) recorded from the three*** *D. vulgaris* ***specimens collected off the northern Tunisian coast: one abnormal specimen (ISPAB-Dipl vul 01) and two normal specimens (ISPAB-Dipl vul 02 and ISPAB-Dipl vul 03).***
***Tab. 1: Morfometrične meritve (izražene kot odstotki standardne dolžine, %SL), meristična štetja in skupna telesna teža (v gramih), zabeležene pri treh primerkih vrste*** *D. vulgaris****, zbranih ob severni tunizijski obali: enem nenormalnem vzorcu (ISPAB-Dipl vul 01) in dveh normalnih vzorcih (ISPAB-Dipl vul 02 in ISPAB-Dipl vul 03).***

| **References** | **ISPAB-Dip-vul 01** | | **ISPAB-Dip-vul 02** | | **ISPAB--Dip-vul 03** | |
|---|---|---|---|---|---|---|
| **Condition** | **Abnormal** | | **Normal** | | **Normal** | |
| **Morphometric measurements** | mm | %SL | mm | %SL | mm | %SL |
| Total length | 108 | 131.0 | 107 | 120.2 | 115 | 129.2 |
| Fork length | 91 | 110.0 | 98 | 110.1 | 98 | 110.1 |
| Standard length | 82 | 100.0 | 89 | 100.0 | 89 | 100.0 |
| Head length | 31 | 37.4 | 26 | 29.5 | 28 | 31.0 |
| Eye diameter | 10 | 12.2 | 9 | 10.3 | 9 | 10.1 |
| Pre-orbital length | 12 | 14.1 | 11 | 11.9 | 10 | 11.3 |
| Post-orbital length | 11 | 13.1 | 11 | 11.9 | 11 | 12.7 |
| Dorsal fin length | 43 | 51.9 | 40 | 45.2 | 46 | 52.0 |
| Pectoral fin length | 9 | 10.6 | 6 | 7.3 | 7 | 8.0 |
| Pelvic fin length | 8 | 10.0 | 7 | 7.6 | 7 | 7.6 |
| Anal fin length | 19 | 23.5 | 20 | 22.9 | 22 | 25.2 |
| Caudal fin length | 12 | 14.4 | 9 | 10.3 | 10 | 11.7 |
| Snout length | 10 | 12.7 | 9 | 10.3 | 10 | 11.4 |
| Body height | 51 | 62.4 | 40 | 45.3 | 43 | 47.9 |
| Pre-dorsal fin length | 39 | 47.0 | 38 | 43.1 | 38 | 42.9 |
| Pre-pectoral fin length | 32 | 39.3 | 29 | 32.5 | 30 | 33.9 |
| Pre-pelvic fin length | 37 | 45.4 | 38 | 42.7 | 39 | 43.9 |
| Pre-anal fin length | 62 | 75.2 | 59 | 66.4 | 59 | 66.0 |
| Length of the longest spine of the pectoral fin | 36 | 43.1 | 30 | 33.8 | 43 | 48.2 |
| Thickness | 18 | 22.0 | 15 | 16.4 | 16 | 17.7 |
| **Meristic counts** | | | | | | |
| Vertebral number | 45 | | 26 | | 26 | |
| Lateral line scales | 65 | | 60 | | 60 | |
| Dorsal fin rays | XII+14 | | XI+14 | | XI+14 | |
| Pectoral fin rays | 15 | | 15 | | 15 | |
| Pelvic fin rays | I+5 | | I+5 | | I+5 | |
| Anal fin rays | III+14 | | III+13 | | III+13 | |
| Caudal fin rays | 20 | | 20 | | 20 | |
| **Weight (g)** | 32.06 | | 21.08 | | 23.93 | |

formaldehyde, and deposited in the Ichthyological Collection of the Institut Supérieur de Pêche et d'Aquaculture de Bizerte (Tunisia) under catalogue numbers ISPAB-Dipl vul 01 for the abnormal specimen, and ISPAB-Dipl vul 02 and ISPAB-Dipl vul 03 for the two normal specimens. The vertebral column anomalies in the abnormal specimen were identified following descriptions provided by Elie & Girard (2014) and Jawad & Ibrahim (2018), which include scoliosis (lateral curvature), lordosis (ventral curvature), kyphosis (dorsal curvature), and ankylosis (fusion of vertebrae) – conditions reported in many wild and cultured fish species. Additionally, three regions were considered, partially following Louiz *et al.* (2007): the anterior or cephalic region, the intermediate or abdominal region, and the terminal or caudal region.

A *t*-test was performed to compare lateral line scale and vertebral counts between the abnormal *D. vulgaris* specimen and normal conspecifics. The total length (TL) to total body weight (TBW) ratio, analysed in all three specimens, was used as a baseline for assessing whether the abnormal specimen could develop in the wild similarly to normal individuals, following Froese *et al.* (2011). This length-weight relationship (LWR) was modelled as $TBW = aTL^b$ and log-transformed to its linear form: $\log TBW = \log a + b \log TL$. Correlations were estimated via least-squares regression. The scaling coefficient $b$ was tested against the null hypothesis of isometric growth ($b = 3$), with $b > 3$ indicating positive allometry and $b < 3$ indicating negative allometry (Pauly, 1983). Analyses were conducted in StatView 5.0.

## RESULTS AND DISCUSSION

The collected specimens were identified as *D. vulgaris* through a combination of key morphological characters: body ovoid and compressed; snout conical and pointed; lips rather thick; scales present on cheek and opercle; preopercle broad, scaleless; base silver-grey coloration with two prominent black bands (one from nape to pectoral fin axil and upper margin of opercle, another across the caudal peduncle overlapping posterior anal and dorsal fin bases), caudal fin dark with black external margin (Fig. 2).

The abnormal specimen exhibited a prominently developed upper margin, arched into a hump, a pointed upper head profile, and a strongly curved lateral line. The caudal peduncle was also curved, with both lobes more developed than those typically observed in normal specimens (Fig. 2).

X-ray imaging revealed four distinct vertebral column deformities in the abnormal specimen. At the level of the abdominal region, the vertebral column is markedly arched, forming two areas of hyperkyphosis separated by a more pronounced lordosis (Fig. 3). In the caudal peduncle region, a second, less developed and less severe lordosis is observed. No signs of scoliosis were detected in the abnormal specimen.

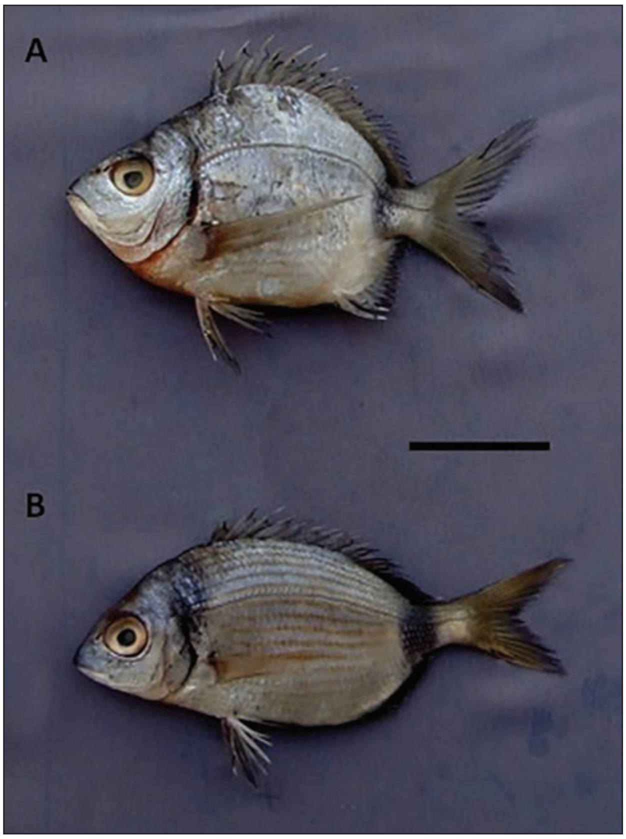

***Fig. 2:*** *D. vulgaris* ***specimens from the northern Tunisian coast. A: Abnormal specimen (ISPAB-Dipl vul 01); B: Normal specimen (ISPAB-Dipl vul 02). Scale bar = 30 mm.***

**Sl. 2: Primerki vrste** *D. vulgaris* **iz severne tunizijske obale. A: Nenormalen primerek (ISPAB-Dipl vul 01); B: Normalen primerek (ISPAB-Dipl vul 02). Merilo = 30 mm.**

The number of lateral line scales in the abnormal specimen was 65, significantly higher than in the normal specimens (which had 60; *t*-test = 37, df = 1, $p < 0.03$). In Bauchot & Hureau (1986), this number ranged from 59 to 65. Similarly, the number of vertebrae in the abnormal specimen – 45 – was significantly higher than the 26 in the normal specimens (*t*-test = 37, df = 1, $p < 0.01$). Such differences in the number of scales and vertebrae between normal and abnormal specimens are likely attributable to the curvature of the lateral line and the deformities of the vertebral column. The elevated vertebral count also suggests that the vertebrae are not fused (no ankylosis).

The general morphology of the abnormal specimen and the deformation of the lateral line can be considered primary consequences of the vertebral column malformation, which in this case includes both hyperkyphosis and lordosis. Such abnormalities are frequently reported in the ichthyological literature (see Dawson, 1964, 1966, 1971; Dawson & Heal 1971; Jawad & Ibrahim,

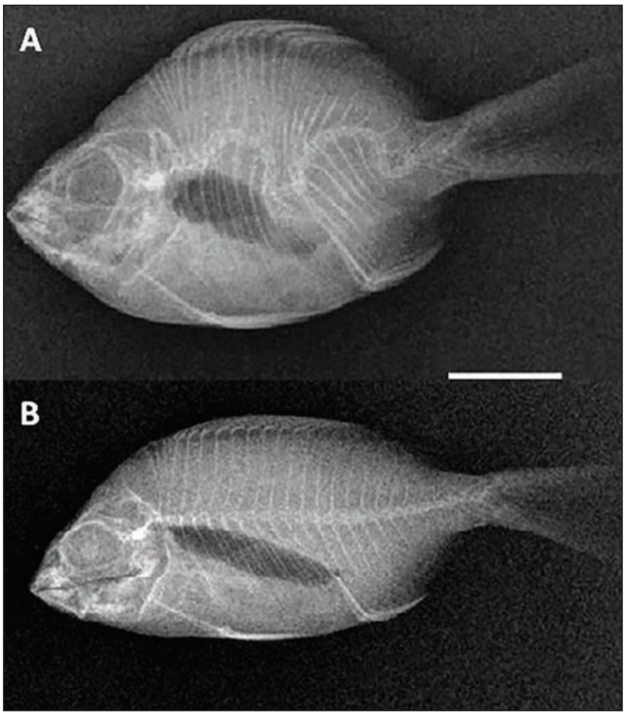

***Fig. 3: X-ray images of** D. vulgaris **from the northern Tunisian coast. A: Abnormal specimen (ISPAB-Dipl vul 01); B: Normal specimen (ISPAB-Dipl vul 02). Scale bar = 30 mm.***
***Sl. 3: Rentgenske slike primerkov vrste** D. vulgaris **s severne tunizijske obale. A: Nenormalen primerek (ISPAB-Dipl vul 01); B: Normalen primerek (ISPAB-Dipl vul 02). Merilo = 30 mm.***

2018; Jawad & Akyol, 2023).

However, the observed deformities did not appear to impair the survival of the abnormal specimen in the wild, as it exhibited growth comparable to that of normal specimens from the same size class. This is supported by the total length (TL) to total body weight (TBW, in g) relationship shown in Fig. 4: log TBW = -4.733 + 2.953 * log TL; r = 0.990, indicating a slight negative allometry. While Matsuoka (1987) and Boglione *et al.* (2006) reported lethal effects of severe skeletal deformities in teleost species living in natural environments, other studies – including Khenfech *et al.* (2011) on the annular sea bream *Diplodus annularis* (Linnaeus, 1758) from the Lagoon of Bizerte, and Rafrafi-Nouira *et al.* (2019, 2021) on other sparid species, such as the striped sea bream *Lithognathus mormyrus* (Linnaeus, 1758) and the saddled bream *Oblada melanura* (Linnaeus, 1758), captured off Ras Jebel – showed that deformed specimens can coexist in the wild alongside normal conspecifics.

Abnormalities in fish species occur during the early stages of development and may have a genetic origin. However, mechanical causes from capture and/or handling cannot be entirely ruled out either. For instance, specimens entangled in gillnets may successfully escape, but often experience morphological deformities and distortion in the normal vertebral shape, leading to the remodelling of the vertebral column due to extrinsic forces (Jawad & Ibrahim, 2018). Additionally, these deformities could even indicate unfavourable environmental conditions, the presence of pollutants, or other stressors in the wild (Sfakianakis *et al.*, 2004). In fact, several cases of abnormalities have been documented in animal species collected from the Lagoon of Bizerte, a restricted brackish area polluted by both inorganic and organic nutrients, and heavy metals (Mzoughi *et al.*, 2002).

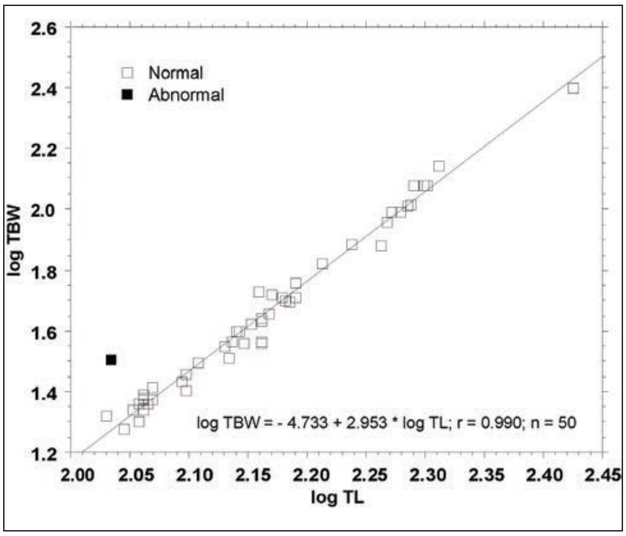

***Fig. 4: Total length (TL) to total body weight (TBW) relationship, expressed in logarithmic coordinates, for** D. vulgaris **specimens collected off the northern Tunisian coast.***
***Sl. 4: Odnos med totalno dolžino (TL) in celokupno telesno maso (TBW), izraženo z logaritemskimi koordinatami za primerke vrste** D. vulgaris**, ujete ob severni tunizijski obali***

Global warming of marine waters worldwide may also contribute to skeletal deformities in fish (Jawad & Ibrahim, 2018). The Mediterranean Basin has faced this escalating problem for at least two decades (Ben Raïs Lasram & Mouillot, 2009), with the rising sea temperatures attracting alien species from the Red Sea (through the Suez Canal) and the eastern tropical Atlantic (through the Strait of Gibraltar). Such species have been increasingly encroaching on Tunisia's northern coast and reports of skeletal abnormalities in fish have become more frequent in this region than previously documented (Rafrafi-Nouira, 2016). However, thorough investigations – coupled with environmental monitoring – are still needed to clarify the local roles of pollutants and temperature in these deformities (Rafrafi-Nouira, 2016, 2019).

# MORFOLOŠKE DEFORMACIJE PRI FRATRU, *DIPLODUS VULGARIS* (OSTEICHTHYES: SPARIDAE), IZ SEVERNIH TUNIZIJSKIH VOD (OSREDNJE SREDOZEMSKO MORJE)

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## *POVZETEK*

*V vzorcu fratrov,* Diplodus vulgaris*, zbranih s severne obale Tunizije, je bila pri enemu primerku očitna nenormalna morfologija. Ta primerek je imel vidno razvit zgornji rob, usločen v grbo, koničast zgornji profil glave in močno ukrivljeno pobočnico. Rentgensko slikanje je pokazalo nenormalne ukrivljenosti v hrbtenici, kot sta hiperkifoza in lordoza. Analiza dolžinsko-masnega razmerja na 49 normalnih osebkih in nenormalnem osebku, je pokazala rahlo negativno alometrijo, kar nakazuje, da so takšni osebki sposobni živeti skupaj z normalno populacijo v naravi.*

**Ključne besede:** *Diplodus vulgaris*, hiperkifoza, lordoza, okoljsko onesnaževanje, dolžinsko-masni odnos

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# THE CURRENT STATUS OF *POLITITAPES AUREUS* (MOLLUSCA: BIVALVIA) IN THE COASTAL ZONE OF SFAX, TUNISIA (CENTRAL MEDITERRANEAN)

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## *ABSTRACT*

*The clam* Polititapes aureus *is one of the most abundant shellfish species in southern Tunisian waters. Its potential future commercial value is key resource for artisanal fisheries. This study was conducted to assess stocks and develop a management plan for natural clam populations along the Sfax coast. The results revealed significant density fluctuations across the study area, which was divided into six main sites, with stock density ranging from 0 to 6 ind.m$^{-2}$ and biomass values varying between 0 and 41 g.m$^{-2}$. Total biomass reached 70.1 tons, with an abundance exceeding 16.58 million individuals across 3,867 hectares. Sampled individuals measured between 3 and 32.9 mm in size. Key environmental factors were identified, with several abiotic parameters found to have a significant impact on the distribution of clam species. Conservation guidelines are proposed to restore its stocks to sustainable levels.*

**Key words**: bivalve, *Polititapes aureus*, stock assessment, distribution, size structure, South Tunisia

# STATO ATTUALE DI *POLITITAPES AUREUS* (MOLLUSCA: BIVALVIA) NELLA ZONA COSTIERA DI SFAX, TUNISIA (MEDITERRANEO CENTRALE)

## *SINTESI*

*La vongola gialla* Polititapes aureus *è una delle specie di molluschi più abbondanti nelle acque della Tunisia meridionale. Il suo potenziale valore commerciale futuro è una risorsa chiave per la pesca artigianale. Questo studio è stato condotto per valutare gli stock e sviluppare un piano di gestione delle popolazioni di vongole lungo la costa di Sfax. I risultati hanno rivelato significative fluttuazioni di densità in tutta l'area di studio, che è stata suddivisa in sei siti principali, con una densità di stock che varia da 0 a 6 ind.m$^{-2}$ e valori di biomassa che variano tra 0 e 41 g.m$^{-2}$. La biomassa totale ha raggiunto 70,1 tonnellate, con un'abbondanza superiore a 16,58 milioni di individui su 3.867 ettari. Sono stati identificati i fattori ambientali chiave che hanno un impatto significativo sulla distribuzione delle specie di vongole e proposte linee guida di conservazione per riportare gli stock a livelli sostenibili.*

**Parole chiave:** bivalvi, *Polititapes aureus*, valutazione degli stock, distribuzione, struttura dimensionale, Tunisia meridionale

## INTRODUCTION

The clam *Polititapes aureus* (syn. *Venerupis aurea*, Gmelin 1971) is a Mediterranean endemic species that is widely distributed throughout western Europe (World Register of Marine Species). It is the most common marine mollusk species inhabiting the intertidal zones of the southern Tunisian coast, particularly the vast mudflats and sandy beaches that provide optimal habitat for infaunal bivalves (Ben Salem *et al.*, 2002). This species is commonly found in sandy to silty-sandy sediments, inhabiting estuaries, bays, and coastal lagoons from mid-tidal to shallow subtidal zones (Derbali, 2024). Due to its economic importance, *P. aureus* has attracted significant research interest, particularly in regions of high abundance, such as Egypt (Kandeel, 2013, 2018; Fouda & Abou-Zied, 1990).

In Tunisia, fishery represents a vital socio-economic activity, particularly for rural and disadvantaged communities, and especially those reliant on clam harvesting (Ben Mohamed & Derbali, 2024). Since 2017, however, a gradual stock depletion has been observed. The decline has been attributed to pollution, deterioration of water quality, climate change impacts, and inadequate fishing practices targeting the clam *Ruditapes decussatus* (Linnaeus 1758) - a species heavily exploited from wild populations (Gharbi *et al.*, 2023). Unfortunately, the most biologically productive coastal zones coincide with areas of significant industrial activity (Ben Mohamed & Derbali, 2024).

