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VSEBINA / *INDICE GENERALE / CONTENTS*

BIOTSKA GLOBALIZACIJA
GLOBALIZZAZIONE BIOTICA
BIOTIC GLOBALIZATION

Malek ALI, Aola FANDI & Christian CAPAPÉ
The First Mediterranean Record of Red-Toothed Triggerfish *Odonus niger* (Balistidae) from the Syrian Coast (Eastern Mediterranean Sea) 173
Prvi zapis o pojavljanju rdečezobe balestre Odonus niger *(Balistidae) iz sirske obale (vzhodno Sredozemsko morje)*

Zafer TOSUNOĞLU & Okan AKYOL
Occurrence of *Pterois miles* (Scorpaenidae) in the Mediterranean Sea 179
Pojavljanje navadne plamenke Pterois miles *(Scorpaenidae) v Sredozemskem morju*

Izdihar Ali AMMAR New Non-Native and Rare Marine Invertebrates in Syrian Waters 187
Novi primeri o pojavljanju tujerodnih in redkih morskih nevretenčarjev v sirskih vodah

Luca CASTRIOTA, Manuela FALAUTANO & Laura SINAPI
A New Locality Record for the Range Expanding Fish *Seriola fasciata* in the Mediterranean 199
Nova lokaliteta pojavljanja vrste Seriola fasciata, *ki širi areal v Sredozemskem morju*

F. Saadet KARAKULAK, Mehmet GÖKOĞLU, Uğur UZER & Hakan KABASAKAL
First Record of the *Abudefduf* cf. *saxatilis/vaigiensis/troschelii* Species Complex (Pisces: Pomacentridae) in the Black Sea 205
Prvi zapis o pojavljanju primerka vrste iz kompleksa Abudefduf *cf.* saxatilis/vaigiensis/troschelii *(Pisces: Pomacentridae) iz Črnega morja*

SREDOZEMSKE HRUSTANČNICE
SQUALI E RAZZE MEDITERRANEE
MEDITERRANEAN SHARKS AND RAYS

Farid HEMIDA, Christian REYNAUD & Christian CAPAPÉ
Occurrence of the Rare Blonde Ray, *Raja brachyura* (Rajidae), Off the Algerian Coast (Southwestern Mediterranean Sea) 213
Pojavljanje redke okraste raže, Raja brachyura *(Rajidae), ob alžirski obali (jugozahodno Sredozemsko morje)*

Hakan KABASAKAL, Uğur UZER & F. Saadet KARAKULAK
Occurrence of Longnosed Skate, *Dipturus oxyrinchus*, in the Sea of Marmara 221
Pojavljanje koničaste raže, Dipturus oxyrinchus*, v Marmarskem morju*

Cem ÇEVİK, Gökhan GÖKÇE & Deniz ERGUDEN
Capture of a Juvenile Sharpnose Sevengill Shark, *Heptranchias perlo* (Bonnaterre, 1788), from the Turkish Coast (Eastern Mediterranean Sea) with Updated Records from Mediterranean Waters 229
Ulov mladostnega primerka morskega psa sedmeroškrgarja, Heptranchias perlo *(Bonnaterre, 1788), iz turških voda (vzhodno Sredozemsko morje) z posodobljenim seznamom zapisov o pojavljanju v Sredozemskem morju*

Eloïse DEYSSON, Sarah FOXONET, Etienne RÉGNIER, Chloé MOSNIER, Florane TONDU, Janis BROUTIN-RENAUD Bruno COGNIE, Alessandro DE MADDALENA, Hakan KABASAKAL & Nicolas ZIANI
Additional Historical Records of Great White Sharks, *Carcharodon carcharias*, Caught in the Gulf of Lion, Northwestern Mediterranean Sea, Between the 1920s and 1950s 239
Dodatni zgodovinski zapisi o belih morskih volkih, Carcharodon carcharias*, ujetih v zalivu Lyon (severozahodno Sredozemsko morje) v dvajsetih in petdesetih letih*

Malek ALI, Aola FANDI, Dima GHANEM & Christian CAPAPÉ
Capture of a Juvenile Basking Shark, *Cetorhinus maximus* (Cetorhinidae), Off the Syrian Coast, With Comments on the Occurrence of the Species in the Levant Basin (Eastern Mediterranean Sea) 251
Ulov mladostnega primerka morskega psa orjaka, Cetorhinus maximus *(Cetorhinidae), ob sirski obali s komentarji o pojavljanju vrste v levantskem bazenu (vzhodno Sredozemsko morje)*

