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IS THE GULF OF TRIESTE A POTENTIAL NURSERY AREA FOR CERTAIN ELASMOBRANCH SPECIES?

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ABSTRACT

This study aimed to determine whether the Gulf of Trieste meets the criteria for a nursery area as defined by different sources, primarily Heupel et al. *(2007). The analysis was based on elasmobranch specimens from the collection of the Marine Biology Station Piran (National Institute of Biology, Slovenia), comprising five species (*Mustelus mustelus, M. punctulatus, Torpedo marmorata, Raja asterias, *and* Aetomylaeus bovinus*) caught as bycatch over a 24-year period. Four of the five species (excluding* A. bovinus*) fulfilled all three criteria. According to the data analyzed, the Gulf of Trieste could be considered a communal juvenile nursery area for the assessed species. In addition, records of juveniles belonging to other elasmobranch species reported during the study period in the area suggest the potential importance of this area as a nursery ground for other species as well.*

Key words: elasmobranchs, parturition, nursery area criteria, abiotic conditions, bycatch, northern Adriatic

PUÒ IL GOLFO DI TRIESTE VENIR CONSIDERATO UN'AREA DI NURSERY PER ALCUNE SPECIE DI ELASMOBRANCHI?

SINTESI

Lo studio ha l'obiettivo di verificare se il Golfo di Trieste soddisfi i criteri per essere definito un'area di nursery secondo diverse fonti, in particolare secondo Heupel et al. *(2007). L'analisi si è basata sugli esemplari di elasmobranchi conservati nella collezione della Stazione di biologia marina di Pirano (Istituto nazionale di biologia, Slovenia), comprendente cinque specie (*Mustelus mustelus, M. punctulatus, Torpedo marmorata, Raja asterias e Aetomylaeus bovinus*) catturate come catture accessorie nell'arco di 24 anni. Quattro delle cinque specie (esclusa* A. bovinus*) hanno soddisfatto tutti e tre i criteri. Sulla base dei dati analizzati, il Golfo di Trieste potrebbe essere considerato un'area di nursery giovanile comune per le specie valutate. Le segnalazioni di individui giovanili di altre specie di elasmobranchi registrate nell'area suggeriscono l'importanza potenziale del Golfo come nursery anche per altre specie.*

Parole chiave: elasmobranchi, parto, criteri di area di nursery, condizioni abiotiche, catture accessorie, Adriatico settentrionale

INTRODUCTION

Most elasmobranch species occupy high trophic levels in marine ecosystems and play a major role in their structure and function, which means that their removal would likely be detrimental to these ecosystems (Pough & Janis, 2019). They display K-selected life-history traits, which include slow growth rates, long lifespans, late maturity, long gestation periods, and few offspring (Dulvy *et al.,* 2014). Along with a general tendency toward age and sex segregation, these traits make them especially vulnerable to human impacts, as many species require more than one suitable habitat for different segments of the population (*i.e.*, juveniles and adults, males and females) (Muñoz-Chapuli, 1984; Bradai *et al.*; 2005; Pough & Janis, 2019). In the Mediterranean Sea, volumes and species composition of elasmobranchs captured as bycatch are poorly documented, with available data often too inconsistent to be incorporated in national and international statistics (Dulvy *et al*., 2014) and the taxonomic resolution of catch statistics remaining poor (Cashion *et al*., 2019). Recently, the Important Shark and Ray Area (ISRA) identification process in the Mediterranean Sea has classified 2 ISRAs in the northern Adriatic, namely, the western Vir Sea (Croatia), important for angel sharks (*Squatina squatina*), and Cervia–Marina di Ravenna (Italy), important for sandbar sharks (*Carcharhinus plumbeus*) (ISRA, 2025). Additionally, the entire northwestern Adriatic has been classified as an ISRA for threatened species such as the spiny dogfish (*Squalus acanthias*), and as a reproductive area for the common smooth-hound (*Mustelus mustelus*) (ISRA, 2025). The Gulf of Trieste and the broader northern Adriatic have previously been suggested as nursery areas for certain elasmobranch species by Lipej *et al*. (2008; 2024; Fig. 1), but they have never been directly evaluated as such.

Beck *et al*. (2009) define a nursery area as an environment in which juveniles of a certain species occur at higher densities, experience lower predation risk, or exhibit faster growth rates than in other areas (Tab. 2). Also, the species using an area as a nursery are expected to enter the area as neonates, accumulate biomass, and then move offshore. However, some of these criteria are vague and difficult to assess, even with modern technology (Heupel *et al.,* 2007). Heupel *et al*. (2007) proposed an alternative set of criteria, according to which an area can be defined as an elasmobranch nursery if: i) newborn or young-of-the-year individuals are encountered there more frequently than in other areas; ii) newborn or young-of-the-year individuals tend to remain in or return to for extended periods; iii) the area or habitat is repeatedly used across years (Tab. 2). Martins *et al*. (2018) adopted the criteria proposed by Heupel *et al*. (2007) for viviparous species, but added criteria for discriminating between nursery areas of ovoviviparous and oviparous species, and distinguished juvenile habitats (secondary nursery areas) from nursery habitats (primary nursery areas), as first introduced by Bass (1978). Primary and secondary nursery areas may overlap, but not necessarily. Distinguishing between them is important in areas where many species co-occur, given that cannibalism is common among some elasmobranch groups. In these cases, juvenile aggregation areas that are spatially separated from the adults may in fact function as nursery areas, with the adult–juvenile segregation serving as an important qualifying

Fig. 1: Juvenile and newborn specimens of the Mediterranean starry ray** (Raja asterias) **and adult and newborn specimens of the marbled electric ray** (Torpedo marmorata) **from the Gulf of Trieste. (Photos by Jernej Uhan and Domen Trkov, respectively)
Sl. 1: Mladostni osebki in novorojenčki zvezdaste raže** (Raja asterias) **ter odrasli osebki in novorojenčki marmoriranega električnega skata** (Torpedo marmorata) **iz Tržaškega zaliva. (Avtorja fotografij: J. Uhan in D. Trkov).

characteristic (Heupel *et al.*, 2007; Martins *et al.*, 2018). There have also been records of different species using the same area as a nursery, called a communal nursery, where juveniles of multiple species co-occur while adults are mostly absent (Rosa *et al.*, 2023). However, in such nurseries, juveniles face a trade-off between lower predation risk and increased competition, both with conspecifics and juveniles of other species. This effect may be reduced through resource partitioning, provided these are sufficient within the nursery area (Rosa *et al.*, 2023). The purpose of this study was to examine the available data on elasmobranch species in the Gulf of Trieste and determine whether sufficient evidence exists to classify the area as an elasmobranch nursery.