To prevent further stock depletion and ensure the sustainability of the sector, Tunisian authorities have established a comprehensive institutional and regulatory framework aligned with international standards. They also oversee and regularly monitor the harvest season and have launched several development projects.

Therefore, future exploitation should be carefully planned, starting with a thorough study on *P. aureus* in the present study area. Several studies have been conducted on its reproductive biology and growth in southern Tunisian waters (Derbali, 2022, 2024). Although stock assessment is essential for understanding dynamics, as well as for the management and conservation of marine bivalve populations, only one study has specifically examined *P. aureus* populations to date (Derbali & Jarboui, 2021). The present study therefore aims to update existing information and provide new data on the current status of *P. aureus* along the Sfax coast, focusing on population structure, geographical distribution, and stock size in relation to specific abiotic factors.

## MATERIAL AND METHODS

### Study area

The Sfax region, encompassing southern Tunisia and the northern part of the Gulf of Gabes, extends along 135 km (Fig. 1). The continental shelves are wide and shallow, with a topographically regular structure (Ben Othman, 1973). Substrates consist primarily of muddy sand, some of which are covered by the seagrasses *Cymodocea nodosa* (Ucria) Ascherson and *Nanozostera noltei* (Hornemann) Tomlinson & Posluszny. The gently sloping seabed reaches a depth of 60 m approximately 110 km offshore (Ben Othman, 1973). The intertidal zone is an important source of natural resources for both professional and recreational fishers. This extensive intertidal sand and mudflat zone is heavily utilized for clam harvesting activities, primarily targeting *R. decussatus*.

### Field sampling

Field sampling was conducted over a two-year period (2021–2022) in the coastal zone of Sfax (southern Tunisia). The study area was divided into six distinct sampling sites based on clam distribution (Fig. 1). Transects were surveyed during low tide across the sampling area. Samples were collected at 50-meter intervals along each transect line, from extreme high tide to extreme low tide marks. Along the transects, 4–10 replicates were taken using 0.25 m² quadrats and a shovel. The collected specimens were immediately fixed in a 7% formaldehyde solution and subsequently transferred to the laboratory for analysis.

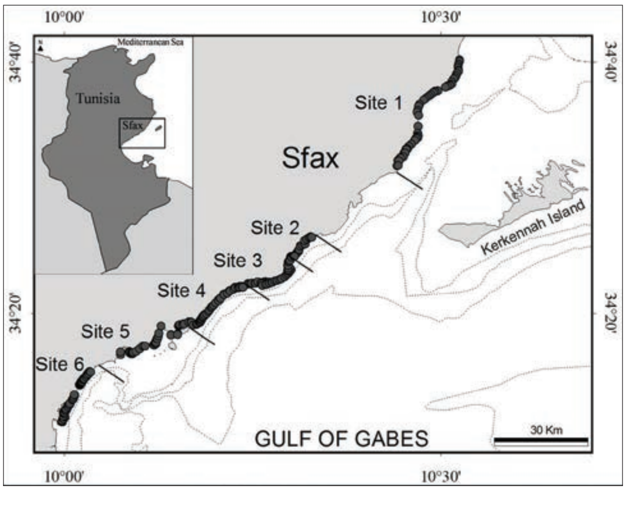

***Fig. 1: Geographic position of sampling transects in southern Tunisia.***
***Sl. 1: Geografski položaj vzorčevalnih transektov v južni Tuniziji.***

Seawater temperature and salinity were measured near the seabed immediately after sampling, using a Multi 340i SET multi-parameter kit. To enhance the research on clam distribution patterns, specific interactions between abiotic and biotic factors affecting *P. aureus* spatial distribution were investigated through sediment granulometry. Sediment samples from each site, collected at a depth of 5 cm, were treated with $H_2O_2$, oven-dried at 40°C, and sieved (2 mm to 63 µm) using AFNOR mesh-type sieves, with grain size classification following Shepard (1954).

### Data analysis

In the laboratory, shell length (SL, mm; maximum anteroposterior distance considered as reference length), shell height (SH, mm; maximum hinge-to-ventral margin distance ), and shell width (SW, mm; maximum distance between closed valves) were measured with a digital caliper and recorded to the nearest 0.01 mm. Total fresh weight (TW) was determined with a top-loading digital balance (precision of 0.001 g). The dataset was pooled to calculate mean density (ind. $m^{-2}$) and biomass (g $m^{-2}$) for each site. Spatial distributions were mapped using ArcGIS 10.8. Stocks were assessed using the Gulland (1969) equation: $Bi = Ni \times Ai/ai \times 1/Xi$, where $Bi$ represents total clam biomass, $Ni$ is the mean abundance across all quadrat samples per site, $Ai$ is site area surface, $ai$ is quadrat swept area, and $Xi$ is the proportion retained.

***Tab. 1: Sediment type recorded in all prospected sites (southern Tunisia).***
***Tab. 1: Tip sedimenta na raziskovanih lokalitetah (južna Tunizija).***

| Sites | %Gravel | %Sand | % Silt/clay |
|---|---|---|---|
| Site 1 | 1.42 | 97.21 | 1.37 |
| Site 2 | 0 | 98.50 | 1.50 |
| Site 3 | 0.25 | 94.67 | 5.08 |
| Site 4 | 0 | 95.57 | 4.43 |
| Site 5 | 0.30 | 90.31 | 9.39 |
| Site 6 | 0.45 | 99.26 | 0.29 |

Statistical analyses included testing data for homogeneity of variance (Levene's test) and normality (Kolmogorov–Smirnov test). The Kruskal–Wallis median test was used to compare densities. Similarities between sites in terms of abundance and biomass were investigated through cluster analysis (group average method). The Spearman correlation coefficient was also applied to identify any significant correlation between clam density and biomass in each site. The results are presented as mean ± standard error (SE), with statistical significance set at $p < 0.05$.

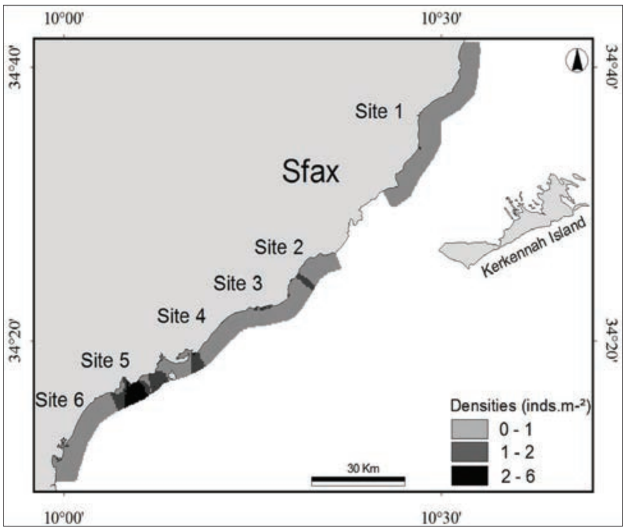

***Fig. 2:** Pollititapes aureus**: spatial distribution of densities in southern Tunisia.***
***Sl. 2:** Pollititapes aureus**: prostorska porazdelitev gostote v južni Tuniziji.***

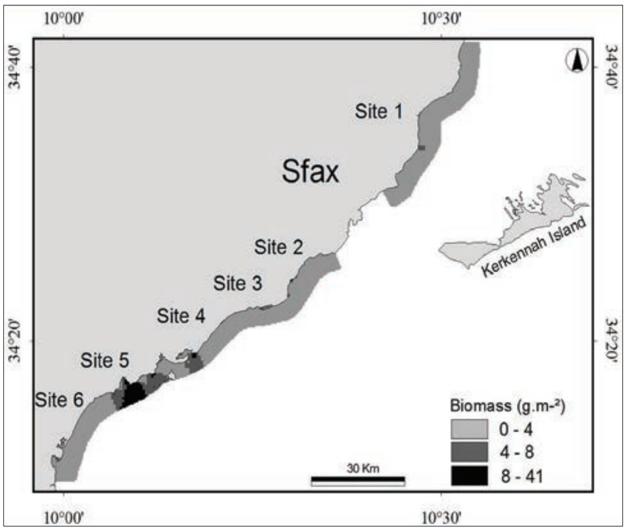

***Fig. 3:** Polititapes aureus**: spatial distribution of biomass in southern Tunisia.***
***Sl. 3:** Polititapes aureus**: prostorska porazdelitev biomase v južni Tuniziji.***

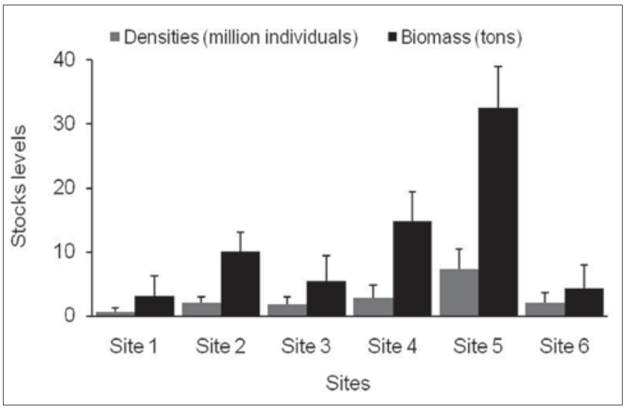

***Fig. 4:** Polititapes aureus**: stock levels in the colonized sites and their standard errors (± SE) in southern Tunisia.***

***Sl. 4:** Polititapes aureus**: ravni staleža na naseljenih lokacijah in njihove standardne napake (± SE) v južni Tuniziji.***

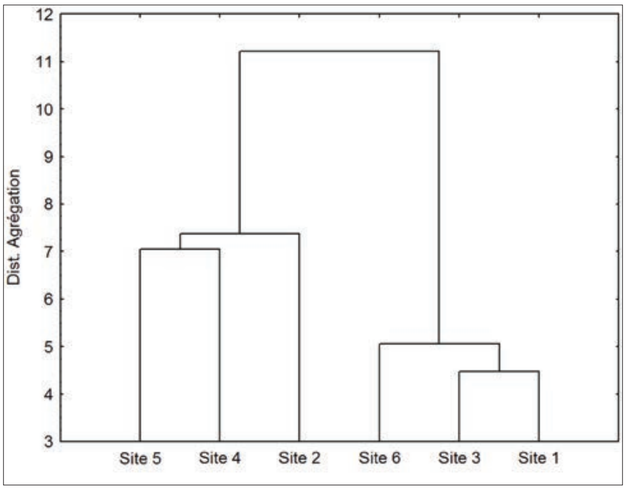

***Fig. 5:** Polititapes aureus**: similarity dendrograms for the colonized sites (average group) in southern Tunisia.***

***Sl. 5:** Polititapes aureus**: dendrogrami podobnosti za naseljene lokacije (povprečna skupina) v južni Tuniziji.***

## RESULTS

### Environmental parameters

Sediments across study sites were predominantly silty-sandy, with the exception of Site 5 (Tab. 1). The majority of sampled areas (>50%) were dominated by the seagrasses *C. nodosa* and *N. noltei*. Water temperatures reached maximum values in July (31°C) and minimum values in February (14.9°C). Salinity fluctuated seasonally, ranging from 37 in winter to 47 in summer.

### Occurrence and abundance

A total of 184 transects were surveyed, yielding a total of 796 samples and covering a total area of 3,867 ha. The clam *P. aureus* was found at all sampling sites, within a depth range of 0 to 1 m. Across quadrats, density ranged from 0 to 6 ind.m$^{-2}$ and biomass from 0 to 41 g.m$^{-2}$ (Figs. 2 & 3). Densities did not follow a normal distribution pattern (Kolmogorov–Smirnov test, $p < 0.05$) and were not homogeneous (Levene's test, $p < 0.05$). Additionally, pairwise comparisons revealed significant differences in abundance and biomass levels across the six sites (Kruskal–Wallis median test, $p < 0.05$).

### Stock assessment

The total stock was estimated at 70.1 ± 15.4 tons (fresh weight), corresponding to 16.58 ± 3.9 million individuals. The average biomass and density estimated from all sampling sites were 1.81 ± 0.4 g.m$^{-2}$ and 0.43 ± 0.1 ind.m$^{-2}$, respectively. Significant variations in stock levels were documented across the sites (Fig. 4). At Site 5, the results were considerably higher than those observed at other locations ($p < 0.05$). In contrast, no significant differences were found among Sites 1, 3, and 6 ($p > 0.05$). Regarding abundance, biomass levels also exhibited significant variation across all sites, with values at Site 5 higher than those recorded at the remaining sites ($p < 0.05$).

Additionally, a cluster analysis was conducted to assess the similarities among sites, revealing two distinct groups spanning all sampled locations (Fig. 5). Analysis of similarity tests indicated that the first group, comprising Sites 2, 4, and 5, differed significantly from the second group, including the remaining sites (global R greater than 0.8; $p < 0.05$). This differentiation was mainly due to the higher abundance of *P. aureus* stocks in the first group compared to the other sites.

### Size structure

The clam population showed a broad size range, with shell lengths (SL) varying from 3 to 32.9 mm (Fig. 6), and a distinct population peak observed at 26 mm SL. The mean shell length was 24.06 ± 1.2 mm SL, with the majority of individuals (79%) falling within the 20–33 mm size classes. The size structure of the clams was analyzed using combined data from all sites within the study area. Size distribution varied significantly across sites, revealing an uneven population structure. Smaller specimens exhibited a heterogeneous distribution across the study area, while larger individuals (11%) were

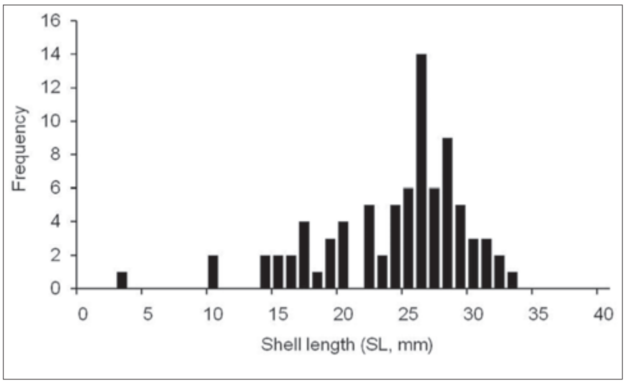

***Fig. 6:*** *Polititapes aureus***: length-frequency distribution in southern Tunisia.**
***Sl. 6:*** *Polititapes aureus***: velikostna porazdelitev v južni Tuniziji.**

geographically restricted to Sites 2, 4, and 5. This spatial pattern could be attributed to natural mortality caused by pollution and increased summer temperatures (31°C).

## DISCUSSION

The present study provides a broad informational foundation on the current status of the clam *P. aureus* in the littoral zone of Sfax by investigating stock levels, spatial distribution, and size structure. The species was encountered at depths ranging from 0 to 1 m; however, the density of individuals varied significantly between localities. Based on biomass estimates, the surveyed area supports a total fresh weight stock of 70.1 tons, with population abundance exceeding 16.58 million individuals. The information on *P. aureus* stock levels remains insufficient. Data on the clam stock are limited to preliminary studies conducted exclusively in the southern part of the Sfax region, which have reported a total biomass of approximately 201 tons and notably high relative abundance, exceeding 91 million individuals (Derbali & Jarboui, 2021). A similar pattern can be observed in another clam species, *R. decussatus*, with a total fresh weight of about 115 tons and a high abundance estimated at over 22.4 million individuals in the same study area (Ben Mohamed & Derbali, 2024). The main drivers of stock depletion are climate change and soft seabed characteristics (Gharbi *et al.*, 2023). Indeed, *P. aureus* populations exhibit significant spatial variability both within and between sampling sites, as well as across geographic regions with distinct seabed characteristics, vegetation cover, and physicochemical factors. The bivalve species appears particularly sensitive to strong multi-level environmental interactions (e.g., physicochemical and soft sediment dynamics in the study area) (Derbali & Jarboui, 2021; Ben Mohamed & Derbali, 2024).

The study was carried out in rural zones faced with a range of complex challenges. These include socio-economic issues such as low income from artisanal fishing and farming, as well as illiteracy. In terms of ecology, the area is confronted with issues such as stock depletion, climate change impacts, and a lack of measures to improve the conditions of local communities. The current study revealed significant spatial variability in the distribution of *P. aureus* populations across all sampling sites. Although hydrodynamic conditions were relatively consistent throughout the study area, several key factors affecting the structure of bivalve populations were identified, including soft substrates and climate change (Derbali, 2011; Derbali & Jarboui, 2021; Derbali *et al.*, 2021).

The clam's distribution seems to be inversely related to the proportion of muddy-sandy substrates. There is some evidence suggesting that a high level of gravel may be detrimental. These findings indicate that high densities of clams are likely to be found on muddy-sandy bottoms. Further study involving sediment and clam sampling in each quadrat is required to support this hypothesis. The significant decline in stocks can be attributed to overexploitation in the most shellfish production areas. The authorities have continued to support this sector by establishing a relatively comprehensive institutional framework and launching several development projects.

The clam *P. aureus* appears to be strongly affected by abiotic factors. In this study, hydrodynamic conditions were found to be consisted throughout the sampling area, suggesting that the relative population growth is influenced by other environmental factors, including sediment type, organic matter content, burrowing behavior, and related strategies to counter dislocation and avoid predation (Derbali & Jarboui, 2021).

In fact, several studies have highlighted interesting connections between environmental conditions and bivalve behavior (Derbali *et al.*, 2011; Derbali *et al.* 2021; Ben Mohamed & Derbali, 2024). The clam population appears to be highest in areas covered by the seagrasses *C. nodosa* and *Z. noltii*, which extend over more than 50% of the habitat. Clam distribution showed a significant correlation with that of these two seagrass species. This correlation could be explained by two factors: i) this positive correlation is linked to the detrital organic matter provided by the seagrasses, and ii) their presence reduces bottom scour and allows organic matter to accumulate. Vilela (1950) demonstrated that one of the dominant sources of organic matter in the diet of *R. decussatus* is derived from *C. nodosa*.

The same conclusion was reached by Ben Mohamed & Derbali (2024) for *R. decussatus* in southern Tunisian waters, and by Sarà (2007) for cockles in Italy. In addition to organic sources, other mechanisms structuring clam populations include the nature of the seabed. Notably, a high stock level of *P. aureus* was observed on a silty-sandy bottom (Site 5).

In colonized areas, natural mortality (F) of *P. aureus* (F = 0.82 yr$^{-1}$) exceeded fishing mortality (M = 0.03 yr$^{-1}$) (Derbali, 2023). The relatively low mortality rate observed in this study (Z = 0.85 yr$^{-1}$) can be attributed exclusively to natural causes (predation, pathogens, anthropogenic impacts, and loss of specimens from unstable sediments due to water currents), since there is no *P. aureus* fishery in the Gulf of Gabes. Nevertheless, Aranguren *et al*. (2014) demonstrated that mortality rates in *R. decussatus*, particularly in natural beds, may results from complex synergies between biotic and abiotic factors. Similarly, Robinson & Richardson (1998) established that *Ensis magnus* (Schumacher, 1817) individuals returned to the seabed were slow to rebury and thus highly vulnerable to crab predation. Moreover, habitat degradation and climate change impacts likely represent the primary drivers of natural mortality (M = 0.82 yr$^{-1}$) in *P. aureus* populations in southern Tunisia.

The elevated water temperatures and salinities observed in the sampling area were significantly higher than those recorded in 2015. Several authors have reported that rising temperature and salinity levels can have a major impact on faunal composition, leading to a decrease in biomass (Fishar, 2000; El-Shabrawy, 2001). These authors have also indicated that elevated seasonal temperatures, particularly summer heat extremes, significantly impact clam populations. Consequently, these unfavorable conditions contribute to mortality in *P. aureus* populations. In this study, the clam population exhibited characteristics similar to those described for other bivalve species. The growth of adult individuals continues to be influenced by mortality rates (Derbali, 2024). According to Ben Mohamed & Derbali (2024), shellfish production areas are influenced by phytoplankton blooms, specifically of diatoms and dinoflagellates. Previous studies have shown that summer blooms of dinoflagellates lead to mass mortalities among bivalve populations (Hamza, 2003; Derbali, 2011), causing them to disappear from large central areas – likely due to anoxia – and to re-colonize these areas again in autumn, once temperatures have cooled (Hamza, 2003).