Hakan KABASAKAL, Uğur UZER & F. Saadet KARAKULAK
Impact of Fishing Capacity and Environmental Parameters on Landings of *Hexanchus griseus* in the Sea of Marmara 257
Vpliv ribolovne zmogljivosti in okoljskih parametrov na ulov vrste Hexanchus griseus *v Marmarskem morju*

MORSKA FAVNA
FAUNA FAUNA
MARINE FAUNA

Tea KNAPIČ, Irena FRKOVIČ, Borut MAVRIČ & Lovrenc LIPEJ
An Insight into the Heterobranch Fauna of Fiesa (Slovenia, Northern Adriatic Sea) 275
Vpogled v favno polžev zaškrgarjev Fiese (Slovenija, severni Jadran)

Francesco TIRALONGO, Alessandro NOTA, Emanuele MANCINI & Luigi MUSCO
Wounds Inflicted on Humans by the White Seabream (*Diplodus sargus*): First Scientific Report of Aggressive Behavior 291
*Rane, ki jih ljudem zadajajo šargi (*Diplodus sargus*): prvo znanstveno poročilo o agresivnem vedenju*

ORNITOFAVNA
ORNITOFAUNA
ORNITHOFAUNA

ANDREA DE ANGELIS & MARIO PELLEGRINI
Nuovo Sito di Nidificazione di Aquila Reale *Aquila chrysaetos* nel Subappennino Abruzzese 301
Novo gnezdišče planinskega orla v subapeninskih Abrucih

FLORA
FLORA
FLORA

Amelio PEZZETTA & MARCO PAOLUCCI
La flora di Taranta Peligna (Abruzzo, Italia) 317
Flora Taranta Peligna (Abruci, Italija)

Kazalo k slikam na ovitku 357
Index to images on the cover 357

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IMPACT OF FISHING CAPACITY AND ENVIRONMENTAL PARAMETERS ON LANDINGS OF *HEXANCHUS GRISEUS* IN THE SEA OF MARMARA

Hakan KABASAKAL
Istanbul University, Institute of Science, Fisheries Technologies and Management Program, Istanbul, Türkiye
e-mail: kabasakal.hakan@gmail.com

Uğur UZER
Istanbul University, Faculty of Aquatic Sciences, Department of Fisheries Technologies and Management, Istanbul, Türkiye

F. Saadet KARAKULAK
Istanbul University, Faculty of Aquatic Sciences, Department of Fisheries Technologies and Management, Istanbul, Türkiye

ABSTRACT

Between July 1967 and December 2023, 136 bluntnose sixgill sharks, Hexanchus griseus*, were caught in the Sea of Marmara (SoM). Although both a generalised linear model (GLM) and the Mann-Kendall trend test indicated an increasing trend in annual landings of* H. griseus*, the estimated smoothing splines of the GLM regression trend line revealed a sharp decline in landings after 2017. While the capture depths ranged from 10 to 1,000 m since the early 2000s, the majority of specimens were caught in the shallow waters of the continental shelf. Deteriorating environmental conditions and increasing deoxygenation in the deep waters of the SoM coincide with a reduction in the capture depth of bluntnose sixgill sharks over the continental shelf. The evidence suggests an ongoing process of vertical habitat compression, which appears to be increasing the vulnerability of* H. griseus *to commercial fisheries in the SoM.*

Key words: Sixgill shark, overfishing, vulnerability, pollution, oxygen, decline

IMPATTO DELLA CAPACITÀ DI PESCA E DEI PARAMETRI AMBIENTALI SUGLI SBARCHI DI *HEXANCHUS GRISEUS* NEL MAR DI MARMARA

SINTESI

Tra il luglio 1967 e il dicembre 2023, nel Mar di Marmara sono stati catturati 136 squali capopiatto, Hexanchus griseus*. Sebbene sia il modello lineare generalizzato (GLM) che il test di tendenza di Mann-Kendall abbiano indicato una tendenza all'aumento degli sbarchi annuali di* H. griseus*, le spline di attenuazione stimate della linea di tendenza della regressione GLM hanno rivelato un forte calo degli sbarchi dopo il 2017. Mentre la profondità di cattura variava da 10 a 1.000 m dai primi anni 2000, la maggior parte degli esemplari è stata catturata nelle acque poco profonde della piattaforma continentale. Il peggioramento delle condizioni ambientali e l'aumento della deossigenazione nelle acque profonde nel Mar di Marmara coincidono con la riduzione della profondità di cattura degli squali capopiatto sulla piattaforma continentale. I dati suggeriscono un processo di compressione verticale dell'habitat in corso, che sembra aumentare la vulnerabilità di* H. griseus *alla pesca commerciale nel Mar di Marmara.*