MATERIAL AND METHODS

Study area

The Gulf of Trieste is the northernmost part of the Adriatic Sea, shared by Italy, Slovenia, and Croatia (Fig. 2). The Istrian peninsula partially closes it off to the south, creating a relatively isolated area (Malačič & Petelin, 2009). Covering around 600 km^2, the gulf has an average depth of 18.7 m and a maximum depth of 25 m (DEIMS-SDR, 2025). Apart from several flat islets at the entrance to the Marano–Grado lagoon, no islands occur within the gulf. Its main freshwater input (Fig. 2) is provided by the Isonzo River (Monti *et al.*, 2012). Although tidal amplitudes in the Gulf of Trieste are among the largest in the Adriatic Sea, they rarely exceed 1 m (Malačič & Petelin, 2009). The southeastern coast, extending from Miramare to Muggia, has been extensively modified by human activity and artificial structures such as piers and harbor facilities (Monti *et al.*, 2012). The majority of the Slovenian part of the gulf is characterized by sedimentary bottom (mud, muddy sand, and sand) (UNEP, 2021). The remaining rocky coastal areas include sandstone habitat types colonized by algal vegetation, whereas sheltered bays support seagrass meadows. Offshore, the soft-bottom seabed is interspersed with thousands of biogenic outcrops formed by calcareous organisms growing on various hard substrates (Falace *et al.*, 2024). The northern Adriatic is one of the

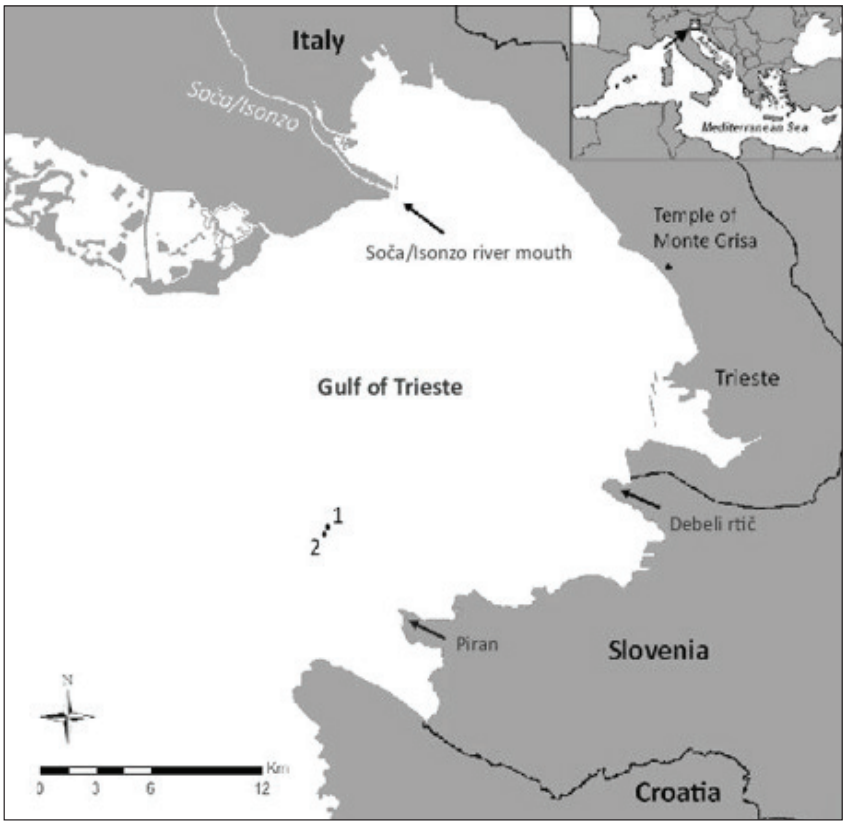

Fig. 2: Map of the Gulf of Trieste.
Sl. 2: Zemljevid obravnavanega območja Tržaškega zaliva.

regions with the highest permanent production in the Mediterranean Sea, where mesozooplankton biomass exhibits a much broader range than elsewhere (Conversi *et al*., 2009).

Species analyzed

A total of 549 specimens belonging to 5 species were assessed, including 2 shark species and 3 batoid species (Tab. 1): the common smooth-hound (*M. mustelus*), the blackspotted smooth-hound (*M. punctulatus*), the marbled electric ray (*Torpedo marmorata*), the Mediterranean starry ray (*Raja asterias*), and the bull ray (*Aetomylaeus bovinus*). All specimens included in the analysis were caught as bycatch in the Gulf of Trieste between 2000 and 2024 and were subsequently handed over to researchers at the Marine Biology Station (National Institute of Biology) in Piran. Specimens were sexed based on the presence or absence of secondary sexual characters (*i.e*., claspers). Sexual maturity and age were determined using indicators such as clasper calcification, umbilical scars, and body size compared to known size at maturity. For specimens without direct age/maturity data but for which biometric data were available, maturity was estimated as newborn, juvenile, or adult based on publicly available literature (CIESM, 2025; FishBase, 2025). For each specimen, we calculated Fulton's condition factor using the formula (Fulton, 1902): K = (W/L^3) x 100, where *K* is Fulton's condition factor, *W* is the weight of the fish (g), and *L* is the length (typically total length in cm). We then compared these values to species-specific condition factors from previous studies conducted in the Mediterranean Sea. Condition factors serve as indicators of fish welfare and population health, as they reflect environmental quality and suitability, including water quality and food availability. They also provide information on the interaction between biotic and abiotic factors influencing the physiological condition of different species (Ragheb, 2023).

The occurrence of the species in the Adriatic Sea was also included in the analysis. Five occurrence classes were defined by Soldo & Lipej (2022): rare – when species is recorded after a long period of time (decades); occasional – recorded every few years; common – with several single records on a yearly basis; abundant – multiple records in catches or sighted every year; questionable/not confirmed – when a record needs confirmation. All five species included in this study have been reported to favor shallow coastal waters along the continental shelf, characterized by high food availability, as reproductive and nursery habitats (Serena & Relini, 2006; Consalvo *et al*., 2007; Enajjar *et al*., 2015; Catalano *et al*., 2021); therefore, the Gulf of Trieste was considered a strong candidate for a potential nursery area.