In conclusion, this study provides crucial information on the current status of *P. aureus*, a potentially valuable commercial species in southern Tunisian waters, by investigating its stock levels, population distribution, and size structure. The findings offer new insights into stock density and the factors contributing to its variability, with distinct assemblages clearly corresponding to major environmental conditions. To support sustainable production, further research should investigate additional biological parameters to enable precise monitoring of clam exploitation. Adopting and implementing regulations, such as size-selective harvest limits, will be essential for protecting this emerging fishery resource, similar to *R. decussatus* wild populations.

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# TRENUTNO STANJE VRSTE *POLITITAPES AUREUS* (MOLLUSCA: BIVALVIA) NA OBALNEM OBMOČJU SFAXA V TUNIZIJI (OSREDNJE SREDOZEMLJE)

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## *POVZETEK*

*Školjka* Polititapes aureus *je ena najpogostejših vrst školjk v vodah južne Tunizije. Njena potencialna komercialna vrednost v prihodnosti je ključni vir za obrtni ribolov. Ta študija je bila izvedena za oceno staležev in razvoj načrta upravljanja za naravne populacije školjk vzdolž obale Sfaxa. Rezultati kažejo znatna nihanja gostote na območju, ki je bilo razdeljeno na šest glavnih predelov, z gostoto od 0 do 6 os.m$^{-2}$ in vrednostmi biomase med 0 in 41 g.m$^{-2}$. Skupna biomasa je znašala 70,1 tone, gostota pa je presegla 16,58 milijona osebkov na 3867 hektarih. Primerki so merili od 3 do 32,9 mm. Ugotovljeni so bili ključni okoljski dejavniki, pri čemer je bilo ugotovljeno, da ima več abiotskih parametrov pomemben vpliv na razširjenost vrst školjk. Predlagane so smernice za ohranjanje, da se njeni staleži obnovijo na trajnostne ravni.*

**Ključne besede**: školjka, *Polititapes aureus*, ocena staleža, razširjenost, velikostna struktura, južna Tunizija

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# CURRENT KNOWLEDGE ON THE DISTRIBUTION OF THE POORLY KNOWN ECHIURID SPECIES *MAXMUELLERIA GIGAS* (M. MÜLLER, 1852) IN THE SLOVENIAN SEA

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## *ABSTRACT*

*In September 2024, a specimen of* Maxmuelleria gigas *(*M. Müller, 1852*) was found during a monitoring campaign in the Bay of Koper. This record is the second one of this less known macrobenthic species in the Slovenian Sea and one among few up to date reported in the Adriatic Sea, as well. Sediment mounds observed with an underwater video sledge on muddy bottom in the southern part of the Gulf of Trieste have been related to this species. The species distribution and density (47 per 100 m$^2$) were estimated based on the quantification of the observed sediment mounds. The potential underestimation of the density and distribution of this species in the Gulf of Trieste in the past studies is discussed in relation to sampling method.*

**Key words:** Echiura, sediment mounds, videotransects, Northern Adriatic

# CONOSCENZA ATTUALE DELLA DISTRIBUZIONE DI *MAXMUELLERIA GIGAS* (M. MÜLLER, 1852), SPECIE DI ECHIURIDE POCO CONOSCIUTA, NEL MARE SLOVENO

## *SINTESI*

*La prima segnalazione di* Maxmuelleria gigas *(*M. Müller, 1852*) nelle acque slovene risale al 2020. In settembre 2024, è stato rinvenuto un secondo esemplare di questa specie durante una campagna di monitoraggio nella Baia di Capodistria. Durante alcuni campionamenti con l'uso di una videocamera subacquea sui fondali fangosi nella parte meridionale del golfo di Trieste, sono stati rilevati dei coni di sedimento che vengono attribuiti a questa specie. La distribuzione e la densità della specie (47 per 100m$^2$) è stata stimata sulla base del conteggio dei cumuli di sedimento osservati. Viene discussa la potenziale sottostima della densità e della distribuzione di questa specie nel Golfo di Trieste nei lavori precedenti, in relazione al metodo di campionamento.*

**Parole chiave:** Echiura, cumuli di sedimento, videotransetti, Nord Adriatico

## INTRODUCTION

Named for their spoon-like proboscis, the Echiura or spoon worms, are present in soft-bottom marine environments from the intertidal to the deep sea (Biseswar, 2009; Hughes *et al.*, 1996a). The pelagic stage in their larval development, as well as their ability to withstand wide range of temperature and salinity, enables them to colonize vast areas from the Atlantic to the Indo-West Pacific ocean (Biseswar, 2009, 2012). Out of the six species known in the Mediterranean (Murina, 1984) only two have been recorded in the Adriatic Sea: *Bonellia viridis* (Zavodnik, 2016) and *Maxmuelleria gigas* (Atkinson *et al.*, 1998; Minelli *et al.*, 2003; Simonini *et al.*, 2007). While the first has been observed in the past (Lipej & Vrišer, 1999; Sket, 2003), the latter was only recently recorded for the first time in the Slovenian Sea (Pitacco, 2020).

The species of the genus *Maxmuelleria* inhabiting soft sediments build U-shaped burrows, 42 cm deep (Nickell *et al.*, 1995), with two openings on the surface that can be up to 100 cm apart (Hughes *et al.*, 1996b). One of the openings is used primarily for feeding while the other serves as an excretory vent for the sediment discharge. Animals were observed to be located towards one side of the burrow, from where they extend their spoon-like proboscis to collect the surface sediments (Hughes *et al.*, 1996a), carrying it towards the funnel-shaped opening, measuring 4 cm in diameter (Nickell *et al.*, 1995). The expulsion of sediment in the form of a blow or fluidized slurry on the other side of the tunnel can result in a formation of a sediment mound around the opening, which can grow up to 60 cm wide and 30 cm high (Moore *et al.*, 2013) in the shape of a dome or a sharp cone. While the active ejection of sediment can be observed throughout the day, the appearance of proboscis, retracting suddenly when shined on by a light, could only be recorded by night with an infrared-sensitive camera (Hughes *et al.*, 1996a). All information on the burrow structure and feeding activity was derived from the observation of *Maxmuelleria lankesteri* (Herdman, 1897) in the Northern Atlantic. However, besides some differences in the distribution of papillae on proboscis, *M. lankesteri* and *M. gigas* are believed to be closely related species, which some authors consider the same (Stephen & Edmonds, 1972).

Active specimens of *Maxmuelleria lankesteri* were usually observed with an underwater television camera (Hughes *et al.*, 1996a) or while SCUBA diving (Nickell *et al.*, 1995). The shape of their burrows was described based on the shape of resin casts, where polyester or epoxy material was poured into the burrow to obtain its shape when hardened (Seike *et al.*, 2012). The few records reporting the species *M. gigas* in the Adriatic mostly rely on the observation of active proboscis (Atkinson *et al.*, 1998) and the presence of sediment mounds (Zavodnik, 2016) for species identification. Recently, a live specimen was caught off Koper, Slovenia, which confirmed the presence of *M. gigas* in Slovenian waters (Pitacco, 2020). The present study introduces the second record of *M. gigas* in the Slovenian Sea, as well as the estimated distribution of the species, which was derived from integrated point sampling data obtained with Van Veen grab and visual data obtained with underwater video transects.

## MATERIAL AND METHODS

A specimen of *M. gigas* was captured on September 23rd, 2024, during a monitoring project of soft-bottom macrofauna in the waters of Slovenia, North Adriatic (Fig. 1). Sediment samples were taken with the Van Veen grab (0.1 $m^2$) at a depth of 22.3 m at the sampling location (45.591667°N, 13.666667°E), 2.8 km west of the Punta Grossa, on a soft-bottom sediment floor; 53% silt, 27% clay and 20% sand with 40-50% carbonate content (Ogorelec *et al.*, 1991). The specimen was pinched with the grab scoop, which caused damage to the body wall and evisceration. The animal was released after being photographed. Van Veen grab is used for sampling of infaunal species, present in the upper layers of the sediment (Mackie *et al.*, 2007).

Linear video transects of the soft bottom were recorded by a video sledge (SKIKAM) during an observation of circalittoral benthic habitats in the Slovenian Sea. The study was carried out by the Marine Biology Station, Piran (National Institute of Biology, Slovenia) from 2021 to 2023 under the project "An upgrade on knowledge of biotic and abiotic characteristics and extent of benthic habitat types of circalittoral coarse sediments (MC3), circalittoral mixed sediments (MC4) and circalittoral sands (MC5)" (Mavrič *et al.*, 2023). The transects covered an area of 13046 $m^2$, with a mean depth of 22.4 m and pelite content ranging from 20% to 60%. In this study, cone-shaped structures associated with *Maxmuelleria* burrows were observed and counted. The sediment mounds surrounding a burrow opening were mostly observed individually; occasionally, two to three mounds were merged with the respective number of openings observed on top. The counting criteria included the presence of an open burrow opening (not closed with sediment) surrounded by a sediment mound; in the case of merged mounds, one opening was counted as one mound. The sign of activity was marked in case of a light colored sediment (fluidized slurry) present on top of a mound around the opening as described by Hughes *et al.* (1996a) and Atkinson *et al.*(1998). Occasionally, blows of sediment were observed coming from the top of the mound. The mound density was calculated in relation to the surface area covered by the video transects, analyzed for this study (5166.6 $m^2$).

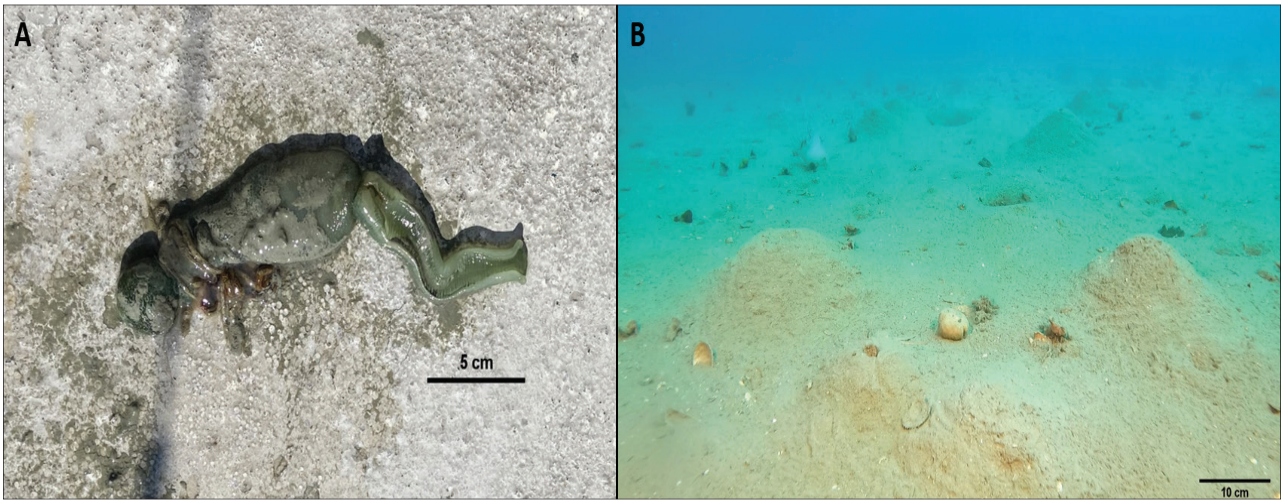

***Fig. 1:** Maxmuelleria gigas**. A) Whole specimen, ventral view, B) sediment mounds, associated with** M. gigas**, found on the soft bottom in the Gulf of Trieste.***

***Sl. 1:** Maxmuelleria gigas**. A) Primerek s trebušne strani, B) sedimentni hribčki povezani z** M. gigas**, najdeni na sedimentnem dnu v Tržaškem zalivu.***

## RESULTS AND DISCUSSION

The specimen collected in 2024 represents the second record of *Maxmuelleria gigas* in the Slovenian Sea. It measured 11 cm in total length and was identified as *M. gigas* (M. Müller, 1852) based on a non-bifid proboscis and a green colored sausage-like body (Fig. 1A). Green coloration of the echiurid is not related to chlorophyll, but instead comes from a chlorin pigment bonellin, which has proven to cause cytolysis and toxic effects on spermatozoa and echinoid egg development (Agius *et al.*, 1979). The cytolysis and other effects turned out to be accelerated by light (photodynamic action), which could serve as a defense mechanism if released in the environment in the presence of predators (Agius *et al.*, 1979).

Sediment mounds (Fig. 1B), have been observed in high quantities (47 per 100 m$^2$; overall surface area 5166 m$^2$) during the sampling of the seafloor by a video-sledge (SKIKAM) in the northeastern part of the Gulf of Trieste (Fig. 2). They were similar to those associated with *Maxmuelleria lankesteri* in Scotland (Hughes *et al.*, 1996b). The mounds were mostly observed individually (75%) and with clear openings (99.6%), where signs of activity were scarcely present (3%), mostly in the form of fluidized slurry around the opening. Most of the time, these mounds had other openings on the sides or in their vicinity, probably made by other burrowing species of crustaceans (e.g. *Squilla mantis, Nephrops norvegicus*) and fish. The black goby (*Gobius niger*) was observed dwelling near the burrow openings (0.9 per 100 m$^2$), where it fled once the video-sledge approached; the brown comber (*Serranus hepatus*) was observed hiding behind the mounds (2 per 100 m$^2$), carefully observing the approaching sledge before fleeing the field of view; one sighting of a fleeing shrimp included a tail disappearing into one of the holes on the side of a sediment mound.

The mounds were observed in higher density (81 per 100 m$^2$; surface area 2243.2 m$^2$) on predominantly muddy seafloor with high proportions of silt (50–60%) in the inner parts of the Gulf of Trieste, on the southern opening of the Bay of Koper (Fig. 2, green). The density of mounds decreased (17 per 100 m$^2$; surface area 3297 m$^2$) moving off-shore, where silt content in bottom sediments is lower (40–50%) (Fig. 2, blue). Silt content in sediments is known as a key factor influencing benthic communities in the studied area (Pitacco *et al.*, 2023). Higher density of mounds in the areas with larger proportion of silt can be related to the high detritus quantity in the surface sediment layers favoring the establishment of detritus-feeding macrobenthic communities (Rosenberg, 1995; Pan & Pratolongo, 2021).

Similar structures to sediment mounds were described in the area offshore Ancona, Italy (Atkinson *et al.*, 1998) and related to *M. gigas* as the only sediment-burrowing species of echiurids recorded in the Adriatic Sea (Zavodnik, 2016). These structures have been related to *M. gigas* due to the emergence of the proboscis, observed by underwater television recordings first by Atkinson *et al.* (1998) in Ancona and later recorded by divers in the area of Fiesa, Slovenia, in March 2023 (C. Mlinar Cic & B. Mavrič, *personal communication*). In the latter, the proboscis was observed retracting into the inhalant burrow, carrying a load of sediment into the opening in an action resembling a conveyor belt.

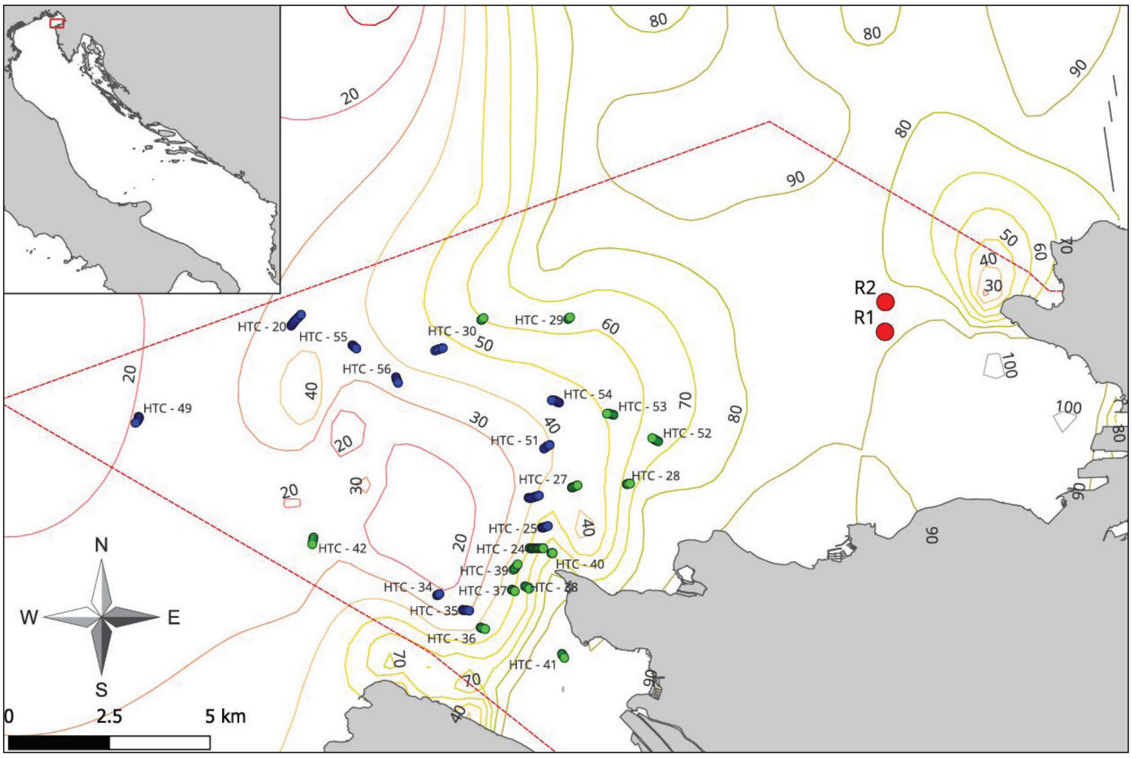

*Fig. 2: A map of the study area in the Slovenian Sea. GPS positions of the video transects are marked in blue and green. The silt content in sediment (%) is marked by isoclines. The points in red present the GPS positions of the first (Pitacco, 2020; R1) and second record of this species (present work; R2).*
*Sl. 2: Zemljevid obravnavanega območja slovenskega morja. Z zeleno in modro barvo so označene GPS lokacije video transektov. Vsebnost pelita v sedimentu (%) je označena z izoklinami. Z rdečo sta označeni GPS lokaciji prvega (Pitacco, 2020; R1) in drugega zapisa o pojavljanju vrste (to delo; R2).*

However, no systematic sampling of these organisms has been done in the Northern Adriatic, which would provide direct association of each burrow and sediment mound to the presence of this species; therefore, we cannot assume the exclusivity of other burrowing fauna creating or inhabiting these kinds of sediment mounds. While the activity of the proboscis leaves little doubt in the identification, the mound structures of *M. gigas* can otherwise be recognized by a layer of ejected sediment of different color around the opening, with occasionally present faecal pellets 2-4 mm long and 0.7-1 mm wide (Hughes *et al.*, 1996a).

Some species of burrowing shrimp (*Necallianassa truncata, Gliyossius tyrrhenea, Jaxaea nocturna*) create similar sediment mounds around one of the burrow openings, however, the size of the mound is usually smaller than the one of *M. gigas* (Pervesler & Dworschak, 1985; Moore *et al.*, 2013), while the other opening is usually in the shape of a funnel (Ziebis *et al.*, 1996; Dworschak, 2001). Other species of sediment-dwelling shrimp usually build burrows with more than two openings (*Upogebia pusilla, U. tipica, Squilla mantis, Nephrops norvegicus*), which have a sediment excrete present around the opening, but never in the shape of a discrete mound (Rice & Chapman, 1971; Atkinson *et al.*, 1997, 1998; Dworschak, 2004). Other burrowing species present on the soft muds of the Northern Adriatic (*Solecurtus strigilatus, Brachynotus gemmellari, Gobius niger*) were also observed on the same grounds as the mounds of *M. gigas* (Nickell *et al.*, 1995; Moore *et al.*, 2013), however, their burrow structures do not resemble the ones associated with the echiurid; *S. strigilatus* builds burrows swith openings flush with the surface, 3 – 6 cm apart (Dworschak, 1987); the burrows of *B. gemmellari* are a shallow excavation, with only one opening (Atkinson *et al.*, 1998); *G. niger* usually settles in abandoned shrimp burrows, where it modifies one of the openings to create a chamber close to the surface (Atkinson *et al.*, 1998).