Parole chiave: squalo capopiatto, pesca eccessiva, vulnerabilità, inquinamento, ossigeno, declino

INTRODUCTION

From a conservation perspective, well-managed shark fisheries require robust scientific research into various aspects of shark life history and population status to protect them from overexploitation (Shiffman & Hammerschlag, 2016). However, due to the scarcity of long-term systematic data on the distribution and abundance of many shark species (McPherson & Myers, 2009), fishery-dependent data collection or opportunistically collected data, such as anecdotal reports of incidental landings or catches, often constitute the only source of information on large predatory sharks (Morgan & Burgess, 2005). The value of "opportunistic records", i.e., observations not directly derived from scientific field surveys aimed at quantifying fish abundance (Hiddink *et al.*, 2023), has been confirmed in several studies (Bengil, 2020; Bargnesi *et al.*, 2020, 2022; Kabasakal & Bilecenoğlu, 2020; Kabasakal, 2023a) highlighting the effectiveness of opportunistic methods, such as citizen science, social media, etc., in providing additional or complementary data on elasmobranchs.

The bluntnose sixgill shark, *Hexanchus griseus* (Bonnaterre, 1788) (Hexanchiformes: Hexanchidae), is a large predatory shark species with a confirmed maximum total length (TL) of 570 cm (Lipej *et al.*, 2022) and an estimated trophic level of 4.3 (Ferretti *et al.*, 2008). With a patchy circumglobal distribution, *H. griseus* is one of the most well-known large demersal predators inhabiting continental shelves and slopes down to depths of 2,500 m, though it typically prefers depths between 200 and 1,100 m (Ebert *et al.*, 2021). The bluntnose sixgill shark is found throughout the Mediterranean (Serena *et al.*, 2020; Barone *et al.*, 2022), with its range extending to the Sea of Marmara (SoM) and the Black Sea, where records are extremely scarce (Kabasakal, 2023b). Unlike several large Mediterranean shark species whose populations are estimated to have declined by over 90% from their former abundance (Ferretti *et al.*, 2008), *H. griseus* is estimated to have 'only' declined by 20–29% across its global range (Finucci *et al.*, 2020). A recent assessment of the status of *H. griseus* in the Mediterranean has emphasised the importance of collecting region-specific data on its abundance to obtain reliable estimates of population trends throughout the region (Nuez *et al.*, 2023). Although the distribution and status of *H. griseus* in Turkish waters have been evaluated in previous studies (Kabasakal *et al.*, 2017; Kabasakal & Bilecenoğlu, 2020; Kabasakal, 2023b), the impact of fishing capacity and environmental degradation on bluntnose sixgill shark landings remains unexplored. Aiming to correct that shortfall, in this study we analyse the temporal trends of *H. griseus* landings in the SoM. Additionally, we examine the effects of fishing capacity and environmental parameters on landings of incidentally caught bluntnose sixgill sharks.

MATERIAL AND METHODS

Study area

In the General Fisheries Council of the Mediterranean (GFCM) Geographical Subarea (GSA) classification, the SoM is designated as GSA 28 (Fig. 1) (Carpentieri *et al.*, 2021). Identified as the easternmost extension of the Mediterranean ecosystem (Stanley & Blanpied, 1980), the SoM is a small basin located between Europe and Asia, covering a surface area of 11,500 km^2 and reaching a maximum depth of 1,390 m (Beşiktepe *et al.*, 1994). Due to anthropogenic impacts, primarily from the disposal of urban and industrial waste and nutrient runoff from surrounding agricultural fields, dissolved oxygen levels have fallen below the hypoxic threshold (80 μmol/L) in shelf waters deeper than 25 m, while anoxic conditions with low levels of hydrogen sulphide formation prevail at depths below 500 m (Yücel *et al.*, 2023). Despite being one of the most disturbed marine ecosystems in the Mediterranean today (Saygu *et al.*, 2023), the SoM has historically been considered one of Turkey's most productive fishing grounds (Yıldız & Karakulak, 2016).