Criteria for nursery areas

Among several nursery area definitions, we decided to use the criteria defined by Heupel *et al*. (2007) (Tab. 2), as they can be applied to areas such as the northern Adriatic, where bycatch and sighting reports are scant and tracking data for juveniles or adults are unavailable. The biotic and abiotic conditions of the Gulf of Trieste were also compared to the environmental preferences of each of the five species through a systematic literature review. Analyzing these parameters alongside comparable data from the rest of the northern Adriatic and the Mediterranean Sea, we assessed whether the Gulf of Trieste can be considered a nursery ground for certain elasmobranch species found in the Adriatic Sea, based on the three nursery area criteria described by Heupel *et al*. (2007).

Tab. 1: Species analyzed, occurrence status in the Adriatic, total number of specimens caught, number of specimens with available biometric data (males:females), and total length (TL) at maturity for each sex.
Tab. 1: Analizirane vrste, njihov status v Jadranu, število ujetih osebkov, biometrični podatki (samci: samice) in celotna dolžina (TL) ob spolni zrelosti za vsak spol.

Latin name	Common name	Occurrence in the Adriatic Sea (Soldo & Lipej, 2022)	No. of specimens caught (2000-2024)	No. of male : female specimens with biometric data	Total length at maturity for males : females in cm	Reproductive Period / parturition
Mustelus mustelus	common smooth-hound	abundant	138	13 : 20	70–80 cm : 70–80 (Lipej *et al*., 2011; FishBase 2025)	late spring (Saïdi *et al*., 2008; Ozcan & Başusta, 2018; Boscolo Palo *et al*., 2022)
Mustelus punctulatus	blackspotted smooth-hound	common	175	111 : 56	90 cm : 100 (Lipej *et al*., 2011; FishBase, 2025)	mid-May to early June (Saïdi *et al*., 2009; Boscolo Palo *et al*., 2022)
Torpedo marmorata	marbled electric ray	common	74	47 : 27	24.1 : 26.1 (Bajt *et al*., 2024)	May, August, September–February (Capapé, 1979; Consalvo *et al*., 2007; Chatzispyrou *et al*., 2021)
Raja asterias	Mediterranean starry ray	common	127	88 : 22	45–54 : 56.1–60 (Sviben *et al*., 2019; CIESM, 2025)	summer to early autumn (Stehmann & Bürkel, 1984; Serena & Relini, 2006)
Aetomylaeus bovinus	bull ray	rare	37	20 : 17	80–95 : 90–100 (CIESM, 2025)	late spring and summer (Michael, 1993)

Tab. 2: Summary of nursery area definitions and criteria according to different authors.
Tab. 2: Pregled definicij in meril za območja odraščanja (ang. nursery areas) po različnih avtorjih.

Publication	Nursery Area Criteria
Heupel *et al.*, 2007	(1) Newborn/young-of-the year individuals are more commonly encountered there than in other areas. (2) Newborn/young-of-the-year individuals have a tendency to remain or return for extended periods. (3) Newborn/young-of-the-year individuals repeatedly use the area or habitat across years.
Beck *et al.*, 2009	> an area in which juveniles occur at higher densities, > they avoid predation more successfully, > they grow faster compared to a different habitat, > the species moves into the area as larvae/neonates, accumulate biomass, and then move offshore, > contribution per unit area to the production of individuals that recruit to adult populations is greater, on average, than production from other habitats in which juveniles occur, from any combination of four factors, the ideal being an area having all 4 factors at high values: (1) density (2) growth (3) survival of juveniles (4) movement to habitats inhabited by adults
Martins *et al.*, 2018	> **Egg case nursery/Primary nursery area/For oviparous species:** (1) high densities of eggs and egg cases in contact with the benthos or permanent structures (2) area must be used as an egg-laying area over multiple years by adults (3) newborns should leave the area promptly after hatching > **Juvenile nursery area/Secondary nursery area**: (1) should have a high abundance of neonates and juveniles, (2) may or may not be distinct from the egg case nursery (3) should strongly contribute to population recruitment > **Nursery area for viviparous species (Heupel *et al.*, 2007)**: (1) Newborn/young-of-the-year individuals are more commonly encountered there than in other areas. (2) Newborn/young-of-the-year individuals have a tendency to remain or return for extended periods. (3) Newborn/young-of-the-year individuals repeatedly use the area or habitat across years.

RESULTS AND DISCUSSION

Smooth-hound, *Mustelus mustelus* (Linnaeus, 1758)

A total of 138 *M. mustelus* specimens were caught as bycatch during the study period and included in the analysis. All individuals examined were juveniles, and no newborns with postnatal scars were reported. Juvenile females were more frequent than juvenile males, with a female-to-male ratio of 60:40 (Fig. 3). All specimens were caught over a 10-year span, specifically in September and October between 2011 and 2021. The average Fulton's condition factor across all specimens was 0.0032 (Tab. 3) with a standard error of ±0.000221, and females had a slightly higher mean than males (Tab. 4). Since all specimens were juveniles, no comparisons of condition factor between juveniles and adults could be made.

Blackspotted smooth-hound, *Mustelus punctulatus* (Risso, 1827)

Of the 175 *M. punctulatus* specimens included in the analysis, males were more frequent than females, with a sex ratio of 66:33 (Fig. 3). While no newborns were recorded, juvenile specimens of both sexes accounted for 65.3% of all specimens. Both juvenile and adult specimens were reported from September to November, as well as in January and from April to June. The specimens included in this study were caught in 2002, 2003, 2011, and 2014, with juveniles reported in each of those years. The average Fulton's condition factor was 0.0031 (Tab. 3) with a standard error of ±0.000302, and males had a higher average than females (Tab. 4). Since biometric data were only available for juvenile specimens, no comparisons of Fulton's condition factors could be made between juvenile and adult specimens.