Despite biannual samplings of sediment grabs along the Slovenian coast from 2007 onward (http://www.arso.gov.si/vode/podatki/), this species was considered rare in the Northern Adriatic (Pitacco, 2020). Although grab sampling is used for collecting soft-bottom burrowing fauna in the Northern Adriatic (Pitacco *et al.*, 2023), grabs and corers are not suitable for deep-burrowing organisms, which live below the penetration of most samplers with the average sediment penetration depth 20 cm, the deepest 45 cm (Mackie *et al.*, 2007); while a relative species *Maxmuelleria lankesteri* burrow can reach up to 80 cm deep (Hughes *et al.*, 1996b). The previous lack of records in the Northern Adriatic may be due to the limitation of this point-sampling method. The method of resin casts made from the hardened material in the shape of the mold is widely used for describing the morphology of burrows, mostly made by burrowing crustaceans (Pervesler & Dworschak, 1985; Atkinson *et al.*, 1997; Dworschak, 2001) and gobies (Rice & Johnstone, 1972; Atkinson *et al.*, 1998). However, it is not optimal for discovering the true occupancy of the burrow, especially for the echiuran species, where only the slight green coloration of the resin cast can hint at the presence of the animal (Hughes *et al.*, 1996b). Sampling with ship-borne equipment and in situ with SCUBA are also limited by the surface of the area studied, while underwater television is more suitable to cover large areas of soft-sediment floor.

The underwater television observation technique has proven efficient in the stock assessment of the Norwegian shrimp (*N. norvegicus*) (Naseer *et al.*, 2022), however, there is still too little information of the burrowing structure of *M. gigas* to completely exclude the doubts surrounding burrow identification, burrow detection, counting strategies and most importantly occupancy assessment (Marrs *et al.*, 1996). While the strategy of "one burrow, one animal" has been adjusted for the Norwegian shrimp, further studies on the echiuran abundance in the Northern Adriatic are needed, before implementing similar density estimation strategies.

Although the ecology of the genus *Maxmuelleria* is poorly known, studies from the Irish Sea suggest their great importance in the role of bioturbation of soft sediments, overturning 13 g of dry sediment a day (Hughes *et al.*, 1996b). The sediment mounds on the seafloor also increase the surface area, consequently enhancing the benthic flux (King, 2011). The density of 120 sediment mounds per m$^2$ created by a burrowing shrimp *Necallianassa truncata* increased the surface of the sediment-water interface by 400% (Ziebis *et al.*, 1996). Furthermore, oxygenation of upper sediment layers was increased by a factor of 1.5 on the seafloor with a high density of sediment mounds (22 mounds per m$^2$), where oxygen penetrated deeper (40 mm) around a mound than on a smooth surface (4 mm) (Ziebis *et al.*, 1996). Besides increasing the surface-water interface area, the mounds create a more structured seafloor providing habitat also for bottom dwelling fish such as the black goby, which is known for its opportunistic use of burrows, mostly reworking the upper parts of the burrows of Maxmuelleria and infaunal shrimps (*Squilla mantis, Callianassa subterranea*) (Atkinson *et al.*, 1998).

The high number of sediment structures observed in the present work on video-recordings indicated that the true density and distribution of *M. gigas*, together with its ecological role, have been underestimated so far.

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# TRENUTNO POZNAVANJE PROSTORSKE RAZPOREDITVE MANJ POZNANE VRSTE ZVEZDAŠA *MAXMUELLERIA GIGAS* (M. MÜLLER, 1852) V SLOVENSKEM MORJU

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## *POVZETEK*

*Septembra 2024 je bil najden osebek vrste* Maxmuelleria gigas *(*M. Müller, 1852*) med vzorčenjem v Koprskem zalivu. Poleg redkih opažanj te vrste v Jadranskem morju, ta najdba predstavlja drugega in enega od novejših zapisov pojavljanja te vrste v slovenskem morju. Sedimentni hribčki, opaženi z video sanmi na muljastem sedimentnem dnu v Tržaškem zalivu, so bili povezani z dejavnostjo te vrste. Razporeditev in gostota osebkov (47 na 100 m$^2$) sta bili ocenjeni na podlagi pojavljanja sedimentnih hribčkov. Avtorici obravnavata morebitno podcenjenost gostote pojavljanja te vrste v Tržaškem zalivu, v povezavi z vzorčevalno metodo.*

**Ključne besede:** Echiura, sedimentni hribčki, podvodni videozapisi, severni Jadran

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# LONG-TERM STUDY OF ZOOPLANKTON BIOMASS IN THE SOUTH-EASTERN PART OF THE GULF OF TRIESTE (ADRIATIC SEA)

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## ABSTRACT

*We present a dataset of zooplankton biomass spanning more than four decades (1974–2019). The dry mass of zooplankton ranged from below 10 to almost 100 mg* $m^{-3}$*, was highest in 1989–2002 and declined thereafter. The interannual variability of zooplankton dry mass in the period 1993–2018 was compared with the regional atmospheric index WeMOi, chlorophyll a and frequency of jellyfish blooms. Increased dry mass values were associated with a positive phase of the regional atmospheric index WeMOi, higher chlorophyll a and a lower frequency of jellyfish blooms.*

**Key words**: net zooplankton, dry mass, time series, chlorophyll *a*, jellyfish blooms

# STUDIO A LUNGO TERMINE DELLA BIOMASSA ZOOPLANCTONICA NELLA PARTE SUD-ORIENTALE DEL GOLFO DI TRIESTE (MARE ADRIATICO)

## *SINTESI*

*Gli autori presentano un set di dati sulla biomassa zooplanctonica che copre un arco temporale di oltre quattro decenni (1974–2019). Il peso secco dello zooplancton variava da meno di 10 a quasi 100 mg* $m^{-3}$*, raggiungendo i valori più elevati nel periodo 1989–2002 e diminuendo successivamente. La variabilità interannuale del peso secco dello zooplancton nel periodo 1993–2018 è stata confrontata con l'indice atmosferico regionale WeMOi, la concentrazione di clorofilla a e la frequenza delle fioriture di meduse. I valori più elevati del peso secco sono risultati associati a una fase positiva dell'indice atmosferico regionale WeMOi, a una maggiore concentrazione di clorofilla a e a una minore frequenza di fioriture di meduse.*

**Parole chiave**: zooplancton, peso secco, serie storiche, clorofilla *a*, fioriture di meduse

## INTRODUCTION

Zooplankton represents an important trophic step in the pelagic food web and connects the primary producers with the higher trophic levels. It acts as a recycler, converting particulate organic matter into dissolved pools, and plays an important role in the biological pump and carbon export (Steinbeck & Laundry, 2017). Monitoring zooplankton biomass over extended periods of time provides valuable insights into ecosystem health, productivity and resilience. By facilitating the assessment of anthropogenic impacts, such data can support the development of evidence-based management strategies, such as the European Marine Strategy Framework Directive (MSFD, 2008/56/EC) and the Integrated Monitoring and Assessment Programme (IMAP, UNEP/MAP, 2016) of the Barcelona Convention. Quantitative estimates of zooplankton biomass are therefore of paramount importance (Ratnarajah *et al.*, 2023), but in general, observational data are sparse.

The most commonly used metrics to determine net zooplankton biomass are settling and displacement volume (volumetric methods) and wet, dry and ash-free dry mass (gravimetric methods). The methodological bias is reduced if the displacement volume or wet mass is quantified instead of the settling volume, and even more so if the dry mass is measured and the fluids are eliminated (Postel *et al.*, 2000). While volumetric methods were already used in the 19th century to determine the quantity of net plankton, the measurement of dry mass became established as a widely used method in the 1960s (Hagen, 2000).

Alternatively, researchers can determine the abundance and taxonomic composition of the plankton community and then convert this data into dry mass using published conversion factors. This method is much more time-consuming, and the effort increases if the dry mass of a particular taxonomic group or species is determined directly, but the results provide additional important information.

The measurement of the bulk dry mass is straightforward and standardised in marine ecology studies despite some disadvantages. The main drawbacks include the destruction of organisms that cannot be used for further taxonomic analyses, the inability to capture variability due to differences in community structure, especially when the abundance of gelatinous organisms is considerable, and the lack of information on the specific biochemical composition, which is important for assessing the role of zooplankton in trophic dynamics. Nevertheless, the use of standard dry mass methods enables consistent results and can therefore be used for comparisons across different geographical locations and over time.

The main objective of the present study was to describe the long-term and interannual fluctuations of the zooplankton stock in the northernmost part of the Adriatic Sea and to identify possible changes. We report here the temporal patterns of net zooplankton dry mass in the Gulf of Trieste over more than four decades (1974–2019). We also investigated the relationships between zooplankton and phytoplankton biomass as well as the regional climate index as possible explanatory variables for the observed fluctuations. Finally, we use data on the occurrence of jellyfish blooms to interpret the observed changes in zooplankton biomass and identify a possible top-down control.

## MATERIAL AND METHODS

### Sample collection and processing

The zooplankton samples were collected in the south-eastern part of the Gulf of Trieste (northern Adriatic Sea) at the long-term ecological research site LTER Gulf of Trieste, Slovenia (LTER GoT SI, 22 m water depth, Fig. 1). The Gulf of Trieste is the northernmost extension of the Adriatic Sea and is characterised by a shallow water depth of less than 20 m on average. Due

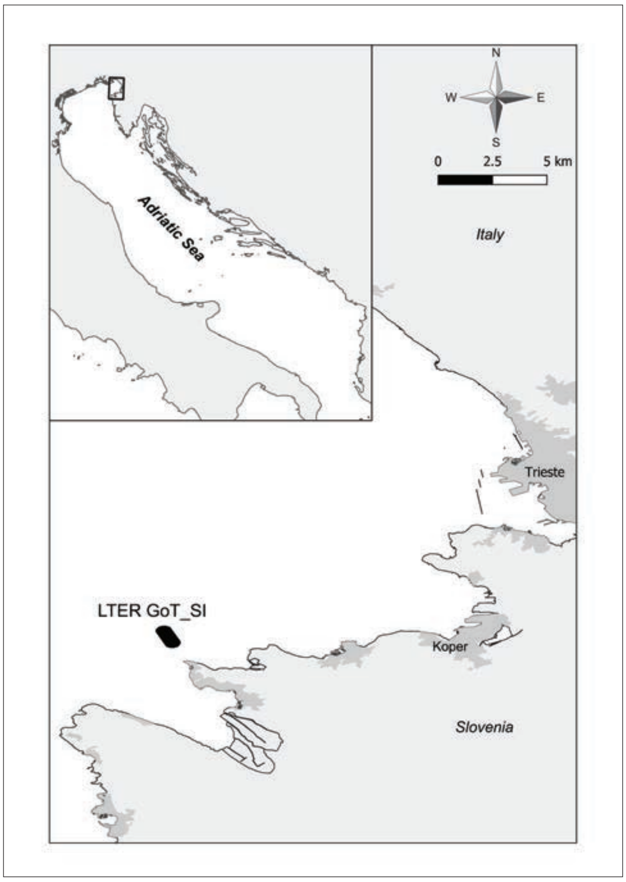

***Fig. 1: The site of the long-term ecological research station LTER Gulf of Trieste, Slovenia.***
***Sl. 1: Lokacija dolgoročne ekološke raziskovalne postaje LTER, Tržaški zaliv, Slovenija.***

to its location and shallow depth, the climatic conditions have a strong influence on the oceanographic and biological characteristics. The water column is thermally stratified in the warmer part of the year and well mixed in winter. The main freshwater source (the Soča River) flows into the Gulf from the north-west coast and plays an important role in the bottom-up control of phytoplankton (Vascotto *et al.*, 2024). Our sampling station is located in the south-eastern part of the Gulf, which is more strongly influenced by the EAC (Eastern Adriatic Current) and the open waters of the northern Adriatic and is considered mesotrophic to oligotrophic (Brush *et al.*, 2021).

The time series of zooplankton monitoring with different sampling frequencies was established in 1974. However, the monitoring was interrupted several times (1976–1978; 1981–1988; 2003) and was carried out regularly from 2004 until it was discontinued in 2019. The zooplankton samples were collected by vertical tows from the near bottom to the surface using three different nets: with a mouth opening of 0.25 $m^2$ and a mesh size of 212 µm (1974–1975), with an opening of 0.5 $m^2$ and a mesh size of 250 µm (1979–1980) and since 1989 with the WP2 net, mouth opening of 0.25 $m^2$ and a mesh size of 200 µm. The volume of water filtered was calculated from tow length and net opening. The samples were fixed on board with buffered formaldehyde (2%–4% final concentration).

The frequency of sampling varied from five to six times a year (1974–1975, 1979–1980, 1989–1992) to monthly from 1993 and bi-monthly from 2004. Since the beginning of 1993, the seawater samples for chlorophyll *a* determination have been collected using 5-litre Niskin bottles.

In the laboratory, the zooplankton samples were divided into two halves using a Folsom splitter and one half-split was used to determine the biomass (dry mass – DM). The DM samples were briefly rinsed with freshwater, placed in pre-weighed ceramic crucibles, dried at $60^0$ C for 24 hours (Lovegrove 1966) and weighed to the nearest 0.1 mg. The results were expressed as dry mass in milligrams per cubic meter (mg DM $m^{-3}$). The concentrations of chlorophyll *a* (Chl *a*), corrected for phaeopigments, were determined fluorometrically in 90% acetone extracts (Holm-Hansen *et al.*, 1965).

### Time series analyses

Monthly time series of the entire DM dataset were generated and descriptive statistics (mean, geometric mean, standard error, median, standard deviation, and 10th and 90th percentiles) were calculated. We also calculated the coefficient of variation (CoV) as SD/mean. The normalised annual DM anomalies, calculated by dividing the anomalies by the long-term standard deviation, were estimated for the entire study period (1974–2019).

We investigated the relationships of DM with phytoplankton biomass (Chl *a*), the Western Mediterranean Oscillation climate index (WeMOi) and jellyfish blooms as potential explanatory variables for changes in zooplankton biomass. The basic working hypothesis was that zooplankton DM was influenced by Chl *a* as proxy of food availability and by WeMOi as proxy for environmental conditions. As we had several major interruptions in zooplankton sampling (1976–1978; 1981–1988) we analysed the fluctuations in zooplankton biomass in relation to Chl *a* and the WeMOi only for the last 25 full years of the study (1993–2018), using monthly series for all parameters. DM results were missing for some months (21 out of 301 results), which were scattered over the entire period. To fill in these missing values, the approx. function in R was used. The same was done for missing Chl *a* values (33 out of 301 results).

WeMOi measures the difference between the standardised atmospheric pressure in Padua, northern Italy, and San Fernando, Cádiz, Southwestern Spain (Martin-Vide & Lopez-Bustins, 2006) and reflects the regional weather conditions. The positive phase of WeMO correlates significantly with lower sea surface temperatures and higher river discharges and has been shown to be associated with increased productivity of plankton and small pelagic fish (Martin *et al.*, 2012). Monthly WeMOi data were downloaded from crudata.uea.ac.uk/cru/data/moi/Web_WeMOi-2020.txt. Pearson's product moment correlations were used to assess the relationship between zooplankton DM and Chl *a*, and DM and WeMOi using time series of monthly data. Additional analyses considered a time lag of one month for zooplankton DM. The annual WeMOi is the average value of the corresponding monthly WeMOi (Martin *et al.*, 2012).

Jellyfish blooms were defined according to the methodology described by Pestorić *et al.* (2021). During the study period, the following macrojellyfish species (Cnidaria, Scyphomedusae: *Aurelia solida*, *Chrysaora hysoscella*, *Cotylorhiza tuberculata*, *Pelagia noctiluca*, *Rhizostoma pulmo* and Ctenophora, Lobata: *Mnemiopsis leidyi*) were found to be blooming in the Gulf of Trieste (Kogovšek *et al.*, 2010; Pestorić *et al.*, 2021, own observations). The annual jellyfish bloom index (Jbi) was calculated as the cumulative number of months in a year in which macrojellyfish blooms occurred in the study area. The non-parametric Kruskal–Wallis test and Dunn's post-hoc multiple pairwise comparison test were used to determine whether there were significant differences in zooplankton DM results between years with different JBi. Hierarchical clustering and non-metric multidimensional scaling (NMDS) were used to visualise how the different years clustered based on the Bray-Curtis dissimilarities of the DM influenced by WeMOi and Jbi.

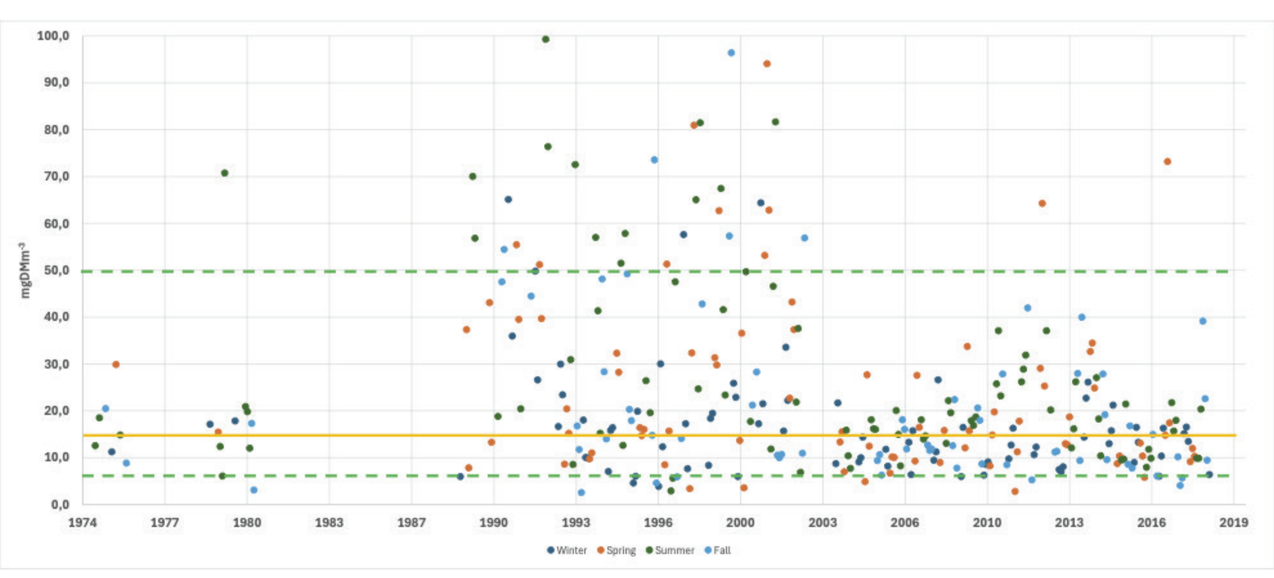

***Fig. 2: Scatter plot of zooplankton dry mass (mg m$^{-3}$) over the study period (1974–2019), the median (full yellow line) and the 10th and 90th percentiles (dashed green lines). The different seasons are marked with different colours (winter – dark blue, spring – orange, summer – green, autumn – light blue).***

***Sl. 2: Diagram suhe mase zooplanktona (mg m$^{-3}$) v preiskovanem obdobju (1974–2019) z mediano (rumena linija) ter 10. in 90. percentilom (črtkani zeleni liniji). Sezone so označene z različnimi barvami (zima – temno modra, pomlad – oranžna, poletje – zelena, jesen – svetlo modra).***

## RESULTS

Fig. 2 shows all zooplankton DM (318 results) in the study period 1974–2019, while the descriptive statistics with mean, geometric mean, median, standard error and deviation are shown in Table 1.