Bluntnose sixgill shark landing data sources

Opportunistic records of *H. griseus* landings include newspaper articles and social media posts reporting the capture and/or display of bluntnose sixgill shark in the SoM. Prior to 2006, reports of *H. griseus* comprised articles published in printed newspapers and/or angling magazines, peer-reviewed articles, and fishermen's logs. Records for the period from 2006 to 2023 are limited to internet media articles and social media posts. Opportunistic records can be problematic due to inconsistent time series and unclear observation effort (Swetnam *et al.*, 1999); however, they can still serve as valuable data sources for indicating local population status (Grant *et al.*, 2022).

A 'record' refers to an individual bluntnose sixgill shark encountered on a specific date, whereas a 'report' denotes a single bluntnose sixgill shark encounter event; therefore, a report may include several bluntnose sixgill shark records (Hiddink *et al.*, 2023). Following the recommended procedure (Hiddink *et al.*, 2023), our search for opportunistic records involved examining all pages of daily newspapers from Turkish mainstream media, currently archived at the Atatürk Library in Istanbul, for reports of bluntnose sixgill shark encounters from July 1967 to June 2005. We also conducted data mining on the Internet to extract web articles and social media posts related to the bluntnose sixgill shark. To streamline the search and filter relevant information (Kim *et al.*, 2016), we used the following hashtags in Turkish: "*köpekbalıkları (sharks)*, *yakalandı (captured)*, *bozcamgöz (bluntnose sixgill shark)*, *canavar (sea monster)*, *Marmara Denizi (SoM)*". To avoid repetition or duplication of records and to confirm their provenance, we contacted the original post or article owner for each occurrence and obtained a photograph of each landed bluntnose sixgill shark (Kabasakal, 2023a). As online communities and website administrators may respond negatively to the use of their content by researchers, all Internet content scraping activities were conducted responsibly following the proposed code of ethics (Monkman *et al.*, 2017) to avoid compromising personal data or images. Where possible, the following information was collected either by contacting the owner of the post or article, or extracted from the media report: number of individuals, total length (TL, cm), total weight (TW, kg), depth of capture (echo-sounder screen image), and location of capture.

Fishing capacity and environmental parameter data sources

According to Saygu *et al*. (2023), the fisheries of the SoM are mainly coastal for demersal species, using beam trawling, while the rest of the fishery is pelagic, employing gill- and trammel-netting, as well as purse-seining. Bottom (or otter) trawling is strictly prohibited. The total fishing capacity (TFC) of the commercial fishing fleets operating in the SoM is recorded annually either by vessel length or by gross registered tonnes (GRT) of the fishing vessels, without distinguishing the type of fishing gear used (TURKSTAT, 2023). The types of fishing vessels include gill- and trammel-netters,