Marbled electric ray, *Torpedo marmorata* (Risso, 1810)

A total of 74 *T. marmorata* specimens were analyzed. The adult sex ration was almost 50:50, whereas juvenile males were more frequent than juvenile females, with a 3:1 ratio (Fig. 3). Three newborn males were recorded, and together with the other juveniles, they accounted for 55.4% of all specimens caught. *T. marmorata* was the most frequently caught species on a monthly basis. From September to March and in May, both adult and juvenile specimens were caught, with one newborn specimen caught in January and two in

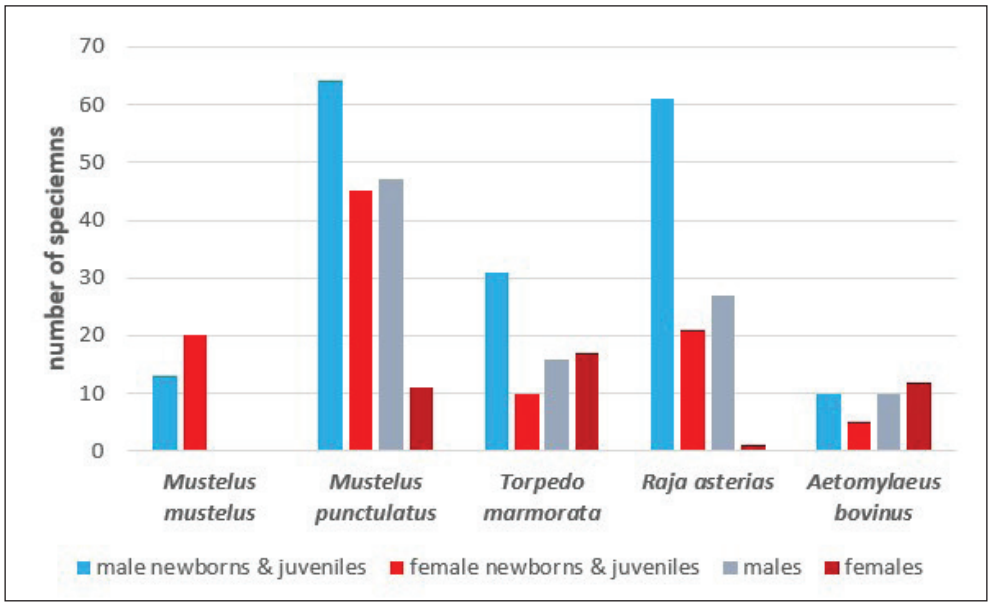

Fig. 3: Maturity and sex distribution in adults and juveniles of the five species included in this study. Males (grey) and females (dark red) refer to adult individuals.
Sl. 3: Porazdelitev zrelosti in spola pri odraslih osebkih in mladostnih primerkih petih vrst, vključenih v to raziskavo. Samci (sivo) in samice (temno rdeče) se nanašajo na odrasle osebke.

Tab. 3: Fulton's condition factor values for the five species included in this study compared with values reported from other Mediterranean studies.
Tab. 3: Vrednosti Fultonovega kondicijskega faktorja za pet vrst, vključenih v to raziskavo, v primerjavi z vrednostmi iz drugih sredozemskih študij.

Species	Range	Average	Study
M. mustelus	0.0028–0.0036	0.032	**this study**
	0.002–0.003	/	Filiz & Mater, 2002
	0.003–0.004	/	Ismen et al., 2007
	/	0.004	Ozcan & Başusta, 2018
	0.003–0.01	/	Colombelli & Bonanomi, 2022
M. punctulatus	0.026–0.036	0.0031	**this study**
	/	0.003	Colombelli & Bonanomi, 2022
T. marmorata	0.0119–0.0870	0.0285	**this study**
	0.022–0.027	/	Filiz & Mater, 2002
	0.019–0.023	/	Ismen *et al.*, 2007
	/	0.025	Duman & Başusta, 2013
R. asterias	0.0007–0.0068	0.0055	**this study**
	/	0.007	Karakulak et al., 2006
	/	0.007	Ferrà et al., 2016
A. bovinus	0.0022–0.0141	0.0052	**this study**
	0.012–0.022	/	Başusta *et al.*, 2012
	/	0.004	Tsikliras & Dimarchopoulou, 2021
	0.014-0.021	/	Colombelli & Bonanomi, 2022

Tab. 4: Fulton's condition factor values for the five species included in this study by sex.
Tab. 4: Vrednosti Fultonovega kondicijskega faktorja po spolu za pet vrst, vključenih v to raziskavo.

Species	Males		Females	
	Range	Average	Range	Average
M. mustelus	0.0028–0.0035	0.0031	0.0028–0.0036	0.0032
M. punctulatus	0.0026–0.0036	0.0032	0.0028–0.0034	0.0030
T. marmorata	0.0119–0.0870	0.0255	0.0168–0.0795	0.0337
R. asterias	0.0043–0.0065	0.0055	0.0007–0.0068	0.0057
A. bovinus	0.0022–0.0050	0.0031	0.0026–0.0141	0.0059

Tab. 5: Fulton's condition factor values for the five species included in this study by maturity stage.
Tab. 5: Vrednosti Fultonovega kondicijskega faktorja po stopnjah zrelosti za pet vrst, vključenih v to raziskavo.

Species	Newborns		Juveniles		Adults	
	Range	Average	Range	Average	Range	Average
M. mustelus	/	/	0.0028–0.0036	0.0032	/	/
M. punctulatus	/	/	0.0026–0.0036	0.0031	/	/
T. marmorata	0.0204–0.0870	0.0380	0.0119–0.0795	0.0305	0.0168–0.0738	0.0252
R. asterias	/	/	0.0007–0.0068	0.0056	0.0048–0.0066	0.0055
A. bovinus	/	/	0.0022–0.0040	0.0030	0.0026–0.0141	0.0056

December. In April and August, only adult specimens were caught, while no specimens were caught in June or July. The *T. marmorata* specimens analyzed in this study were caught between 2011 and 2014, with both juveniles and adults reported in each year. The average Fulton's condition factor was 0.0285 (Tab. 3) with a standard error of ±0.017578. Females had a higher average than males (Tab. 4), and newborns and juveniles had a higher average than adults (Tab. 5).

Mediterranean starry ray, *Raja asterias* (Delaroche, 1809)

Male *R. asterias* juveniles and adults outnumbered females, with a combined sex ratio of 4:1 (Fig. 3). No newborns were recorded; however, juveniles of both sexes accounted for 74.6% of all individuals. Specimens were caught in April and from July to December during the period 2011–2016, with juveniles recorded in each year. The average Fulton's condition factor was 0.0055 (Tab. 3) with a standard error of ±0.000908. Females had a higher average than males (Tab. 4), and juveniles had a higher average than adults (Tab. 5).