Overall, zooplankton DM varied widely, from less than 10 mg m$^{-3}$ (23% of results) to 99.3 mg m$^{-3}$, with 9% of results above the 90th percentile. CoV was slightly higher in the periods before 2004 (0.77 for 1974–1980, 0.74 for 1989–2002) and was lowest in the latter period (0.61). In the years 1989–2002, DM was frequently above the overall median (67% of results) and the mean (51% of results). In contrast, high results were less frequent in the years 1974-1980 and after 2004. In particular, the periods between 2004 and 2010 and after 2014 were characterised by low DM (66% of results were below the median and 86% below the overall mean).

### Interannual and seasonal changes in zooplankton DM

The interannual variations in zooplankton DM were considerable (Figs. 2 and 3). Years with statistically significant ($p \leq 0.01$) lower DM values were observed before 1980 (except for 1979) and after 2004 (with the exception of 2012, 2014). The years with the highest annual CoV (> 0.8) were 1993–1997, 2012 and 2017, while the DM results fluctuated the least in 2004–2009 and 2014–2016 (CoV < 0.5). The annual fluctuations in zooplankton DM can be clearly visualised by calculating the normalised annual anomalies (Fig. 3): the positive anomalies are concentrated in the years 1989 to 2002, followed by the conspicuous negative anomalies from 2004 onwards.

***Tab 1: Descriptive statistics for zooplankton dry mass results in the period 1974–2018.***

***Tab. 1: Opisna statistika za rezultate zooplanktonske suhe mase v obdobju 1974–2018.***

| **Dry Mass (mg/m$^3$)** | |
|---|---|
| Mean | 22.4 |
| Geometric Mean | 17.1 |
| Standard Error | 1.0 |
| Median | 16.2 |
| Standard Deviation | 18.2 |
| Sample Variance | 332.8 |
| 10th Percentile | 7.3 |
| 90th Percentile | 49.8 |

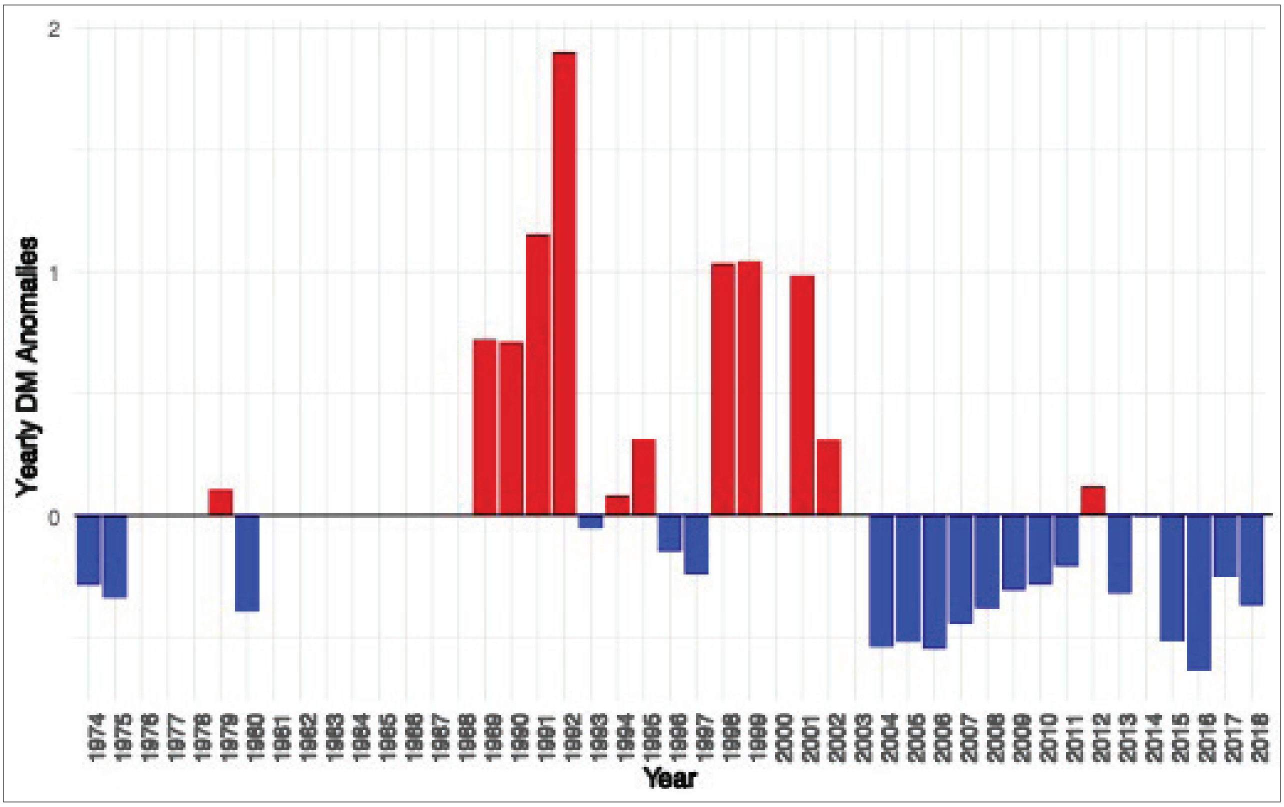

***Fig. 3: Normalized annual anomalies of zooplankton dry mass during the study period (1974–2018).***
***Sl. 3: Normalizirane letne anomalije zooplanktonske suhe mase v obdobju 1974–2018.***

The average annual cycle of zooplankton DM throughout the study period showed higher biomass but also greater variability in the warmer season (May–September) (Fig. 4), while values were lower in the colder months (December–April). The annual DM maxima were most frequently measured in May (44 % of all years), followed by September (16 %).

### Comparison with Chl *a*, WeMOi and jellyfish blooms (Jbi)

Due to gaps in sampling and the lower frequency of sample collection, we decided to conduct further analyses and examine DM relationships to phytoplankton biomass and climate index only for results since 1993. Chl *a* fluctuated widely with maximum values above 10 mg m$^{-3}$ (10.15 and 12.06 mg m$^{-3}$ in November 1996 and February 1999, respectively), while the lowest value was measured in June 2018 (0.16 mg m$^{-3}$). In addition, the entire period after 2006 was characterised by lower Chl *a* with annual mean values below 1.0 mg m$^{-3}$, in contrast to the previous years with mean values of 1.07 to 2.11 mg m$^{-3}$.

The monthly WeMOi showed positive and negative values with the highest monthly value of 3.19 (April 1994) and the lowest –3.18 (June 2006). While a considerable part of the WeMOi was neutral (values between –1.00 and 1.00), the positive WeMO phase prevailed in the 1990s and early 2000s and the negative WeMO from 2002 onwards.

Correlations between zooplankton DM, Chl *a* and WeMOi were analysed using monthly data from 1993–2018. Although we found positive correlations between zooplankton DM and Chl *a* as well as DM and the positive phase of WeMOi, these were weak (0.131 and 0.151, respectively) and not significant. Reanalysis with a time lag did not improve the correlation.

Analysis of the annual WeMOi time series indicated that before 2002 the positive WeMO phase prevailed (Fig. 5). It is associated with higher rainfall and river flows as well as lower sea temperatures, conditions that are considered favourable for overall biological productivity (Martin *et al.*, 2012).

Throughout the study period, there were years without massive jellyfish blooms and/or with short-lived seasonal blooms of one or two species (Jbi ≤ 3) as well as years in which several species bloomed over a longer period and at different times of the year. Typically, the blooms of *A. solida* occurred in winter-spring, *C. tuberculata* in summer, *R. pulmo* in autumn-winter-spring and since 2016 *M. leidyi* in summer-autumn.

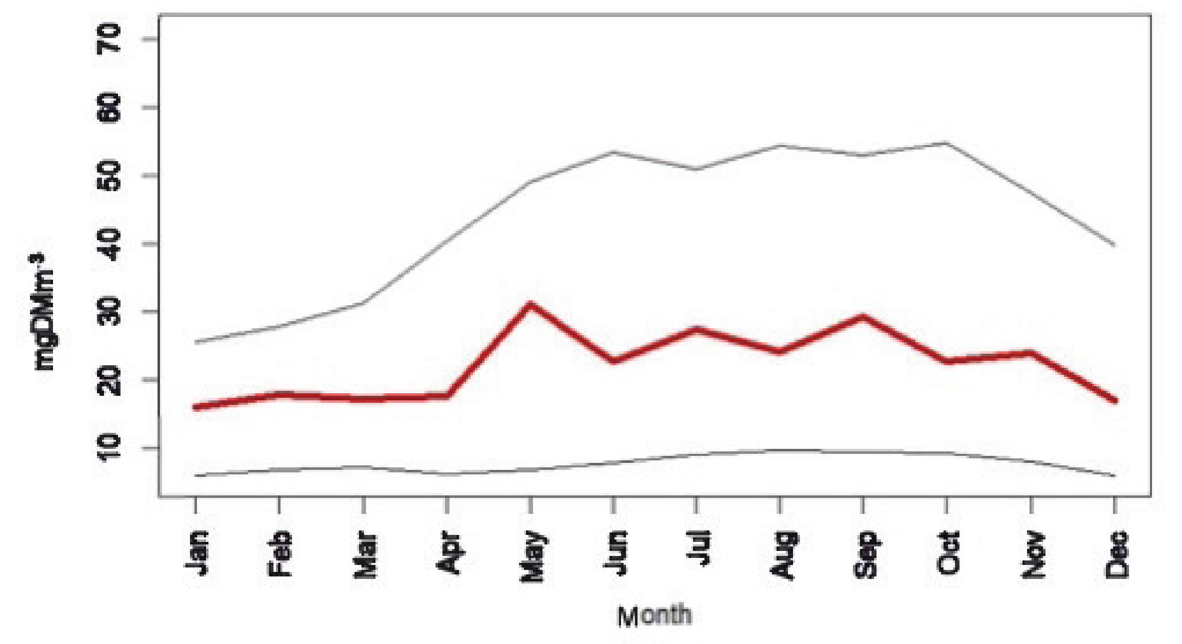

***Fig. 4: Mean seasonal pattern (1974–2018) of zooplankton dry mass (mg m$^{-3}$) (red line) and the 10$^{th}$ and 90$^{th}$ percentiles (grey lines).***

***Sl. 4: Sezonskost povprečne (1974–2018) zooplanktonske suhe mase (mg m$^{-3}$) (rdeča linija) z 10. in 90. percentilom (sivi liniji).***

The annual Jbi varied from 0 (no bloom in one year) to 10 (ten months with bloom in one year). Until 2004, there were nine years without blooms, moreover, the Jbi was lower in the years 2009–2014 (≤ 5) than in the years 2004–2008 and 2015–2019 (Jbi 6-10).

The Kruskal–Wallis test ($p = 0.0016$) and Dunn's post-hoc multiple pairwise comparison test ($p = 0.0016$) revealed significant differences in zooplankton DM between the years without blooms and the years with Jbi ≤ 3 and those with multi-species blooms over a longer period (Jbi ≥ 4). Hierarchical clustering and nMDS ordination of DM showed that WeMOi and Jbi affected DM in different ways and their influence varied across years. While a higher Jbi was associated with a lower DM (years from 2004 onwards), a higher DM was generally related to the positive WeMOi phase (1980s and 1990s).

## DISCUSSION AND CONCLUSIONS

Many marine organisms that are critical to the functioning of the ecosystem and to humans, such as exploited fish, shellfish, squid, some marine mammals, seabirds and sea turtles, to name but a few, are affected by the quantity of zooplankton. Therefore, zooplankton biomass can be considered a key indicator of changes due to environmental and anthropogenic pressures, including responses to climate change. Zooplankton data are also important for the effective implementation of the MSFD (Gorokhova *et al.*, 2016), particularly for the development of methods to assess biodiversity in pelagic habitats (Descriptor 1) and food webs (Descriptor 4). Especially in the Mediterranean Sea, where zooplankton-based indicators are still in the development phase, long-term data are important to define the baseline situation and capture trends and shifts (Francé *et al.*, 2023).

Among the various methods used to determine zooplankton biomass, the dry mass procedure has been evaluated and standardised since the seminal work of Lovegrove (1966). Although there are many papers on various aspects of zooplankton in the northern Adriatic (Pearson *et al.*, 2021), few report on biomass, especially DM. In our article, we present the results of more than four decades of monitoring zooplankton biomass in the Gulf of Trieste using this standardised method. Furthermore, the very similar mesh size (200 – 250 µm) of the zooplankton nets used and the standardised determination of DM at $60^0$ C ensure that our dataset provides comparable results over the period from 1974 to 2019.

The results of zooplankton biomass measurements of the Adriatic Sea during 1971–1981 were summarised in an article by Benović *et al.* (1984). These authors reported significant differences in zooplankton DM, with results from the northern Adriatic, including the Gulf of Trieste, being higher than in other coastal areas and open Adriatic waters. The range of DM values in

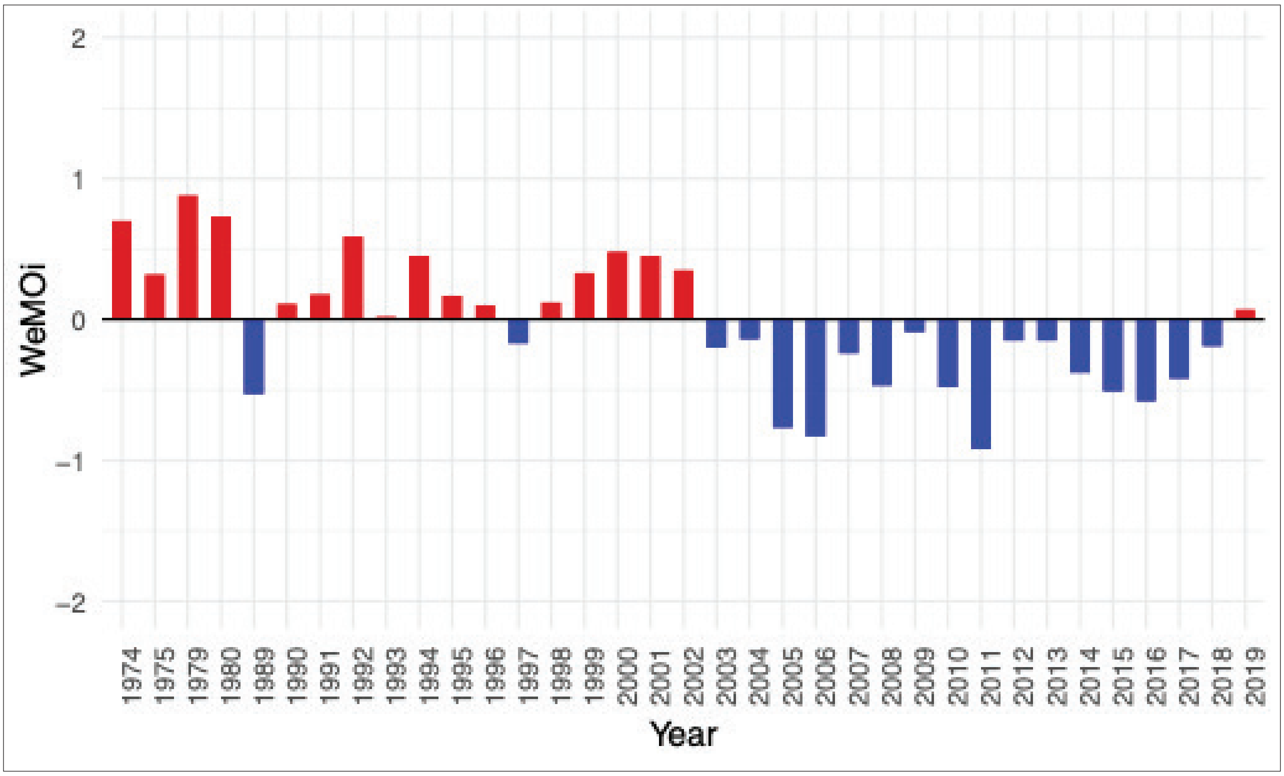

***Fig. 5: Annual WeMOi (Western Mediterranean Oscillation index) from 1974 to 2019: red bars – positive WeMO phase, blue bars – negative WeMO phase.***

***Sl. 5: Letni indeks WeMO (Zahodna sredozemska oscilacija) v letih od 1974 do 2019: rdeči stolpci – pozitivna WeMO faza, modri stolpci – negativna WeMO faza.***

the Gulf of Trieste was between less than 10 and over 100 mg m$^{-3}$ (1.2 – 177.2 mg m$^{-3}$) and the mean value was 18.5 mg m$^{-3}$. The largest proportion of results (36.7 %) was between 10 – 20 mg m$^{-3}$ with the highest values measured in spring and the lowest in winter. The observed seasonal dynamics was consistent with ours, but our mean DM value over the entire period 1974–2019 was thus higher (22.4 mg m$^{-3}$, Tab. 1). However, we found a significant difference between the period before and after 2003 (mean 29.5 vs. 16.0 mg m$^{-3}$, respectively). This decline in zooplankton DM in the Gulf of Trieste is consistent with the findings of Mozetič *et al.* (2012), who reported a regime shift in plankton between 2002 and 2003. This shift was related to lower nutrient concentrations due to reduced freshwater inputs from the Soča River in 2002–2007, particularly in 2003, a decline in seasonal diatom blooms and the dominance of smaller-sized phytoplankton.

A study (Kamburska & Fonda Umani, 2009) focussing on the temporal pattern of net zooplankton at a coastal station in the western part of the Gulf of Trieste covered two decades of monthly sampling (1986–2005) and was complemented by some earlier data. The DM values were in a similar range to ours (1 – 95 mg m$^{-3}$), and like us they found the highest monthly average in May and lower from November to February. In contrast to our observations of decreasing DM after 2003, they reported higher DM in the last two years of their study (2004, 2005 only until September), while their values in the 1990s were similar to ours. Nevertheless, the work of Benović *et al.* (1984), Kamburska & Fonda Umani (2009) and ours indicate a large seasonal and interannual variability of zooplankton DM, similar seasonal dynamics and a comparable range of DM values. However, in the last period of our study (after 2003), which was not covered by previous reports, we found a significantly lower zooplankton DM. Despite some interannual differences, this decline is consistent with general observations of oligotrophication in the northern Adriatic (Brush *et al.*, 2021).

Despite numerous studies on zooplankton communities, the estimated DM values of samples collected using nets with a comparable mesh size to ours (200–250 μm) have rarely been reported from other Mediterranean regions. A ten-year study (2007–2017) in the western Mediterranean (Fernández de Puelles *et al.*, 2023) showed considerable variability without clear temporal trends, with higher DM values (> 10 mg m$^{-3}$) in the western Alborán Sea and lower values (< 5 mg m$^{-3}$) in the eastern Balearic Sea. In an earlier study (1994–2003) in the Balearic Sea, Fernández de Puelles & Molinero (2008) also reported similarly low DM values with an average of 5.4 mg m$^{-3}$. Average annual DM values between 1.43 and 3.56 mg m$^{-3}$ were found off Marseille, with the biomass being highest at the nearshore stations (Gaudy & Champalbert, 1998). Similar DM values (0.7 – 5.2 mg m$^{-3}$) were found in the coastal area of Cyprus, while higher DM values were measured in the Saronikos Gulf (up to 11.9 mg m$^{-3}$ on average) and in the north-eastern Aegean Sea (Hannides *et al.*, 2015). Lakkis (1990) reported values (2 – 20 mg m$^{-3}$) in the Lebanese coastal waters. These comparisons show that despite oligotrophication in recent decades, zooplankton DM in the Gulf of Trieste is still higher than in most Mediterranean regions.