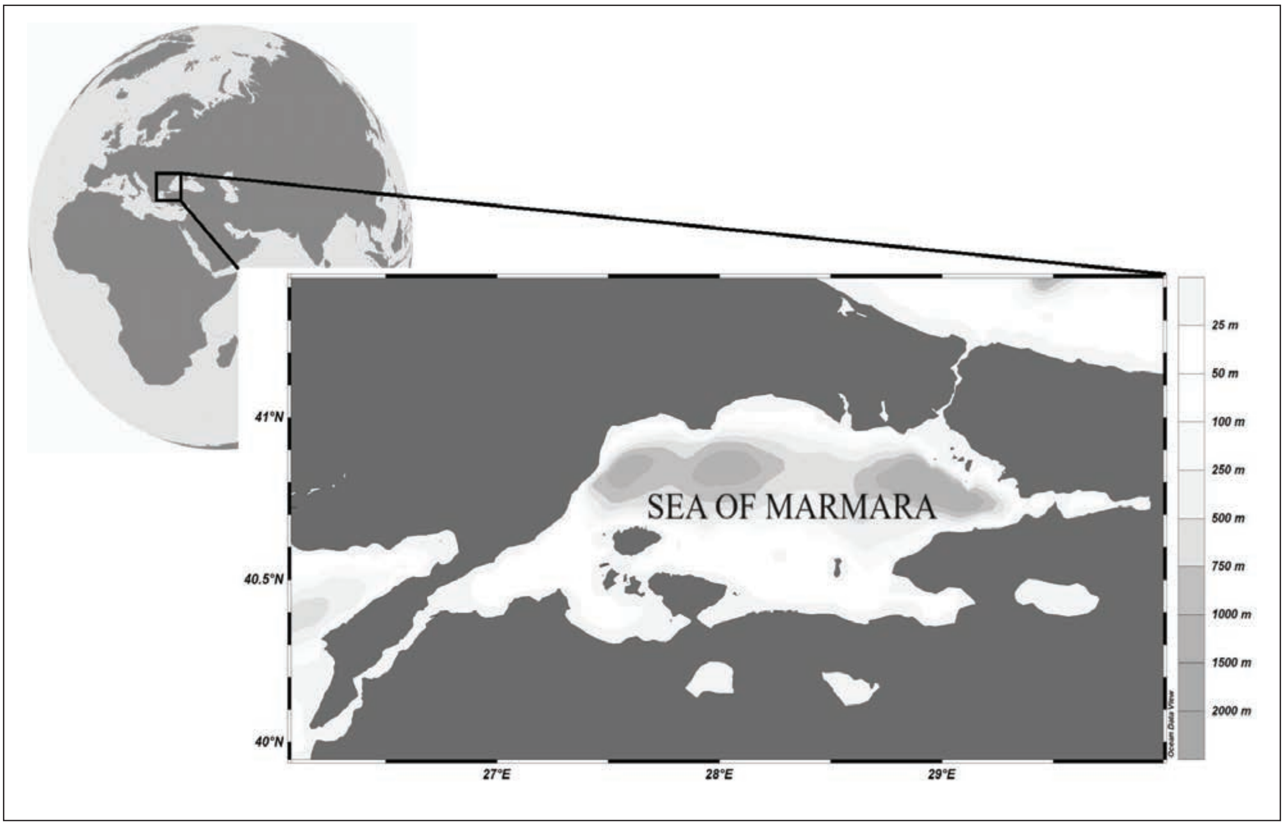

Fig. 1: Map showing the geographical position of the SoM in the Mediterranean ecosystem. Bathyal depressions, where seafloor depth exceeds 1,000 m and anoxic conditions are imminent, are shown as the darkest grey areas in the north of the SoM basin.
Sl. 1: Zemljevid prikazuje geografski položaj Marmarskega morja v sredozemskem ekosistemu. Batialne depresije, kjer globina morskega dna presega 1000 m in v katerih so anoksične razmere neizbežne, so prikazane kot najtemnejša siva območja na severu Marmarskega morja.

purse-seiners, and beam-trawlers, and range from 4 to over 500+ gross tonnes (TURKSTAT, 2023). In the absence of long-term records of *H. griseus*-specific fishing efforts in the SoM, the TFC of the fishing fleet registered to operate in the SoM (TURKSTAT, 2023), expressed in GRT, was used as a proxy for fishing pressure in the analyses. The use of TFC as a proxy for fishing pressure in the absence of long-term records of fishing effort by gear type has been reported in the literature (Barausse *et al.*, 2014). Landings were analysed in relation to several environmental parameters. Annual loads of phosphates (P, micromoles per litre), and nitrates and nitrites (N, micromoles per litre) were included to represent the effects of past anthropogenic nutrient enrichment and current oligotrophication of the basin (Yücel *et al.*, 2023). Relevant data were extracted from the Marmara Sea Integrated Strategic Plan (Marmara Denizi Bütünleşik Stratejik Planı 2021-2024).

Data analyses

All data are presented as log-transformed values. Parametric or non-parametric tests were used depending on data distribution as determined by the Shapiro-Wilk normality test (Legendre & Legendre, 1998). Since the p-values resulting from the normality tests were less than 0.05, the non-parametric Mann-Whitney test was used to identify any statistically significant differences between landings and fishing capacities for the periods up to 2006 and from 2006 to 2023 (Parab & Bhalerao, 2010). The Mann-Kendall time series trend test was used to detect annual trends in the landings data (Gilbert, 1987).