Bull ray, *Aetomylaeus bovinus* (Geoffroy Saint-Hilaire, 1817)

While *A. bovinus* was the only species in which juvenile specimens were less abundant than adults, juveniles still accounted for 40.54% of all caught individuals. Adult males and females occurred at an almost equal 1:1 frequency, while juvenile males outnumbered females by 2:1 (Fig. 3). Four male embryos were

found inside pregnant females; however, these were not included in the analysis. Both adult and juvenile specimens were reported from August to September 2005. The average Fulton's condition factor was 0.0052 (Tab. 3) with a standard error of ±0.003550. Females had a higher average than males (Tab. 4), and adults had a higher average than juveniles (Tab. 5).

Fulfillment of the three criteria defining nursery areas for the studied species

The first criterion – that juveniles are more frequently encountered in the area compared to other areas – was met by four of the five species. While catches of juveniles and adults of the examined species have been sporadically reported in the northern Adriatic, mostly along the Croatian coast, no solid nursery areas for any of the examined species have been confirmed yet. In the southern Adriatic, a nursery area for *R. asterias* has been proposed along the Albanian coast (Bakiu & Kule, 2024), however, it is unlikely that the *R. asterias* specimens caught in the northern Adriatic originated there.

For *M. mustelus*, all individuals recorded in the Gulf of Trieste during the study period were juveniles; therefore, the first criterion is considered fulfilled for this species. Given that no established nursery area for *M. mustelus* has been identified nearby and that the entire northwestern Adriatic has been classified as an ISRA important for the reproduction of this species (ISRA, 2025), it is possible that the Gulf of Trieste – as a confined part of the wider northwestern Adriatic area – plays an important role in its reproduction.

Juveniles also accounted for 65.3% of all *M. punctulatus* specimens, 55.4% of *T. marmorata* specimens, and 74.6% *of R. asterias* specimens; therefore, the first criterion is considered fulfilled for these species as well. In the Mediterranean, the closest suggested nursery area for *M. punctulatus* is in the Gulf of Gabes, southern Tunisia (Enajjar *et al.*, 2015), while for *R. asterias*, a nursery area has been identified within a restricted coastal zone of the southern Ligurian and northern Tyrrhenian Seas (Serena & Relini, 2006); therefore, the high proportion of juveniles of these two species recorded in the Gulf of Trieste is unlikely the result of a spillover from nearby nursery areas. For *T. marmorata*, both juvenile and adult specimens were recorded during the same period, suggesting that the species uses the Gulf of Trieste both as a reproductive habitat and a nursery area (pers. observation). This interpretation is further supported by observations from the shallow waters off the Sečovlje salina and within the salina channels, where numerous juvenile electric rays have been captured, sighted, photographed, and filmed (Kristina Gorišek, pers. comm.).

While juvenile specimens only accounted for 40.54% of all *A. bovinus* records, the occurrence of adults and pregnant females in the Gulf of Trieste during the same period suggests that reproduction may also take place in or near the area. Since *A. bovinus* is considered a thermophilic species, individuals may migrate seasonally into the Gulf of Trieste from more southern regions, potentially for foraging, given that all our records originate from the summer months. The closest potential nursery areas for *A. bovinus* in the Mediterranean are located along the southern Tunisian coast (Capapé and Quignard, 1975) and in the Amvrakikos Gulf in Greece (Ciprian *et al.*, 2026). The specimens recorded in the Gulf of Trieste may have originated from the latter area, given that the juvenile individuals for which TL/DW data were available were relatively large and close to the reported size at maturity for the species (87.5 cm for the male and 86.0 and 87.9 cm for the two females).

The second criterion – that juveniles remain in or return to the area for extended periods – was also fulfilled by four of the five species. Juvenile specimens were recorded over a period of several months, indicating that they are present not only following the reproductive period of adults, but also throughout the year. For all species except *A. bovinus*, both juvenile and adult specimens were recorded during periods corresponding to reproduction and immediately thereafter, also suggesting an increased abundance of juveniles shortly after the reproductive season.

Studies on the reproductive biology of *M. mustelus* place parturition in late spring (Saïdi *et al.*, 2008; Ozcan & Başusta, 2018; Boscolo Palo *et al.*, 2022). However, juveniles in the Gulf of Trieste were recorded in autumn, suggesting that they use the area independently of adult reproductive grounds, potentially as a secondary or juvenile nursery area. Accordingly, the second criterion can be considered met for this species.

Studies on *M. punctulatus* suggest that gestation begins in November, with parturition occurring from mid-May to early June (Saïdi *et al.*, 2009; Boscolo Palo *et al.*, 2022). Both juvenile and adult *M. punctulatus* individuals were reported in the Gulf of Trieste in autumn, winter, and spring, suggesting that the species may be using the basin as both a primary and a secondary nursery area. Therefore the second criterion is met for this species, too.

The *T. marmorata* records are in compliance with data from other studies on this species' reproductive biology in the Mediterranean Sea, where late pregnant individuals were found from July to October and post-pregnant individuals from September to February, as well as in May and August (Capapé, 1979; Consalvo *et al.*, 2007; Chatzispyrou *et al.*, 2021).