In our analysis of monthly data, no clear relationship was found between the regional atmospheric index WeMOi and zooplankton DM, although a weak positive correlation was established, i.e. positive WeMOi were associated with higher DM. Despite the non-significant correlation, years with lower DM showed a higher frequency of negative WeMOi monthly values below - 2.00, which are assumed to have a stronger influence on dry conditions (Martín *et al.*, 2012). Accordingly, Milošević *et al.* (2016), who studied seasonal and annual precipitation (1963–2012) in Slovenia, found that a positive WeMO phase led to more precipitation, especially in spring and autumn, which could have an impact on local river discharge.

In the northern Adriatic, a negative WeMO phase is associated with dry and stable weather with less precipitation and lower river discharge. In addition, higher surface temperatures during stronger and longer negative WeMO phase lead to stronger thermal stratification, which reduces the mixing of nutrients in the surface layers. While the analysis of the relationship between the monthly WeMOi data and zooplankton DM did not provide conclusive results, the annual WeMOi time series (1974 – 2019) showed a clear difference between the period before 2002, when the positive phase prevailed and zooplankton DM was higher, and the more recent period with negative WeMO phase and lower DM (Fig. 5).

Martín *et al.* (2012) found a clear link between climate fluctuations, i.e. positive WeMOi values, and higher sardine and anchovy production. They suggested that WeMOi impacted fish populations indirectly through effects on local environmental factors such as temperature and river discharge and referred to the positive phase of WeMO as a "cool waters, high river runoff phase". Their conclusion was that "a regional climatic index such as the WeMOi is more closely linked to local environmental conditions and explains a higher proportion of the variation in fisheries productivity than other climatic indices commonly used for the Atlantic Ocean, such as the NAOi".

Based on a 13-year study in the northwestern Mediterranean (Bay of Calvi), Fullgrabe *et al.* (2020) found a correlation between the winter NAO and the spring zooplankton peak and hypothesised an influence of large-scale processes on the regional zooplankton. In contrast, Feuilloley *et al.* (2022) found no significant correlation with NAOi and WeMOi in their long-term zooplankton study (1995–2019), which was also conducted in the northwestern Mediterranean (entrance to Villefranche Bay) and pointed to the importance of biotic interactions. Piontkovski *et al.* (2011) investigated the effects of atmospheric anomalies on zooplankton communities in the northern Adriatic and Black Sea using the NAO as an example and found that while some species showed a correlation with the NAO, changes in integrative characteristics such as DM were not pronounced. Berline *et al.* (2012) compared six mesozooplankton time series from 1957–2006, including the coastal location in the western Gulf of Trieste. They found no significant correlations between the climate indices and pointed out that local factors dominate at these coastal stations. However, they suggested that the link between local and large-scale climate should be further investigated if we want to understand the fluctuations in zooplankton.

Our analysis of 25 years (1993–2018) of paired phytoplankton and zooplankton samples showed a weak and statistically non-significant positive correlation between Chl *a* and zooplankton DM. This lack of strong coupling may be related to several reasons. Both biomass measurements are integrative and do not provide information on taxonomic composition and specific feeding relationships. Furthermore, there may be a different time lag between primary producers and consumers at different times of the year, in addition to possible predatory control of zooplankton.

Jellyfish can exert a strong top-down control on other zooplankton (Schneider & Behrends, 1998). The studies suggest that the effects are potentially large but show strong spatial and temporal variation depending on the occurrence of the blooms (Stoltenberg *et al.*, 2021). Most studies on the control of zooplankton by jellyfish in European seas come from the enclosed marine systems such as the Baltic Sea and the Black Sea. However, Stoltenberg *et al.* (2021), who reviewed the trophic interactions of jellyfish in the Baltic Sea, conclude that the lack of spatially and temporally consistent data on both jellyfish and their prey communities does not currently allow for a more holistic and quantitative assessment of the impact of jellyfish on mesozooplankton.

We compared the frequency of jellyfish blooms and zooplankton DM in the northernmost gulf of the enclosed Adriatic Sea. Statistical tests showed that DM was significantly lower in years when jellyfish blooms of several species occurred over longer periods of time.

A similar conclusion was reached by Malej (1989), who studied zooplankton DM and community composition in three years, one of which was characterised by a prolonged *Pelagia noctiluca* bloom; the "*Pelagia* year" had the lowest DM. A more general conclusion can be drawn from the study by Wright *et al*. (2021). Despite the paucity of data on global jellyfish biomass, they used a global biogeochemical model to suggest that jellyfish play an important role in regulating global marine plankton ecosystems which has generally been neglected.

In summary, we report the results of zooplankton biomass over more than four decades in the Gulf of Trieste using a standardised method to determine dry mass. The use of nets with similar mesh sizes (200 – 250 µm) ensures that our dataset provides comparable results for the period 1974–2019. The range of DM values was large (< 10 to almost 100 mg $m^{-3}$), we found a significant difference between the period before and after 2002, and the decline in the last period was consistent with the regime shift in plankton observed between 2002 and 2003 by Mozetič *et al.* (2012). Although the correlations between monthly regional climatic index WeMOi, Chlorophyll *a* and zooplankton DM were not significant ($p > 0.05$), they were weakly positively correlated. Moreover, the period with lower zooplankton DM (after 2002) was characterised by the predominance of the negative WeMO phase. In addition, the statistical tests showed that DM values were significantly lower in years when several jellyfish species bloomed over longer periods.

## ACKNOWLEDGEMENTS

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# DOLGOROČNA ŠTUDIJA ZOOPLANKTONSKE BIOMASE V TRŽAŠKEM ZALIVU (JADRANSKO MORJE)

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## *POVZETEK*

*V prispevku poročamo o rezultatih zooplanktonske biomase v Tržaškem zalivu, ki smo jo merili z uporabo standardizirane metode za suho maso v več kot štirih desetletjih. V tem obdobju (1974–2019) smo za vzorčenje zooplanktona uporabljali mreže s primerljivo velikostjo okenc (200 – 250 µm) kar zagotavlja primerljivost meritev. Izmerjene vrednosti suhe mase so nihale v širokem razponu (< 10 do blizu 100 mg* $m^{-3}$*), ugotovili smo statistično značilne razlike med obdobji pred in po letu 2003, upad biomase v zadnjem obdobju pa je bil skladen z ugotovitvami spremenjenega režima v planktonu med 2002 in 2003. Čeprav korelacija med regionalnim atmosferskim indeksom (WeMOi), klorofilno biomaso in zooplanktonsko suho maso ni bila statistično značilna, so bile višje vrednosti biomase povezane s pozitivno fazo WeMO in višjimi vrednostmi klorofila. Statistični testi pa so pokazali značilno nižjo biomaso zooplanktona v letih, ko smo beležili masovno pojavljanje več vrst želatinastega planktona, ki so trajali daljša obdobja.*

**Ključne besede**: mrežni zooplankton, suha masa, časovni niz, klorofil *a*, masovno pojavljanje meduz

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# OCCURRENCE OF THE LONGJAW SNAKE EEL, *OPHISURUS SERPENS* (OPHICHTHIDAE), IN TUNISIAN WATERS (CENTRAL MEDITERRANEAN SEA)

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## *ABSTRACT*

*This paper documents an additional and rare record of the longjaw snake eel,* Ophisurus serpens *(Osteichthyes: Ophichthidae), in Tunisian waters. The individual, captured off Ras Jebel, was a juvenile measuring 330 mm in total length and weighing 19.8 g. This constitutes the sixth overall and fifth well-documented record of* O. serpens *in Tunisia, suggesting the successful establishment of a viable population in the region. The study provides a detailed description of the specimen, including morphometric measurements and meristic counts.*

**Key words:** *Ophisurus serpens,* morphometric data, meristic counts, brackish area, Tunisian waters

# PRESENZA DEL PESCE SERPENTE, *OPHISURUS SERPENS* (OPHICHTHIDAE), NELLE ACQUE DELLA TUNISIA (MAR MEDITERRANEO CENTRALE)

## *SINTESI*

*Il presente lavoro documenta un ulteriore e raro ritrovamento del pesce serpente,* Ophisurus serpens *(Osteichthyes: Ophichthidae), nelle acque tunisine. L'esemplare, catturato al largo di Ras Jebel, era un giovane con una lunghezza totale di 330 mm e un peso di 19,8 g. Si tratta del sesto record complessivo e del quinto ben documentato di* O. serpens *in Tunisia, che suggerisce il successo dell'insediamento di una popolazione vitale nella regione. Lo studio fornisce una descrizione dettagliata dell'esemplare, comprese le misure morfometriche e i conteggi meristici.*

**Parole chiave:** *Ophisurus serpens*, dati morfometrici, conteggi meristici, area salmastra, acque tunisine

## INTRODUCTION

The serpent eel, *Ophisurus serpens* (Linnaeus, 1758), has a broad distribution spanning the western Indian Ocean, from southern Mozambique to South Africa, and the western Pacific, including waters off Japan and Australia (Bauchot, 1986). The species also occurs in the eastern Atlantic, from the northern coast of the Iberian Peninsula to South Africa (Bauchot, 1986), with additional records around the Madeira Islands (Wirtz *et al.*, 2008).

*O. serpens* has occurred in the Mediterranean Sea since Dieuzeide *et al.* (1954) first recorded the species off the Algerian coast. It has since been reported from multiple Mediterranean regions, including Italian waters (Tortonese, 1970), the Alboran Sea (Abad *et al.*, 2007), the Aegean Sea (Ulaș & Akyol, 2015), and the Adriatic Sea (Soldo & Lipej, 2022).

Bauchot (1986) remarked that the species was only found in the western Mediterranean Basin. However, Kousteni & Christidis (2019) reported occurrences off the Libyan coast (Shakman & Kinzelbach, 2007) as well as the Egyptian coast (El Sayed *et al.*, 2017), and further east, with 8 records from Turkish and 4 from Greek waters over the past 50 years. In the eastern Mediterranean, the species occurs in the Turkish Aegean Sea (Ulas & Akyol, 2015; Tuncer *et al.*, 2020), Mersin Bay (Ergüden *et al.*, 2016), the Sea of Marmara (Uzer *et al.*, 2024), and the Levant Basin, where it was recorded off the Lebanon coast (Bariche & Fricke, 2020).

While a few specimens of *O. serpens* have been recorded in the northern areas of Tunisia (Ben Amor *et al.*, 2009, 2017; Rafrafi-Nouira *et al.*, 2015), the species – as previously reported (Bradaï, 2000) – seems to be unknown in Tunisian southern waters. This new capture allows us to comment on the species' true status in the area.

## MATERIAL AND METHODS

Information on the capture of a specimen of *O. serpens* was provided by local fishermen familiar with the fishing grounds. The individual was collected on 30 August 2020, off Ras Jebel, a city in northeastern Tunisia (37°15′27.00″ N and 10°09′44.03″ E) (Fig. 1). It was captured using a trammel net with 30 mm mesh size, at a depth of 45 m over rocky sandy bottom, alongside mullid, scorpaenid and soleid species.

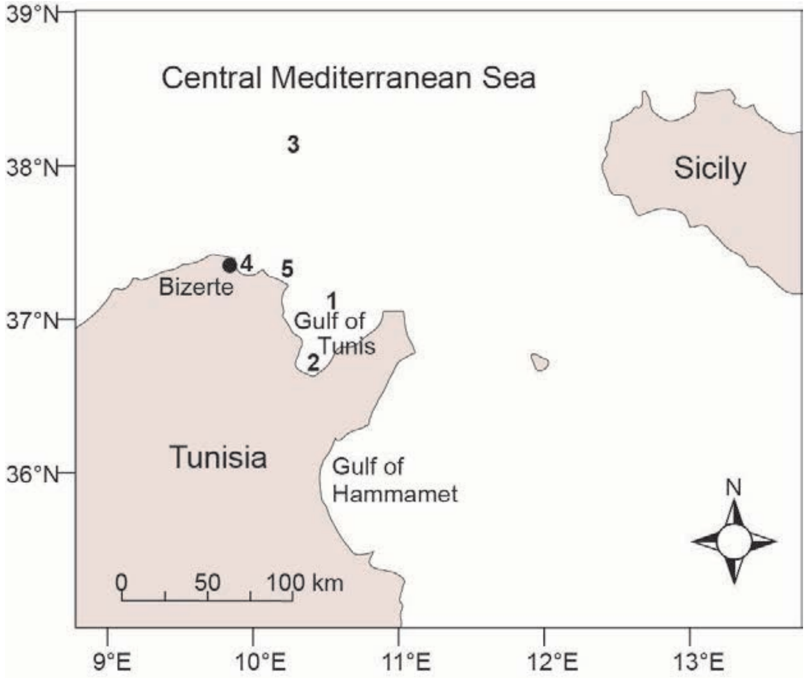

***Fig. 1: Map of the northern Tunisian coast indicating the capture sites of* O. serpens *in the area. 1. Gulf of Tunis (Lubet & Azouz, 1969). 2. Tunis Southern Lagoon (Ben Amor* et al.*, 2009). 3. Near Skarkis Bank (Rafrafi* et al.*, 2015). 4. Lagoon of Bizerte (Ben Amor* et al.*, 2017). 5. Off Ras Jebel (this study).***

***Sl. 1: Zemljevid severno tunizijske obale z označenimi lokalitetami ulova vrste* O. serpens *na obravnavanem območju. 1. Tuniški zaliv (Lubet & Azouz, 1969). 2. Tuniška južna laguna (Ben Amor in sod., 2009). 3. Blizu lokalitete Skarkis Bank (Rafrafi in sod., 2015). 4. Laguna v Bizerti (Ben Amor in sod., 2017). 5. V vodah okoli Ras Jebel (ta študija).***

All measurements of the specimen were taken using a digital calliper, with total length recorded to the nearest millimetre and total weight to the nearest 0.1 gram. The measurements are summarised in Table 1, along with meristic counts. The specimen was fixed in 10% buffered formaldehyde, preserved in 75% ethanol, and deposited in the Ichthyological Collection of the Institut Supérieur de Pêche et d'Aquaculture de Bizerte (Menzel Jemil, Tunisia), under catalogue number ISPAB Oph serp 01.

## RESULTS AND DISCUSSION

The present specimen measured 330 mm in total length (TL) and weighed 19.8 g (Fig. 2). It was identified as *Ophisurus serpens* based on a combination of key morphological characters: body extremely elongated, cylindrical and scaleless; eyes relatively small; snout slender and conical with protruding upper jaw, both jaws elongated and extending posteriorly beyond the eye; teeth in one-two series in jaws, canines in front, teeth in one row on vomer, enlarged anteriorly; dorsal, anal, and pectoral fins well-developed, pelvic and caudal fins absent; origin of dorsal fin slightly posteriorly to pectoral fin; anus in the anterior half of the body; coloration brownish-olive dorsally, silvery with yellow iridescences ventrally, dorsal and anal fins with grey margins, pore apertures in *linea lateralis* blackish.

The number of pores in the *linea lateralis* counted in the present specimen of 330 mm TL was 140, which is fewer than the 149 reported by Ben Amor *et al.* (2009) in a specimen measuring 333 mm TL. Such difference is consistent with the findings of Kousteni & Christidis (2019), who noted a positive allometry between body size and the number of pores in *linea lateralis*.

The morphometric measurements and meristic counts of the present specimen are consistent with previous descriptions of *O. serpens* by Dieuzeide *et al.* (1954), Tortonese (1970), Bauchot (1986), Rafrafi-Nouira *et al.* (2015), and Kousteni & Christidis (2019). This specimen therefore constitutes an additional record for Tunisian marine waters. According to Kousteni & Christidis (2019), *O. serpens* is sporadically caught in most areas, typically with 1 or 2 specimens recorded, except for Iskenderun Bay in eastern Türkiye, where Sangun *et al.* (2007) reported the capture of 41 specimens ranging from 210 to 410 mm TL, which allowed the establishment of an isometric relationship between body size and weight. This represents the highest number of *O. serpens* recorded to date from a single catch in the Mediterranean Basin. The individuals were relatively small, suggesting that a viable population may be locally established, despite the absence of larger specimens in the sample. This area could also be a hotspot for the species in the eastern Mediterranean; however, this hypothesis requires confirmation through additional captures.

***Tab. 1: Morphometric data (in mm and % of TL), meristic counts, and total body weight (in grams) of the*** *O. serpens* ***specimen captured off Ras Jebel (catalogue no. ISPAB Oph serp 01).***

***Tab. 1: Morfometrični podatki (v mm in % of TL), meristična štetja in celokupna telesna masa (v gramih) pri primerku*** *O. serpens****, ujetem v vodah blizu Ras Jebel (kataloška številka no. ISPAB Oph serp 01).***

| **Reference** | **ISPAB-Oph-ser 01** | |
|---|---|---|
| **Morphometric measurements** | **mm** | **% TL** |
| Total length | 330 | 100 |
| Preanal length | 145 | 43.9 |
| Predorsal length | 100 | 30.3 |
| Prepectoral length | 30 | 9.1 |
| Dorsal fin length | 230 | 69.7 |
| Anal fin length | 180 | 54.5 |
| Pectoral fin length | 2.5 | 0.8 |
| Body depth | 9.1 | 2.8 |
| Maximum body height | 11.6 | 3.5 |
| Snout length | 12.9 | 3.9 |
| Head length | 29.5 | 8.9 |
| Eye diameter | 2 | 0.6 |
| Pre-orbital length | 6.4 | 1.9 |
| Length of upper jaw | 12.4 | 3.8 |
| Length of lower jaw | 10.5 | 3.2 |
| Pectoral fin height | 7.4 | 2.2 |
| Pectoral fin-vent | 149 | 35.8 |
| Dorsal fin-vent | 45 | 13.6 |
| **Counts** | | |
| Number of pores in *linea lateralis* | 140 | |
| Pectoral fin soft rays | 13 | |
| **Total body weight (in gram)** | 19.8 | |

In Tunisian waters, *O. serpens* was first recorded by Lubet & Azouz (1969) in the Gulf of Tunis; however, no information was provided regarding the number of specimens captured, suggesting a probable local scarcity of the species. Since that initial record, only four specimens were reported from the area. Two were caught in open marine waters and two in restricted

***Fig. 2: Specimen of* O. serpens *captured off Ras Jebel on the northern Tunisian coast (catalogue no. ISPAB Oph serp 01). Scale bar = 200 mm.***
***Sl. 2: Primerek vrste* O. serpens*, ujet v vodah pri lokaliteti Ras Jebel na severni tunizijski obali (katalog no. ISPAB Oph serp 01). Merilo = 200 mm.***

brackish environments, specifically the Tunis Southern Lagoon (Ben Amor *et al.*, 2009) and the Lagoon of Bizerte (Ben Amor *et al.*, 2017). This suggests that in northern Tunisia, *O. serpens* inhabits a variety of aquatic environments and occurs at variable depths.

The local sample of *O. serpens* includes both juvenile and adult specimens, suggesting that a viable population is successfully established in the region. According to Kousteni & Christidis (2019), *O. serpens* nowadays occurs throughout the Mediterranean Sea. Its apparent rarity is likely due to the species' low commercial value, which often leads to discarding at sea when captured. Additionally, it may be misidentified as other closely related species within the same family or as other serpentiform fishes, such as congrid eels.