A generalised linear model (GLM) with a Poisson distribution and associated bootstrapped 95% confidence intervals was used to detect trends between fishing capacity per year and bluntnose

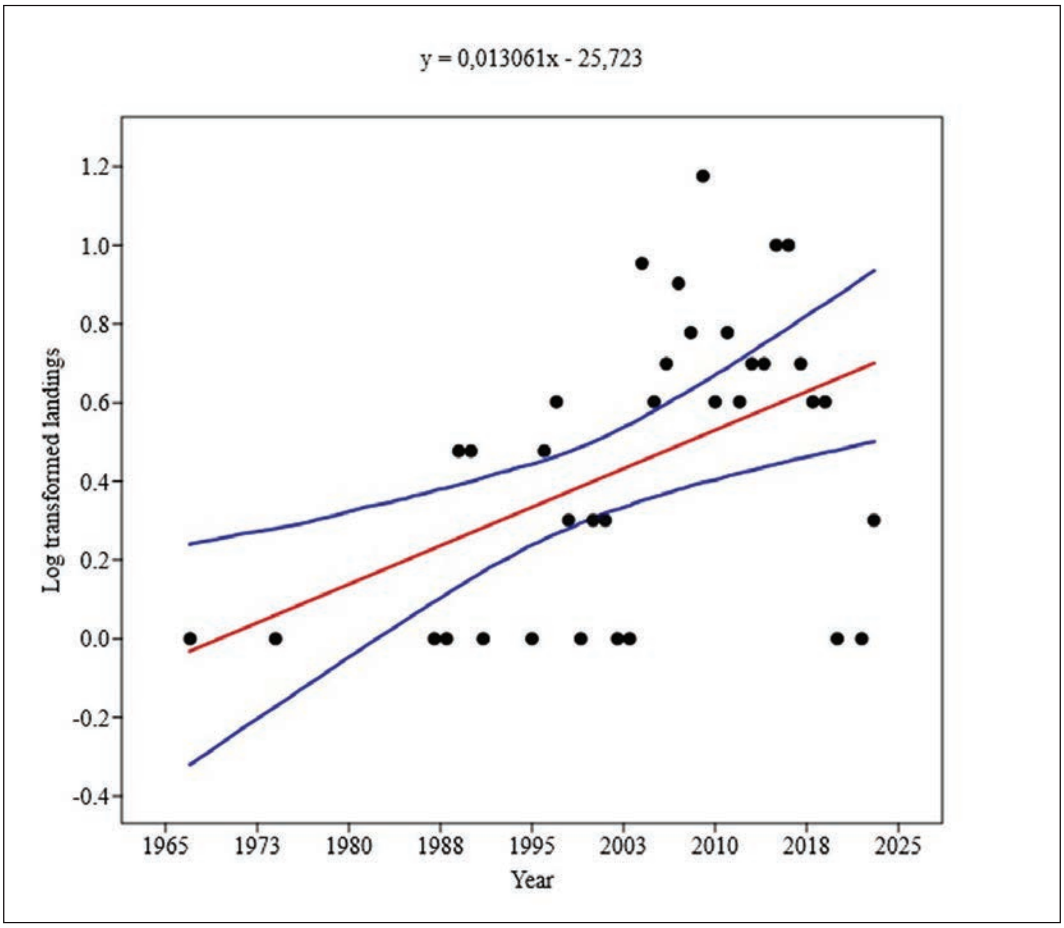

Fig. 2: Annual trends of** H. griseus **landings in the SoM between 1967 and 2023, based on GLM Poisson regression. Blue lines indicate the 95% confidence interval.
Sl. 2: Letni trendi ulova vrste** H. griseus **v Marmarskem morju med letoma 1967 in 2023 na podlagi Poissonove regresije GLM. Modre črte označujejo 95-odstotni interval zaupanja.

sixgill shark landings, TL of specimens landed per year, and the number of specimens landed per year (Coelho *et al*., 2013). Each GLM analysis was conducted separately. As the data sets produced noisy curves, smooth curves were created for modelling using the algorithm proposed in the literature (de Boor, 2001). Differences in bluntnose sixgill shark landings by data source and depth of capture were tested using the Mann-Whitney test to determine whether the temporal differences were statistically significant. Correlations between annual bluntnose sixgill shark landings in the periods before 2006 and from 2006 to 2023, fishing capacity, and environmental parameters were assessed using Spearman's rank correlation coefficient (Barausse *et al*., 2014). Models were fitted using Akaike's Information Criterion (AIC). For the examined individuals where the type of the fishing gear and depth of capture were recorded, the Mann-Whitney test was used to detect any statistically significant differences between gear type and depth of capture (≤200 m vs. >200 m). All analyses were performed using the statistical software PAST, version 4.03 (Hammer *et al*., 2001), and a p-value of 0.05 was defined as statistical significance (Parab & Bhalerao, 2010).