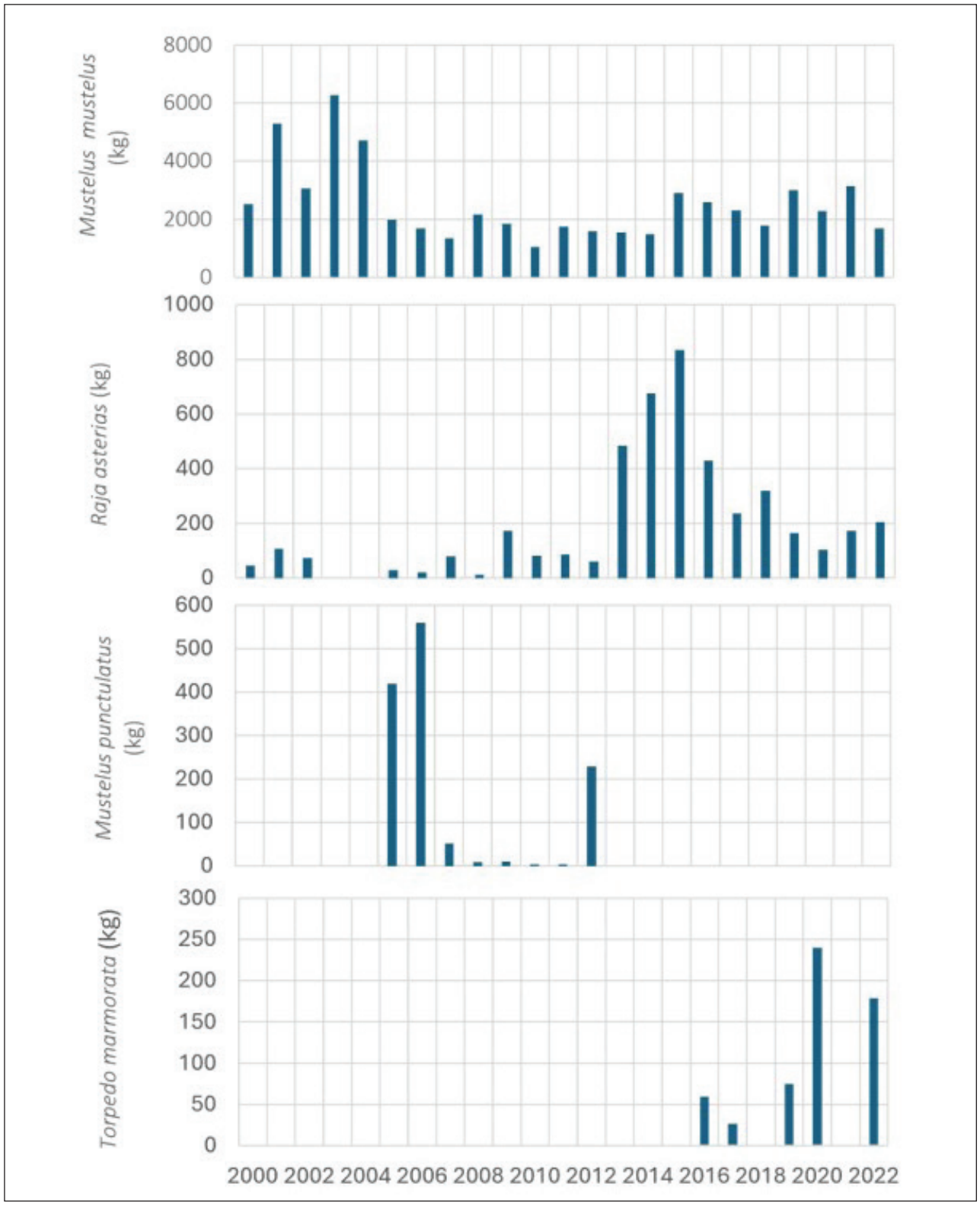

Fig. 4: Annual bycatch (kg) of four of the five species included in this study, based on data from the Slovenian Fisheries Institute (BIOSWEB, 2025).
Fig. 4: Letni prilov (kg) za štiri od petih vrst, vključenih v to raziskavo, na podlagi podatkov Inštituta za ribištvo (BIOSWEB, 2025).

Tab. 6: Suitability of the abiotic conditions in the Gulf of Trieste for the five species included in this study.
Tab. 6: Primernost abiotskih dejavnikov (pogojev) v Tržaškem zalivu za pet vrst, vključenih v to raziskavo.

	Substrate type	Climate	Salinity (psu)	Depth (m)
M. mustelus	sandy, muddy, or detritic bottoms, sometimes swim midwater	temperate	tolerates Mediterranean salinity level (38–40)	5–624 (usually 5–50)
M. punctulatus	inshore, sandy and muddy bottoms	subtropical	tolerates Mediterranean salinity level (38–40)	0–250
T. marmorata	seagrass areas, rocky reefs and adjacent soft bottoms	subtropical (< 20 °C)	tolerates Mediterranean salinity level (38–40)	2–270
R. asterias	benthic in inshore waters on sandy or muddy bottom	subtropical	tolerates Mediterranean salinity level (38–40)	2–700 (usually 20–50)
A. bovinus	demersal and semi-pelagic in estuaries, lagoons and on the continental shelf	subtropical	tolerates Mediterranean salinity level (38–40) as well as lower salinity	0–500
Gulf of Trieste	rocky coastal area, sandstone habitat types overgrown by algal vegetation, seagrass meadows, silty clay, biogenic detritus and soft bottom	temperate–humid subtropical (Cfa)	35–38	max. 37

These results indicate that the occurrence of juvenile, newborn, and adult *T. marmorata* in the Gulf of Trieste is typical of an area where a potential nursery might be located. Therefore, the second criterion is met for this species as well.

Research on the reproductive biology of *R. asterias* in the Mediterranean Sea suggests that juveniles are especially common from January to March and from July to September (Stehmann & Bürkel, 1984; Serena & Relini, 2006). Given that both juveniles and adults were caught in the Gulf of Trieste during and after the typical period when this species reproduces, this may indicate that the area is being used as a nursery. Therefore, the second criterion is also met for this species.

While not much information is available on the reproductive habits of *A. bovinus* in the Mediterranean Sea, the species' mating season generally begins in spring and ends in autumn (Michael, 1993). The reported catches of *A. bovinus* in the Gulf of Trieste align with this general pattern, as they occurred during the assumed reproductive period, with parturition probably occurring elsewhere. Since the juveniles recorded were close to the size at maturity reported for the species, they were likely born the previous year and migrated to the northern Adriatic from another area, possibly Amvrakikos Gulf, during the summer. This means that both adults and juveniles may be transient in the area rather than using it as a nursery.

The third criterion – that juveniles use the area or habitat repeatedly over the years – was also fulfilled by four of the five species. Since no direct tracking data were available, bycatch records from this study, as well as data from the website of the Slovenian Fisheries Institute (ZZRS) reported for different years were used as a substitute. *M. mustelus* was by far the most abundantly caught species included in this study (Fig. 4), with catch records on the ZZRS website exceeding 1000 kg each year (BIOSWEB, 2025). Additionally, the specimens included in the analysis were caught 10 years apart. Therefore, the third criterion is met for this species.