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# POJAVLJANJE ZOBATE JEGULJE, *OPHISURUS SERPENS* (OPHICHTHIDAE), IZ TUNIZIJSKIH VODA (OSREDNJE SREDOZEMSKO MORJE)

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## *POVZETEK*

*Avtorji poročajo o novem in enem od maloštevilnih zapisov o pojavljanju zobate jegulje,* Ophisurus serpens *(Osteichthyes: Opichthidae), v tunizijskih vodah. Primerek, ujet pri Ras Jebelu, je bil mladič, ki je v skupno dolžino meril 330 mm in tehtal 19,8 g. Gre za šesti skupni in peti dobro dokumentiran zapis o pojavljanju vrste* O. serpens *v Tuniziji, kar kaže na uspešno vzpostavitev preživetja sposobne populacije v regiji. Raziskava obravnava podroben opis primerka, vključno z morfometričnimi meritvami in merističnim štetjem.*

**Ključne besede:** *Ophisurus serpens*, morfometrični podatki, meristično štetje, brakični predel, tunizijske vode

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# SEAGRASSES: A PROMISING SOURCE OF BIOACTIVE COMPOUNDS FOR HUMAN HEALTH APPLICATIONS

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## *ABSTRACT*

*Seagrasses are unique marine flowering plants that provide critical ecological services and can serve as valuable reservoirs of bioactive compounds with potential health benefits. This review explores the bioactive metabolites found in four seagrass species native to European marine waters:* Cymodocea nodosa, Posidonia oceanica, Zostera marina, *and* Nanozostera noltei. *These species exhibit diverse chemical properties, including antioxidants, antimicrobials, and anti-inflammatory agents, making them promising candidates for pharmaceutical, nutraceutical, and cosmetic applications. Despite their promising applications in biotechnology, their full potential remains underexplored due to research and technological limitations. Future studies should focus on optimizing extraction methods, exploring synergistic interactions, and ensuring sustainable utilization of these valuable marine resources.*

**Key words:** seagrasses, European marine waters, bioactive compounds, human health applications

# FANEROGAME MARINE: UNA PROMETTENTE FONTE DI COMPOSTI BIOATTIVI PER APPLICAZIONI NEL CAMPO DELLA SALUTE UMANA

## *SINTESI*

*Le fanerogame sono piante marine che forniscono servizi ecologici critici e possono servire come preziosi serbatoi di composti bioattivi con potenziali benefici per la salute. Questa rassegna esplora i metaboliti bioattivi trovati in quattro specie di fanerogame native delle acque marine europee:* Cymodocea nodosa, Posidonia oceanica, Zostera marina *e* Nanozostera noltei. *Queste specie presentano diverse proprietà chimiche, tra cui antiossidanti, antimicrobici e agenti antinfiammatori, che le rendono promettenti candidati per applicazioni farmaceutiche, nutraceutiche e cosmetiche. Nonostante le loro promettenti applicazioni in biotecnologia, il loro pieno potenziale rimane poco esplorato a causa delle limitazioni tecnologiche. Gli studi futuri dovrebbero concentrarsi sull'ottimizzazione dei metodi di estrazione, sull'esplorazione delle interazioni sinergiche e sull'utilizzo sostenibile di queste preziose risorse marine.*

**Parole chiave:** fanerogame, acque marine europee, composti bioattivi, applicazioni per la salute umana

## INTRODUCTION

Seagrasses are the only group of marine flowering plants, uniquely adapted to thrive in underwater environments. Their morphological, physiological, ecological, and genetic adaptations facilitate survival in these habitats, including underwater pollination, internal gas transport, and the presence of epidermal chloroplasts (Hemminga & Duarte, 2000). Originating from terrestrial species, seagrasses have transitioned to marine habitats, forming vast meadows in shallow waters (Papenbrock, 2012). These meadows provide essential ecosystem services, serving as key feeding and breeding grounds for marine organisms (Ruiz-Frau *et al.*, 2017). Referred to as the "lungs of the sea," seagrasses contribute significantly to oxygen production and carbon sequestration, mitigating climate change through the blue carbon storage (Papenbrock, 2012; Bedulli *et al.*, 2020; James *et al.*, 2023). Indeed, seagrass ecosystems are estimated to sequester approximately 140 megagrams of organic carbon ($C_{org}$) per hectare within the top meter of soil (Fourqurean *et al.*, 2012). This accumulation occurs over centennial to millennial time scales, making seagrass up to 40 times more effective at capturing organic carbon compared to terrestrial forest soils. (Serrano *et al.*, 2021). Additionally, they stabilize sediments, filter pollutants, and enhance water quality (Reynolds *et al.*, 2016; Bonanno & Orlando-Bonaca, 2017). As a result, seagrass meadows are recognized as one of the priority habitats in Europe within the EU Habitat Directive (HD, 92/43/EEC) and the evaluation of their status is crucial for the implementation of the EU Water Framework Directive (WFD), and the Marine Strategy Framework Directive (MSFD) (Orlando-Bonaca *et al.*, 2015). Moreover, they are among the least conserved marine ecosystems (Hu *et al.*, 2021).

Beyond their ecological significance, seagrasses are gaining attention for their rich diversity of bioactive compound with antioxidant, anti-inflammatory, cytotoxic and antimicrobial activities (Ameen *et al.*, 2024). Despite increasing interest in marine-derived bioactives, research on seagrasses remains limited, presenting an opportunity for further exploration (Ribas-Taberner *et al.*, 2025). In recent years, there has been growing interest in seagrass-derived bioactive compounds for biotechnological applications (Rotter *et al.*, 2021, 2023). However, challenges such as preservation of their ecological stability and technological limitations hinder their full integration into biotechnology (Rotter *et al.*, 2021; Gono *et al.*, 2022).

This review provides an in-depth examination of the bioactive compounds of biotechnological relevance in the biomedical field, isolated and characterized from four native seagrass species in European marine waters: *Cymodocea nodosa* (Ucria) Ascherson, *Posidonia oceanica* (Linnaeus) Delile, *Zostera marina* Linnaeus, and *Nanozostera noltei* (Hornemann) Tomlinson & Posluszny. The paper also highlights some areas for future research on these seagrass species that could improve their use for human health while maintaining sustainable practices.

## MATERIAL AND METHODS

A systematic literature review was conducted to gain insights into the breadth of studies published on the bioactive compounds of the four European seagrass species and their potential benefits. The literature search, covering 2004–2025, was performed in Scopus Advanced search, VOSviewer and Google Scholar, focusing on peer-reviewed articles and excluding grey literature. The keywords employed in the search included seagrass, *Cymodocea nodosa*, *Posidonia oceanica, Zostera marina* and *Nanozostera noltei,* biotechnology, bioactive compounds, bioactive molecules, bioactive potential, health, pharma and biomedicine.

## RESULTS AND DISCUSSION

### Bioactive compounds in *Cymodocea nodosa*

*Cymodocea nodosa* (commonly known as Lesser Neptune grass) is the most common species in shallow, sheltered to semi-exposed Mediterranean sites, forming meadows that can be either mono-specific or mixed with *N. noltei* (Buia *et al.*, 1985). This species has its origins in tropical regions and is currently confined to the Mediterranean Sea and some areas in the North Atlantic, extending from southern Portugal and Spain to Senegal, including the Canary Islands and Madeira (OSPAR, 2010). It can be found in coastal waters, coastal lagoons, inlets and estuaries and other sheltered and semi-exposed habitats (Ivajnšič *et al.*, 2022). It is recognized as a pioneer species, adept at rapidly colonizing bare patches of the sea floor, since its rhizome can grow several meters annually (Boudouresque *et al.*, 1994).

*C. nodosa* contains several bioactive metabolites with potential pharmaceutical applications (Tab. 1; Fig. 1). Among them, diarylheptanoids and terpenoids have demonstrated antibacterial activity, particularly against mycobacterial strains and methicillin-resistant strains of Staphylococcus aureus (MRSA) (Kontiza *et al.*, 2008). The relatively simple structures of these metabolites also suggest they could be targets for further chemical modification to enhance their antibacterial properties (Kontiza *et al.*, 2008). In addition, diarylheptanoids, especially cymodienol, have shown strong cytotoxicity (Kontiza *et al.*, 2005).

***Tab. 1: Bioactive compounds extracted from the four European marine seagrasses and their reported bioactivities. CN** = Cymodocea nodosa**; ZM** = Zostera marina**; PO** = Posidonia oceanica**; NN**= Nanozostera noltei**.***

***Tab. 1: Bioaktivne spojine, pridobljene iz štirih evropskih morskih cvetnic, in njihove potrjene bioaktivnosti. CN** = Cymodocea nodosa**; ZM** = Zostera marina**; PO** = Posidonia oceanica**; NN** = Nanozostera noltei**.***

| Compound | Bioactivity | Seagrass species | References |
|---|---|---|---|
| Terpenoids | Antibacterial | CN | Kontiza *et al.* (2008) |
| Diarylheptanoids | Antibacterial, anticancer/ cytotoxic | CN, ZM | Kontiza *et al.* (2005); Kontiza *et al.* (2008); Li *et al.* (2021); Cacciola *et al.* (2024) |
| Polysaccharides | Antioxidant, antimicrobial, cytotoxic, antihypertensive, anti-obesity, antidiabetic | CN, PO, ZM | Kolenchenko *et al.* (2005); Berfad & Alnour (2014); Kolsi *et al.* (2015, 2016, 2017a, 2017b, 2018); Benito-Gonzalez *et al.* (2019); Perumal *et al.* (2021); Ribas-Taberner *et al.* (2025) |
| Phenolics | Antidiabetic, anti-inflammatory, antioxidant, analgesic, antihypertensive, antirheumatic, anti-arthritic, antimicrobial, anticancer/ cytotoxic | CN, PO, ZM, NN | Rees *et al.* (2008); Choi *et al.*, (2009); Subhashini *et al.* (2013); Berfad & Alnour (2014); Barletta *et al.* (2015); Custódio *et al.* (2015); Grignon-Dubois *et al.* (2015); Kolsi *et al.* (2017b); Manck *et al.* (2017); Styshova *et al.* (2017); Farid *et al.* (2018); Leri *et al.* (2018); Benito-Gonzalez *et al.* (2019); Sevimli-Gur & Yesil-Celiktas (2019); Vasarri *et al.* (2020); Ammar *et al.* (2021); Mechchate *et al.* (2021); Vasarri *et al.* (2021); Razgonova *et al.* (2022); Abruscato *et al.* (2023); Grignon-Dubois & Rezzonico (2023); Vasarri *et al.* (2023); Chabbani *et al.* (2024); Kevrekidou *et al.* (2024); Micheli *et al.* (2024); De Leo *et al.* (2025) |
| Proteins and peptides | Antioxidant, antimicrobial | PO | Berfad & Alnour (2014); Benito-Gonzalez *et al.* (2019); Punginelli et al. (2023) |

Furthermore, sulfated polysaccharides derived from *C. nodosa* exhibit a diverse range of bioactive properties, including significant antioxidant, antimicrobial, cytotoxic, antihypertensive activity, anti-obesity and anti-diabetic properties (Kolsi *et al.*, 2015, 2016, 2017a; Perumal *et al.*, 2021; Ribas-Taberner *et al.*, 2025; see Tab. 1). Sulfated polysaccharides derived from *C. nodosa* warrant special attention also for treating male infertility and enhancing sperm quality due to their antioxidant capabilities (Kolsi *et al.*, 2018; Ribas-Taberner *et al.*, 2025).

Among phenolic compounds, the chicoric acid, that was found to be abundant in *C. nodosa*, has high potential for management of metabolic alterations, thus representing a target for treatment of diabetes and its complications (De Leo *et al*, 2025). The hydroalcoholic extract of *C. nodosa* containing phenolic compounds exhibits significant antioxidant activity, which may protect against oxidative stress and be applied for managing metabolic disorders, particularly diabetes, by enhancing insulin secretion and reducing hyperglycemia and lipid levels in the blood (Kolsi *et al.*, 2017b). More recently, Chabbani *et al.* (2024) identified additional phenolic compounds in *C. nodosa*, including sinapic acid, myricetin, and quercetin-3-O-rutinoside, which demonstrate potential therapeutic properties, aimed at combating oxidative stress and inflammation. The extract's safety profile, with no cytotoxic effects observed, further supports its application in skincare products (Chabbani *et al.*, 2024).

### Bioactive compounds in *Posidonia oceanica*

*Posidonia oceanica* (the Neptune grass) is the most important Mediterranean endemic seagrass species, that forms meadows extending from the surface to depths of 40–45 m (Telesca *et al.*, 2015). These meadows provide multiple ecosystem services, including protection of coastlines from erosion, provision of breeding and nesting habitats for economically important species, and serving as a vital source of oxygen while facilitating high carbon sequestration within the matte (consisting of intertwined remnants of roots, rhizomes, and leaves, which effectively trap sediment and organic carbon, creating stable substrates) (Pergent-Martini *et al.*, 2021). The widespread distribution of *P. oceanica* in the Mediterranean Sea suggests that these meadows are the product of ecological and evolutionary processes that have unfolded over centuries (Giakoumi *et al.*, 2013; Telesca *et al.*, 2015).

Extracts of *P. oceanica* have shown anti-diabetic, antioxidant, vasoprotective and antimicrobial activities (Gokce & Haznedaroglu, 2008; Ozbil *et al.,* 2024). Phenolic compounds, such as chicoric, gentisic, ferulic and caftaric acid have potential analgesic, anti-inflammatory, antirheumatic, anti-arthritic and anticarcinogenic activities (Grignon-Dubois & Rezzonico, 2015; Mechchate *et al.,* 2021; Micheli *et al.,* 2024), see Tab. 1. These were also observed in *C. nodosa* and such phenolic similarities between *P. oceanica* and *C. nodosa* imply a possible evolutionary connection that may suggest that these families possess adaptive traits developed in response to comparable environmental pressures (Grignon-Dubois & Rezzonico, 2015). Polyphenols including gallic acid, catechin, epicatechin and chlorogenic acid that were isolated in *P. oceanica* extracts were able to inhibit the expression and activity of gelatinases MMP-2 and MMP-9 (enzymes that break down the extracellular matrix), which are associated with cancer cell invasion and metastasis (Barletta *et al.*, 2015). Additionally, Leri *et al.* (2018) highlighted the significant antioxidant properties of these bioactive metabolites, with potential use in therapeutic applications against malignancies and other chronic conditions due to their ability to impair malignant cell migration through autophagy modulation. Furthermore, the (hydro)alcoholic extracts of *P. oceanica* leaves containing phenols has potential anticancer applications, given their antioxidant, anti-inflammatory and anti-glycation properties (Farid *et al.,* 2018; Sevimli-Gur & Yesil-Celiktas, 2019; Abrsucato *et al.,* 2023; Vassari *et al.,* 2023; Kevrekidou *et al.,* 2024)

Cornara *et al.* (2018) reported that the extract of *P. oceanica*, rich in CA, exhibits significant radical scavenging activity and lipolytic activity. Regarding skin protection, the polyphenols of *P. oceanica* have potential therapeutic applications in treating conditions like psoriatic skin inflammation, indicating its potential use in complementary medicine for inflammatory skin diseases (Micheli *et al.*, 2024). Messina *et al.* (2021) concluded that the phenolic compounds found in *P. oceanica* are also promising candidates for applications particularly in cosmeceuticals and as protective agents against oxidative stress and UV-induced damage. They highlighted that the dried leaves of *P. oceanica* demonstrated significantly higher antioxidant activity that fresh leaves.

*P. oceanica* butanol extract containing phenolic acids and flavonoids, encapsulated in gelatin nanoparticles, as a promising and effective antidiabetic therapy (Ammar *et al.*, 2021). Additionally, the extract from *P. oceanica* egagropiles (round-shaped conglomerations created by the progressive disintegration of fibrous material sourced from its foliage and transported to nearby coastal areas by waves) showed a moderate inhibition against H5N1 virus (Farid *et al.*, 2018).

*P. oceanica* extracts containing phenols and flavonoids exhibit anti-inflammatory activities (Vasarri *et al.*, 2020), while those containing polyphenols, polysaccharides and proteins exhibit antioxidant and antimicrobial activities (Berfad & Alnour, 2014; Benito-Gonzalez *et al.,* 2019). The main polysaccharide known from angiosperm land plants in the cell walls is cellulose; however, it is currently lacking biotechnologically relevant biological activity properties for biomedical purposes (Pfeifer & Classen, 2020). The polysaccharides identified in *P. oceanica* that have bioactive qualities include galacturonic acid and xylose, which are components of pectin and hemicellulose. These polysaccharides contribute to the antioxidant, antifungal, and antiviral properties of the extracts, making them potential candidates for use in food and pharmaceutical applications (Benito-Gonzalez *et al.*, 2019).

### Bioactive compounds in *Zostera marina*

*Zostera marina* (commonly known as Eelgrass) is one of the world's most widespread marine phanerogams, predominantly found along the temperate and cold coasts of the Northern Hemisphere, but it is also present in the Mediterranean Sea, where its distribution is more limited. The species fulfils important roles as an ecosystem engineer in estuarine and coastal waters, enhancing biodiversity, contributing to sediment stability, and carbon and nutrient

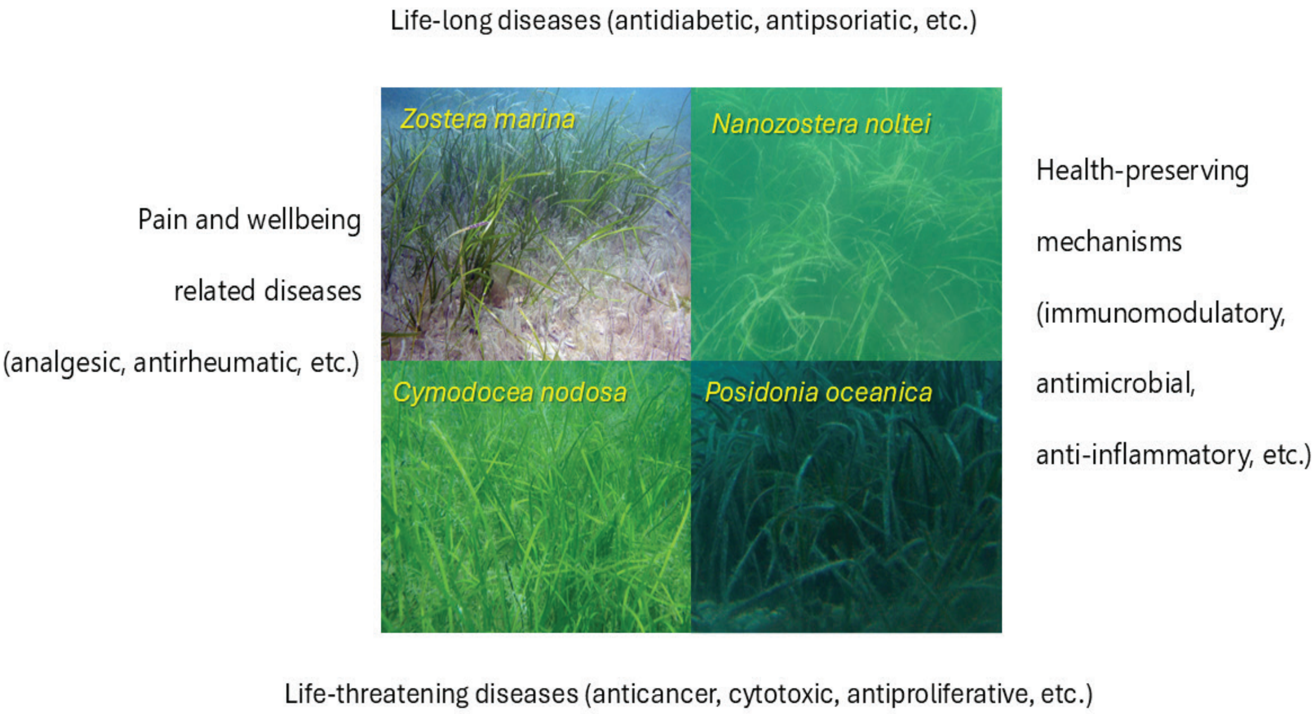

***Fig. 1: Potential bioactive properties of the four European marine seagrasses (photos: Tihomir Makovec).***
***Sl. 1: Potencialne bioaktivne lastnosti štirih evropskih morskih cvetnic (slike: Tihomir Makovec).***

storage (Duarte *et al*., 2013; Blok *et al*., 2018). Distinct life history strategies and a wide tolerance to a range of salinity and temperature conditions allow this seagrass species to exploit areas from brackish estuaries to open oceans over a large geographical range (Nejrup & Pedersen 2008).