RESULTS

Bluntnose sixgill shark landings vs. year

Between July 1967 and December 2023, a total of 136 specimens of *H. griseus* were landed in several fishing ports around the SoM, after being caught incidentally in commercial fisheries operating in the region. GLM regression and Mann-Kendall trend analyses showed an increasing trend in the number of bluntnose sixgill sharks landed with respect to the year of capture (Poisson regression AIC=7.88; Mann-Kendall trend analyses, Z=2.68, S=186, $p<0.05$, $p=0.007$; Fig. 2). The highest number of *H. griseus* landings in the SoM occurred in 2009 (n=15), followed by a decrease between 2010 and 2014 ($n_{max}=6$, in 2011). An increase was noted in 2015 and 2016 (n=10, for both years), but from 2017 onwards, the annual landings of bluntnose sixgill sharks declined dramatically.

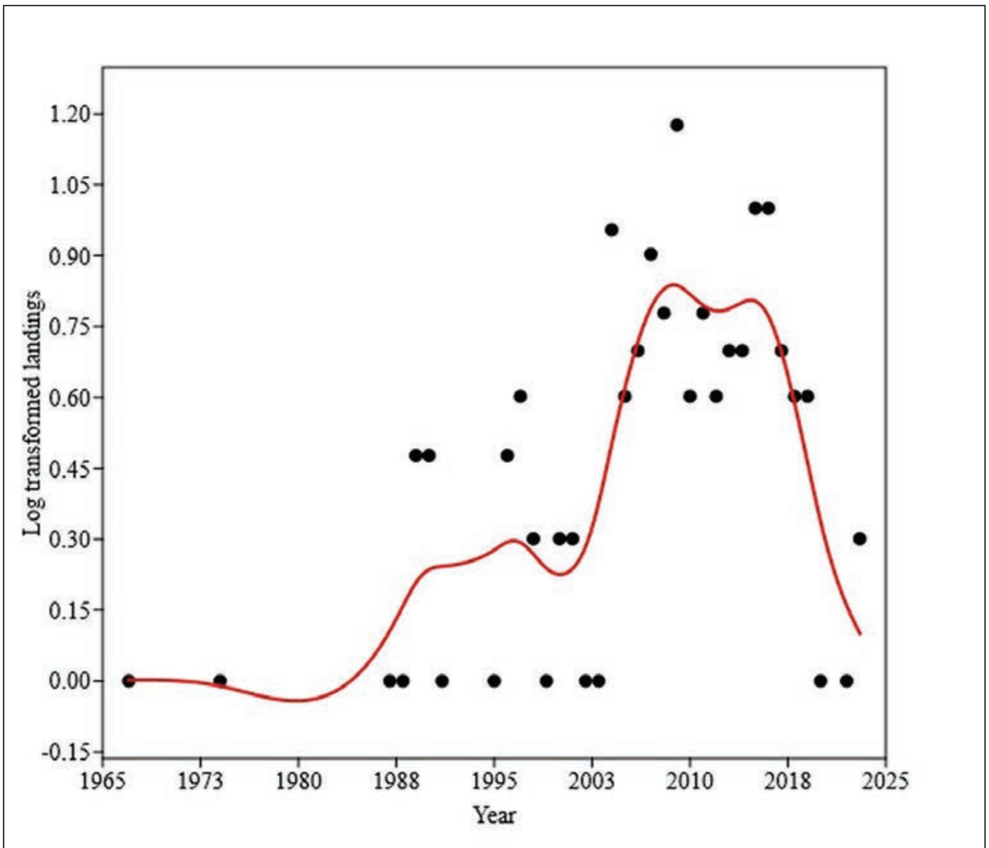

Fig. 3: Estimated smoothing spline of the GLM plot of** H. griseus **landings from 1967 to 2023.
Sl. 3: Ocenjeni izravnalni zlepek grafa GLM, ki prikazuje ulov vrste** H. griseus **od leta 1967 do 2023.

A clear increase in landings of *H. griseus* can be seen between the 1980s and mid-2010s; however, applying a smoothing spline to the noisy data of annual bluntnose sixgill shark landings revealed an instance of steep decline (Fig. 3). While the GLM and Mann-Kendall trend analysis failed to detect the dramatic decrease in annual landings of *H. griseus* from 2017 onwards, this became apparent after the application of the smoothing spline (Fig. 3).