The only catch records available for *M. punctulatus* span the years from 2005 to 2012 (Fig. 4), with no records thereafter (BIOS, 2025). It is possible that *M. punctulatus* and *M. mustelus* records have been conflated, as the two closely related species are known to be frequently misidentified (Marino *et al.*, 2018). One distinguishing feature between the species is size at sexual maturity, estimated at 90 cm for males and 100 cm for females in *M. punctulatus*, compared with 70–80 cm for both sexes in *M. mustelus* (Lipej *et al.*, 2011). Consequently, individuals representing adult *M. mustelus* may have been misidentified as

Tab. 7: Abundance of selected prey items of juveniles of all five species included in this study.
Tab. 7: Številčnost (abundanca) izbranega plena mladih primerkov vseh petih vrst, vključenih v to raziskavo.

Species	Food preference / specialization of juveniles	Abundance	Sources
M. mustelus	**Crustaceans**		Maynou *et al.*, 2004; Farrugio & Soldo, 2015; BIOSWEB, 2025
	Squilla mantis	seasonally abundant (summer)	
	Maja squinado	no data	
M. punctulatus	**Crustaceans**		Maynou *et al.*, 2004; Farrugio & Soldo, 2015; Bacci *et al.*, 2024
	Squilla mantis	seasonally abundant (summer)	
	Ethusa mascarone	present	
T. marmorata	**Teleost fish**		Farrugio & Soldo, 2014; 2015; BIOSWEB, 2025
	Boops boops	seasonally abundant (summer)	
	Spicara spp.	no data	
	Soleidae	seasonally abundant (fall)	
	Crustaceans		
	Cypridina mediterranea	no data	
	Cephalopods		
	Loligo vulgaris	seasonally abundant (winter)	
	Sepia elegans	seasonally abundant (summer)	
R. asterias	**Crustaceans**		Farrugio & Soldo, 2014; 2015; Bacci *et al.*, 2024
	Ethusa mascarone	present	
	Polybius sp.	present	
	Cephalopods		
	Loligo vulgaris	seasonally abundant (winter)	
	Sepia sp.	seasonally abundant (summer)	
	Teleost fish		
	Gobius niger	present	
	Cepola macropthalma	no data	
A. bovinus	**Gastropods**		Bacci *et al.*, 2024
	Gibbula magus	no data	
	Crustaceans		
	Paguristes eremita	present	

juvenile *M. punctulatus*, which could explain why only juveniles of *M. mustelus* have been recorded throughout the study period. The specimens analyzed in this study were caught in 2002, 2003, 2011, and 2014, suggesting that not all catches may be represented in the ZZRS database. As these records span several years, the third criterion is considered met for *M. punctulatus*, too.

There are virtually no catch records of *T. marmorata* on the ZZRS website before 2016, after which irregular annual records are reported, ranging from 30 to 283 kg (Fig. 4). The specimens analyzed in this study were caught between 2011 and 2014, suggesting that not all historical catches are represented in the ZZRS database. Given that juveniles were caught in multiple years, the third criterion is met for this species as well.

R. asterias has been reported every year since 2000, except for 2003 and 2004; however, it should be noted that similar reporting gaps are present for several other species during the mentioned two years, suggesting that the pattern may not accurately reflect landings of *R. asterias* for that period (BIOSWEB, 2025). The *R. asterias* specimens included in this study were caught between 2011 and 2016, with juveniles captured in each year. Therefore, the third criterion is also met for this species.

For *A. bovinus*, no assumptions can be made regarding whether juveniles were recorded across multiple years. Two studies included specimens caught in 2005 (Dulčić *et al.*, 2008; Lipej *et al.*, 2009), while Uhan (2016) reported two adult specimens added to the collection of the Marine Biology Station of the National Institute of Biology in 2014. However, since the ZZRS website does not provide catch records for this species, no conclusion can be drawn regarding the third criterion based on the available data.

Fulton's condition factor and additional criteria

Combining Fulton's condition factor values with the biotic and abiotic conditions of the Gulf of Trieste allowed for an extension of the analysis to ecological factors that could not be assessed through the main nursery area criteria alone.

The mean Fulton's condition factor for *M. mustelus* (Tab. 3) was well within the expected range for the species, as both lower and higher values have been reported in the Mediterranean Sea (Filiz & Mater, 2002; Ismen *et al.*, 2007; Ozcan & Başusta, 2018; Colombelli & Bonanomi, 2022). However, only juvenile specimens had available biometric data, therefore the condition factor values could not be directly compared between juveniles and adults.

As with *M. mustelus*, only juvenile specimens of *M. punctulatus* had available biometry; therefore, condition factor values in juveniles could not be directly compared with those in adults from this study (Tab. 5). However, when compared to similar studies from the region, the mean value (Tab. 3) is slightly higher than those reported for the Mediterranean (Colombelli & Bonanomi, 2022).

For *T. marmorata,* comparable studies in the Mediterranean have reported lower mean values for Fulton's condition factor (Filiz & Mater, 2002; Ismen *et al.,* 2007; Duman & Başusta, 2013); accordingly, the specimens in this study appear to exhibit above-average mean condition factor values (Tab. 3).

Fulton's condition factor mean for *R. asterias* was lower than values reported by comparable studies from the northern Adriatic, which also included a higher proportion of juveniles than adults (Karakulak *et al.*, 2006; Ferrà *et al.,* 2016). It should be noted that some of the specimens in Ferrà *et al.* (2016) originated from the Gulf of Trieste, and the authors recognized the area as an aggregation site for the species (Ferrà *et al.*, 2016).

The mean Fulton's condition factor for *A. bovinus* was within the range reported in comparable studies from the Mediterranean (Başusta *et al.,* 2012; Tsikliras & Dimarchopoulou, 2021; Colombelli & Bonanomi, 2022).

Analyses of the stomach contents of *M. mustelus* suggest that it is an opportunistic predator, feeding on a wide range of prey items, including benthic invertebrates and fishes, as well as prey of varying sizes and morphologies (Ahmed *et al.,* 2022). In the northern Adriatic, decapod crustaceans are considered the most important and frequent prey for juveniles and are present in all seasons (Jardas *et al.*, 2007). This indicates that prey resources for juveniles are likely available throughout the year, supporting the suitability of the Gulf of Trieste as a potential nursery area.