*Z. marina* leaves decay very slowly and indeed, extracts from this seagrass exhibited antimicrobial and antioxidant activities (Zheng *et al*., 2014). Polysaccharides from *Z. marina* exhibit significant antioxidant activities (see Tab. 1). An example is zosterin, a low-etherified pectin with potential in reducing lipid peroxidation products, suggesting its use in therapeutic applications for oxidative stress-related conditions (Kolenchenko *et al*., 2005). Additionally, zosterin has been associated with various pharmacological effects, including hypocholesterolemic, antibacterial, antiviral, and immunomodulating properties, indicating its broad potential in medical applications (Kolenchenko *et al*., 2005).

Phenolics, such as zosteric acid and others, have shown potential as antimicrobial agents (Rees *et al.,* 2008; Choi *et al.,* 2009). Rosmarinic acid (RA) from *Z. marina* was also recognized for its antioxidant properties (Custódio *et al.,* 2016). Rosmarinic acid and flavonoids extracted from *Z. marina* have also evidenced therapeutic potential in the treatment of type 2 diabetes and hyperlipidemia, due to their antioxidant, anti-inflammatory, and immunomodulatory activities (Styshova *et al.*, 2017). Several polyphenols from *Z. marina* (chicoric, p-coumaric, rosmarinic, benzoic, ferulic and caffeic acids) exhibited significant cytotoxic effects against various cancer cell lines, indicating their potential use as chemotherapeutic agents in cancer treatment and as preventive supplements in oncology (Sevimli-Gur & Yesil-Celiktas, 2019). *Z. marina* polyphenols also have potential applications in pharmaceutical industry due to their antioxidant and anti-inflammatory properties (Grignon-Dubois & Rezzonico, 2023; Razgonova *et al*., 2022).

Diarylheptanoids extracted from *Z. marina* exhibited selective cytotoxic effects and significant inhibition of the HCT116 colon cancer cell line and potential for reducing tumor growth *in vivo* (Li *et al.,* 2021; Cacciola *et al.,* 2024).

### Bioactive compounds in *Nanozostera noltei*

*Nanozostera noltei* (the dwarf eelgrass) is widely distributed along the northeastern Atlantic coasts, from Norway to Mauritania, and in the Mediterranean and Black Seas (Short et *al*., 2007). This species frequently thrives in meadows of *C. nodosa* in the infralittoral belt, but it can be found in a variety of habitat types with variable salinity. In lagoonal systems, it establishes a narrow band within the mediolittoral zone, demonstrating its ability to endure partial desiccation (Lipej *et al*., 2006).

Only in recent decades several studies have examined the phenolic profile of this species (see Tab. 1), with rosmarinic, caffeic and zosteric acids having antioxident properties (Grignon-Dubois *et al.,* 2012; Subhashini *et al.,* 2013). Phenolic compounds, flavons and flavonoids from *N. noltei* suggest potential applications in pharmaceuticals (Manck et *al*., 2017).

Extracts of *N. noltei* are notable for their ability to chelate both copper and iron ions, potentially aiding in the reduction of oxidative stress and associated conditions (Custódio *et al*., 2016). This seagrass has demonstrated significant toxicity to various cell lines, suggesting promising applications in cancer research, particularly in targeting hepatocarcinoma cells, and may also contribute to alleviating Alzheimer's disease (Custódio *et al*., 2016).

### Sourcing and extraction of biotechnologically relevant bioactive compounds

Despite the ample evidence that indicates seagrasses as a resource for novel health and pharmaceutical formulations, it is important to highlight that seagrasses provide an excellent substratum for epiphytic organisms (such as bacteria, fungi, protozoa and algae), making these organisms an integral component of seagrass ecosystems (Borowitzka *et al*., 2006). In addition, distinct microbial communities within the seagrass leaves, roots, flowers, fruits, seeds and the rhizosphere are likely involved in ecologically important processes that benefit plants (Tarquinio *et al*., 2021). These microbial communities may be promoting the production or might be the main source of biotechnologically relevant secondary metabolites (Panno *et al.,* 2013; Rotter *et al.,* 2021). When bioprospecting for novel compounds, it is therefore important to sterilize the seagrass surfaces (targeting epiphytes) and conduct molecular analyses to assess the presence of microbial genetic markers. This can identify the producer organism of the biotechnologically relevant compound.

Regardless of the source of the main biological activities, it is important to again highlight that seagrass ecosystems are now recognized as critical habitats supporting biodiversity and ecosystem services (Duarte *et al*., 2025). Hence, when confirming the bioactivity and target sector for compounds from seagrasses, sustainable sourcing of the biomass and supply of biomolecules must be considered to maintain the ecological stability of these fragile communities (Rotter *et al*., 2020, 2021). In the case of seagrasses, research can rely on harvesting or beach wrack, provided that their harvesting is sustainable and does not affect the ecosystem balance in coastal areas (Rudovica *et al*., 2021). Wherever possible, harvesting can also be substituted/complemented by modern biotechnology approaches including systems biology and metabolic engineering (Rotter *et al*., 2024). Finally, to contribute to environmental sustainability to an even higher degree, besides sourcing, extraction methods should be improved by means of greener methodologies avoiding the use of toxic organic solvents (Benito-González et al., 2019).

## CONCLUSIONS

Seagrass meadows are among the most essential and productive yet threatened benthic habitats, warranting significant scientific attention, particularly in the field of biotechnology. The bioactive metabolites found in marine plants have been shown to address various human health concerns, including several diseases, and hold promise for developing new natural-based therapeutic products.

The bioactive compounds found in the reviewed seagrass species exhibit a diverse array of health-promoting properties, positioning them as significant resources for the development of novel therapeutic drugs. Their bioactive potential highlights their ability to act as inhibitors of various harmful pathogens within the pharmaceutical sector. These compounds also show promise in treating metabolic disorders and cancers. Nevertheless, this review does not cover the literature on human clinical trials involving bioactive molecules derived from seagrasses or the sustainable production of drugs, considering the yield, maintenance of ecological balance or the use of green extraction processes, as this represents a separate and extensive area of research. Many bioactive metabolites from seagrasses remain unidentified, and ongoing research aims to uncover all relevant compounds that contribute to human well-being. Future research should focus on environmentally and economically sustainable extraction methods for metabolites with significant therapeutic potential.

Further studies should investigate the long-term stability and shelf life of seagrass extracts and their use in various formulations. Additionally, future research should explore the potential synergistic effects of various seagrass bioactive compounds, both among themselves and in combination with other ingredients, to enhance product effectiveness. Finally, as the extraction of bioactive compounds from marine resources continues to expand globally, it is crucial to assess the environmental impact of harvesting seagrass meadows. This will ensure that sustainable practices are upheld while utilizing this valuable resource. Hence, extraction from seagrasses or their epiphytes should be complemented by using metabolic engineering and chemical synthesis.

# MORSKE CVETNICE: OBETAVEN VIR BIOAKTIVNIH SPOJIN ZA UPORABO V ZDRAVSTVU

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## *POVZETEK*

*Morske cvetnice so edinstvene morske rastline, ki zagotavljajo ključne ekološke storitve in lahko služijo kot dragoceni viri bioaktivnih spojin s potencialnimi koristmi za zdravje ljudi. Ta pregled obravnava bioaktivne metabolite, prisotne v štirih vrstah morskih trav, ki so domorodne v evropskih morskih vodah:* Cymodocea nodosa, Posidonia oceanica, Zostera marina *in* Nanozostera noltei. *Te vrste izkazujejo raznolike kemijske lastnosti, vključno z antioksidativnim, protimikrobnim in protivnetnim delovanjem, zaradi česar so obetavne za uporabo v farmacevtski, nutracevtski in kozmetični industriji. Kljub njihovemu potencialu v biotehnologiji pa ta ostaja premalo raziskan zaradi raziskovalnih in tehnoloških omejitev. Prihodnje študije bi se morale osredotočiti na optimizacijo metod ekstrakcije, raziskovanje sinergijskih učinkov ter zagotavljanje trajnostne uporabe teh dragocenih morskih virov.*

**Ključne besede:** morske trave, evropske morske vode, bioaktivne spojine, uporaba za zdravje ljudi

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# OCENE IN POROČILA

# *RECENSIONI E RELAZIONI*

# *REVIEWS AND REPORTS*

## Book review:
## MIRRORS OF THE SEA: WHEN SCIENCE AND ART MEET. 30 YEARS OF THE UNESCO INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION IN SLOVENIA (ZRCALA MORJA: KO SE SREČATA ZNANOST IN UMETNOST. 30 LET DELOVANJA MEDVLADNE OCEANOGRAFSKE KOMISIJE UNESCO V SLOVENIJI)

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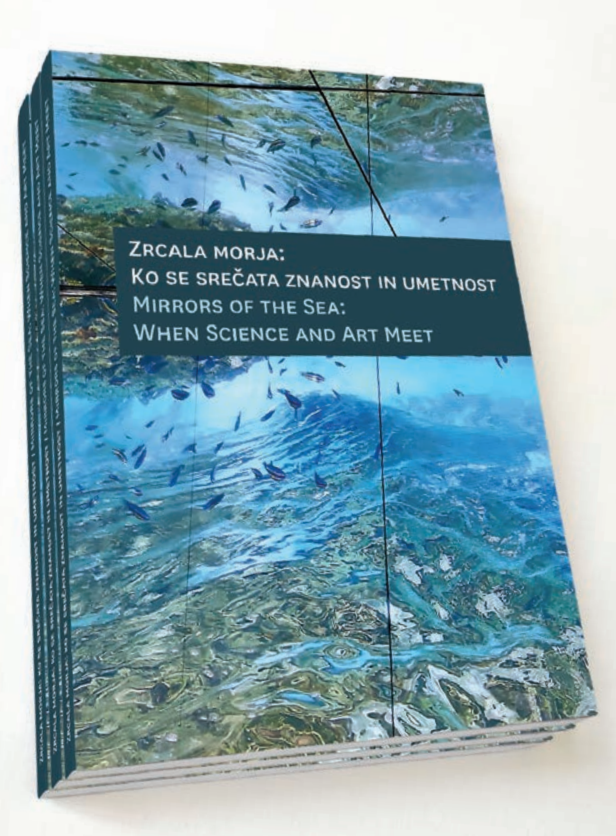
An intriguing new book, *Mirrors of the Sea: When Science and Art Meet* (edited by Glorjana Veber), was published in 2024 by Iriu d.o.o. in Polzela, and KUD Zrakogled, Koper, Slovenia. This 157-page multi-authored and bilingual (written in Slovenian and English) paperback accounts for the 30-year efforts of the Slovenian National Committee of the Intergovernmental Oceanographic Commission of UNESCO (NC/IOC/UNESCO) since Slovenia joined IOC/UNESCO in 1994. The book reflects on the progress made in marine ecosystem research and public education about the marine environment. Its goal is to underscore the importance of a healthy ocean ecosystem for a sustainable Earth and humanity.

The Intergovernmental Oceanographic Commission (IOC) is the sole United Nations (UN) body specializing in ocean science and services. It promotes international cooperation and facilitates and coordinates marine research to improve the management of the oceans, coasts, and marine resources. With 150 Member States, the IOC coordinates programs such as capacity development, ocean observations, tsunami warning systems, and ocean literacy. Currently, the IOC leads the UN Decade of Ocean Science for Sustainable Development 2021-2030, known as the "Ocean Decade."

Oceans, which cover 71% of the Earth's surface, evoke a sense of vastness of infinity. They provide many services to humanity, helping to mitigate climate change, produce oxygen, provide food, and more. Nowadays, however, they are no longer infinite, as the expansion of human activity has increased carbon dioxide emissions, biodiversity loss, and other global environmental issues that harm marine ecosystems. These changes are especially evident in the Northern Adriatic Sea, a semi-enclosed body of water that includes Slovenia's zone. The sea, surrounded by highly populated shores (total population: 25 million), receives significant river discharge (90,000 km$^3$ annually), historically contributing to eutrophication. This process has led to harmful events, such as phytoplankton blooms (red tides), sea-bottom deoxygenation, jellyfish blooms, and mucilage formation. Slovenian marine scientists have been working to understand these phenomena and propose solutions. NC/IOC has supported these efforts through research and public outreach, often integrating art to deepen understanding of marine ecosystems.

The book's introductory chapter, *Art and Science as Related Activities*, explores the relationship between these disciplines. Since ancient Greece, this connection has been recognized, as Aristotle noted in *Physics*: "Generally art, in some cases, completes what nature cannot bring to a finish and, in others, imitates nature." Both art and science share a common goal: to discover the unknown and create something meaningful for humanity. While scientists convey facts, artists evoke emotions and empathy, making complex ideas more accessible to the public.

The first event of such an interdisciplinary approach, *Colors of the Bay*, was organized in 1998, the UN International Year of the Ocean, by scientists from the Marine Biological Station of the National Institute of Biology (MBS/NIB) and artists. The theme of "colors" symbolized their respective methods: marine scientists analyze the colors of the sea to assess the water quality and ecosystem health, while artists use colors to create evocative imagery. The event featured scientific posters explaining marine food webs, from single-celled



phytoplankton to carnivorous fish, and underwater photography showcasing hidden worlds of the sea. Artists contributed vivid illustrations of marine life, such as algae, protozoa, jellyfish, mollusks, crustaceans, and fish, symbolizing healthy marine ecosystems and imaginative depictions of polluted seas.

In the subsequent events, more artists collaborated through texts (entitled *Thieves of the Sea, Mirrors of Stars*, highlighting the sea's fragility and vitality), dance performances (*Is the Sea Still Breathing?*, addressing hypoxia and anoxia), and multimedia art (*Aurelia 1+Hz*, exploring the mystery of jellyfish; *AquA(I) formings*, examining the human impact on the ocean; *LINIJA + 1233M – 1233M*, depicting plankton vertical migration and ocean acoustics; *Echinoidea Future – Adriatic Sensing*, focusing on water quality challenges). Children also participated as young artists in several competitions. Additional exhibitions included themes such as *Natural Heritage of the Sečovlje Saltpans* and *About the Sea and Salt*, featuring the Sečovlje Saltpans, and *The Slovenian Sea – Photographs of the Underwater World*, *Life on Pillars*, *Jellyfish Around Us*, displaying the diverse underwater world of the Gulf of Trieste. These events combined science and art to engage the public and convey vital messages about the ocean's beauty, secrets, complexity, and fragility.

As a biological oceanographer, I contributed to Slovenian marine science through a bilateral project between Hiroshima University, Japan, and MBS/NIB focusing on jellyfish blooms, a shared problem in both the Inland Sea of Japan and the Northern Adriatic Sea. During this time, I also acted as an ambassador of peace, helping publish a Slovenian translation of "*My Hiroshima*" a picture book written in Japanese by hibakusha Junko Morimoto. I had an opportunity to attend an A-bombed tree (hibakujumoku) planting ceremony at the Ljubljana Botanical Garden. The second generation of hibakujumoku, symbolizing world peace and resilience, is firmly rooted in Slovenian soil.

From this book, it is clear that the NC/IOC and MBS/NIB have adopted a unique, interdisciplinary approach to marine education and outreach, fostering a comprehensive understanding of how oceans and the Earth are changing. I applaud the Slovenian people's peace-loving spirit and commitment to sustainability. The year 2024 marks not only the 30th anniversary of NC/IOC's activities but also a milestone for world peace, as the Nobel Peace Prize was awarded to the Japan Confederation of A- and H-Bomb Sufferers Organizations (Nihon Hidankyo). May this year inspire continued efforts for global harmony and a sustainable future.

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## KAZALO K SLIKAM NA OVITKU

SLIKA NA NASLOVNICI: Afriški kostorog (*Stephanolepis diaspros*) je tujerodna vrsta, ena od prvih lesepskih selivk, ki se ji je uspelo prebiti v Sredozemsko morje. Prišla je tudi do slovenskega dela Jadranskega morja. Je zelo oportunistična vrsta, ki poskuša najti hrano tudi znotraj ribjih farm. (Foto: Borut Furlan)

Sl. 1: Za nekatere vrste rakovic, kot je na primer volnata rakovica (*Dromia personata*), je značilno, da si na oklep nadenejo klobuke, ki jih izrežejo iz različnih morskih nevretenčarjev, s čimer postanejo nevidne za plenilce. V današnjem času, ko je morje močno onesnaženo s plastičnimi odpadki, lahko opazimo celo rakovice, ki so si klobuk izdelale iz plastike. (Foto: Borut Furlan)

Sl. 2: Morski travniki zagotavljajo številne ekosistemske storitve – umirjajo delovanje valov, stabilizirajo sediment, nudijo bivalne niše mnogim nevretenčarjem in še marsikaj. Pomembni so tudi za morsko biotehnologijo, saj ponujajo številne možnosti pridobivanja novih učinkovin. (Foto: Borut Furlan)

Sl. 3: Frater (*Diplodus vulgaris*) iz družine šparov (Sparidae) je ena od najpogostejših obrežnih rib. Pri tej vrsti se občasno pojavljajo skeletne deformacije in druge anomalije. Znani so primeri, ko taki primerki brez težav sobivajo z normalnimi osebki v naravi. (Foto: Borut Furlan)

Sl. 4: Vrstijo se odkritja tujerodnih vrst, ki so se skozi Sueški prekop prebile v Sredozemsko morje. Ena izmed njih je tudi glavničasta ustnača *Pteragogus trispilus,* ki so jo potrdili v malteških vodah. (Foto: Borut Furlan)

Sl. 5: Za stražne rakovice (družina Pinnotheridae) je značilno, da kot simbionti prebivajo znotraj lupin školjk. Pred kratkim so v Tržaškem zalivu v dveh primerih odkrili primerka vrste *Pinnotheres bicristatus*, ki so jo doslej zasledili le še v dveh primerih v španskih vodah zahodnega Sredozemskega morja. (Foto: I. Frkovič)

Sl. 6: Morski psi izkazujejo ljubezen na zelo nenavaden način. Samci med parjenjem grizejo samice, da bi jih zadržali ob sebi, kar se kaže v značilnih sledeh »ljubezenskih ugrizov« na samičjih bokih. Tako vedenje so denimo ugotovili pri belem morskem volku (*Carcharodon carcharias*). (Foto: Borut Furlan)

## INDEX TO PICTURES ON THE COVER

FRONT COVER: The reticulated leatherjacket (*Stephanolepis diaspros*) is an alien species and one of the first migratory species to have successfully entered the Mediterranean Sea. It has also reached the Slovenian part of the Adriatic. It is considered a highly opportunistic species, foraging even inside fish farms. (Photo: Borut Furlan)

Fig. 1: Some crab species, such as the sponge crab (*Dromia personata*), are known to wear hat-like objects on their carapaces, which they cut from various marine invertebrates to make themselves invisible to predators. In today's era of severe plastic pollution, it is even possible to observe crabs that have fashioned their hats from plastic waste. (Photo: Borut Furlan)

Fig. 2: Seagrass meadows provide many ecosystem services, as they attenuate the wave action, stabilize sediments, serve as habitats for a wide range of invertebrates, and much more. They are also important from the perspective of marine biotechnology, offering numerous opportunities for obtaining new active biocompounds. (Photo: Borut Furlan)

Fig. 3: The two-banded sea bream (*Diplodus vulgaris*) from the family of sea breams (Sparidae) is one of the most common coastal species. While this fish occasionally displays skeletal deformities and other anomalies, there are documented cases where such specimens successfully coexist with normal individuals in natural environments. (Photo: Borut Furlan)

Fig. 4: Discoveries of alien species that have made their way into the Mediterranean Sea through the Suez Canal are on the increase. Among these is the comb wrasse, *Pteragogus trispilus*, recently confirmed in Maltese waters. (Photo: Borut Furlan)

Fig. 5: Guard crabs (family Pinnotheridae) typically reside within mussel shells as symbionts. Recently, two cases of *Pinnotheres bicristatus* have been discovered in the Gulf of Trieste – a species previously observed only twice in the Mediterranean Sea, both times in Spanish waters. (Photo: I. Frkovič)

Fig. 6: Sharks exhibit love in a very peculiar way. During mating, the males bite the females to maintain proximity, leaving distinct "love bite" marks on their flanks. This behavior has been observed in the white shark (*Carcharodon carcharias*). (Foto: Borut Furlan)

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