Juveniles of *M. punctulatus* in the northern Adriatic have also been shown to mainly feed on crustaceans – unlike adults, which preferentially consume cephalopods (Lipej *et al.*, 2011) – however, there is no clear indication of competition for food resources with *M. mustelus* juveniles (Tab. 6 and Tab. 7), suggesting that the two species may co-occur within the same nursery area.

Analyses of the diet of *T. marmorata* in the Mediterranean show that both juveniles and adults primarily feed on teleost fishes (Chatzispyrou *et al.,* 2021) and cephalopods (Capapé *et al.*, 2007). The species has also shown local dietary specialization (Chatzispyrou *et al.*, 2021). This ability might be especially useful in communal nursery areas to avoid competition for food with juveniles of other species.

Diet analyses of *R. asterias* in the Adriatic Sea show that both juveniles and adults primarily feed on decapods, with cephalopods and teleost fishes occurring in smaller proportions (Sviben *et al.*, 2019). Sviben *et al*. (2019) further report that specimens from the Slovene sector of the Gulf of Trieste exhibited the highest average prey weight, prey diversity, and meal value, suggesting plentiful food resources for the species. This may be particularly relevant in the context of nursery function, especially in a multi-species setting where juveniles of other taxa also primarily consume decapods.

The diet of juvenile *A. bovinus* in the northern Adriatic consists almost exclusively of gastropods, while adults also consume fish (Lipej *et al.*, 2025). The disk width (DW) at birth of specimens from the northern Adriatic was greater than that observed in specimens from other parts of the Mediterranean. Correspondingly, adult individuals from this region attained some of the highest body weights recorded across the species distribution range (Dulčić *et al.*, 2008; Lipej *et al.,* 2009). Dulčić *et al*. (2008) and Lipej *et al*. (2009) suggested that these differences may be related to the apparent absence of parasitic infections in the examined specimens. If so, low parasite prevalence may be another habitat characteristic that favors the presence of this species (Tab. 6 and Tab. 7).

Based on these results, the Gulf of Trieste is most likely used as a communal juvenile habitat (secondary nursery area) by four of the five species examined, as it fulfills the three criteria for a nursery area for all species except *A. bovinus*. It also satisfies the first criterion of a juvenile nursery area as defined by Martins *et al*. (2018) (Tab. 2). However, due to the limited number of specimens and lack of tracking data, it is difficult to assess the contribution of the area to juvenile recruitment. The abiotic (Tab. 6) and biotic (Tab. 7) conditions in the Gulf of Trieste are consistent with those expected of a nursery area for all five species: the gulf is relatively shallow, features both soft-sediment and hard-substrate habitats, and contains abundant prey resources for each species. Some species have been shown to exhibit dietary flexibility in habitats where they overlap with other species in order to avoid intra- and inter-specific competition, which can also depend on their mode of reproduction (Capapé et al., 2003; Chatzispyrou *et al.*, 2021; Ahmed *et al.*, 2022; Finotto *et al.,* 2023). Additionally, primary production measurements suggest that the trophic conditions in the area have not significantly changed in over a decade (Cibic *et al.*, 2022) and have therefore been stable enough to potentially aid the development of a nursery area. None of the five species have any natural predators in the area, and they all occupy high trophic levels typical of predators at the top of the food chain (Lipej *et al.,* 2011; Sviben *et al., 2*019; Ahmed *et al.,* 2022; Lipej *et al.*, 2025).

The characteristics of the Gulf of Trieste indicate that the habitat could support a communal nursery area for all five species. None of the species in this study are subject to protection in the region; in Slovenia, specifically, there are no ongoing regular monitoring programs regarding sharks and rays (Lipej *et al*., 2024). Despite the presence of several suitable sites that could serve as potential nursery areas and already have some form of protection – both in Slovenia (the natural monuments Cape Madonna and Debeli rtič, the Strunjan Nature Reserve, the Sečovlje Salina Nature Park, and Landscape Park Strunjan) and in Italy (the Miramare Marine Protected Area, Duino Cliffs Nature Reserve, and Cavana di Monfalcone) – none have yet been designated or evaluated as potential nursery areas (Lipej *et al*., 2024; WDPA, 2025). Additionally, juveniles of other elasmobranch species, such as *Carcharhinus plumbeus, Alopias vulpinus, Squalus acanthias, Raja clavata, Dasyatis pastinaca, Pteroplatytrigon violacea*, and *Myliobatis aquila*, have also been documented in the Gulf of Trieste over the 24-year period (Fig. 4). However, they were not included in this study as there were insufficient specimens of each species available for further analysis (Lipej *et al.*, 2008; 2016; 2022a; 2022b; 2023). Regardless, this highlights the potential importance of the area as a nursery for an even higher number of species than those considered in this study. Given the limited available data on elasmobranchs in the region, increased efforts to gather more information and conduct accurate future analyses are needed. A proper assessment of the real status of elasmobranch species in the area is essential for informing effective conservation and management measures.

ALI JE TRŽAŠKI ZALIV POTENCIALNO OBMOČJE ODRAŠČANJA (JASLICE) ZA DOLOČENE VRSTE HRUSTANČNIC?

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POVZETEK

*Avtorji poročajo o izsledkih raziskave, katere namen je bil ugotoviti, ali Tržaški zaliv izpolnjuje merila za območje odraščanja, kot jih definirajo različni viri, predvsem Heupel s sodelavci (2007). Analiza je temeljila na osebkih hrustančnic iz zbirke Morske biološke postaje Piran (Nacionalni inštitut za biologijo, Slovenija) in je vključevala primerke petih vrst (*Mustelus mustelus, M. punctulatus, Torpedo marmorata, Raja asterias *in* Aetomylaeus bovinus*), ujetih kot prilov v obdobju 24 let. Štiri od petih vrst (razen vrste* A. bovinus*) so izpolnile vsa tri merila. Glede na analizirane podatke bi Tržaški zaliv lahko obravnavali kot skupno območje odraščanja mladic za preučevane vrste. Poleg tega zapisi o mladih primerkih drugih vrst hrustančnic, o katerih so poročali v obdobju raziskave na tem območju, kažejo na potencialen pomen tega okolja kot območja odraščanja tudi za druge vrste.*

Ključne besede: hrustančnice, skotitev, merila za območje odraščanja, abiotski pogoji, prilov, severni Jadran

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