Bluntnose sixgill shark landings vs. fishing capacity

Despite fluctuations, the registered annual fishing capacity (GRT) in the SoM has increased from 1,099 GRT (1975) to 1,877 GRT (2023) (Fig. 4 and 5). In contrast to the increase in annual fishing capacity since 1975, GLM regression showed a remarkable decreasing trend in landings of bluntnose sixgill sharks (AIC=8.27) (Fig. 4 and 5). Landings of bluntnose sixgill sharks in the SoM did not correlate with fishing capacity (Spearman's r=-0.221, p>0.05; Fig. 7).

Bluntnose sixgill shark landings vs. data sources

Considering the nature of the data sources used in this study, all sources prior to 2006 consist of non-digital records of *H. griseus* landings (n=41) reported in peer-reviewed articles, printed newspapers and/or fishing magazines, or fishermen's logs. In contrast, records of bluntnose sixgill shark landings from 2006 onwards (n=95) are derived exclusively from digital sources such as Internet media articles and social media posts. A statistically significant difference was found between the number of landing records in the two periods (Mann-Whitney test, p<0.05, p=0.0006). Thus, the likelihood of finding information about bluntnose sixgill shark landings through Internet and social

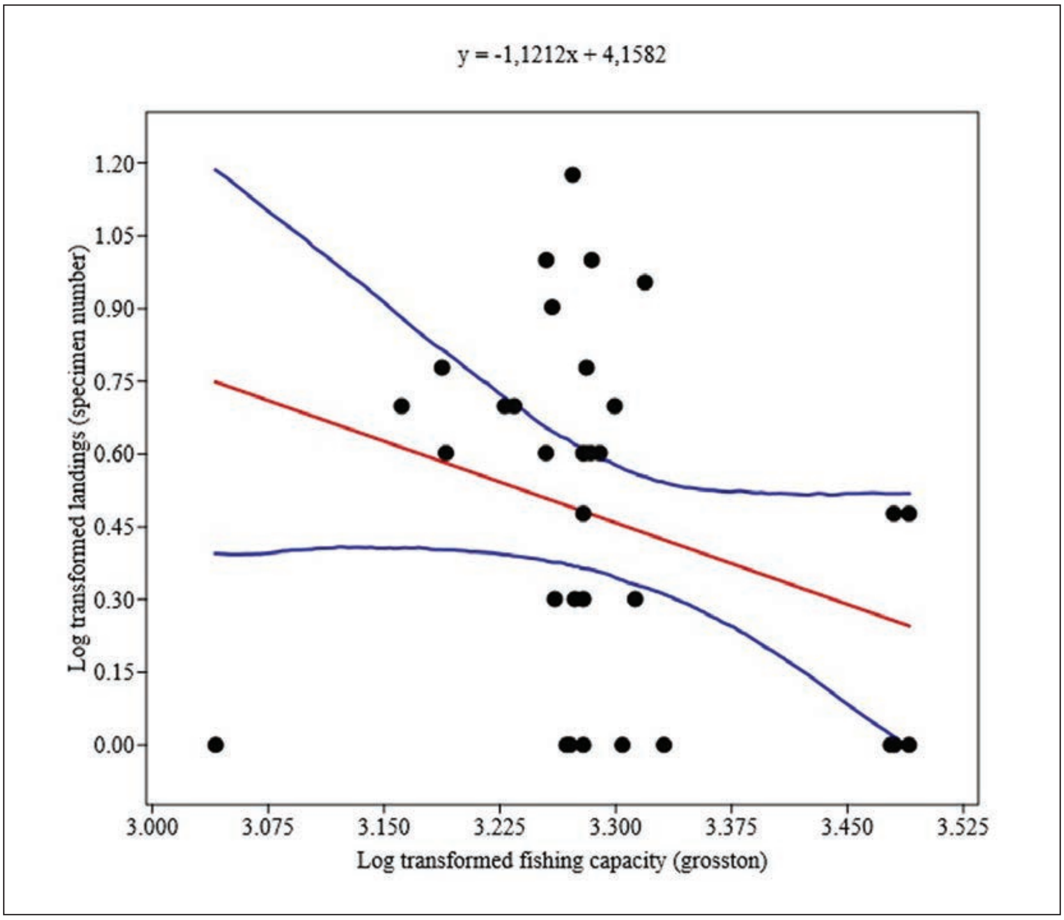

Fig. 4: Landings of** H. griseus **in relation to registered fishing capacity in the SoM. The blue lines indicate the 95% confidence interval.
Sl. 4: Ulov vrste** H. griseus **glede na registrirano ribolovno zmogljivost v Marmarskem morju. Modre črte označujejo 95-odstotni interval zaupanja.

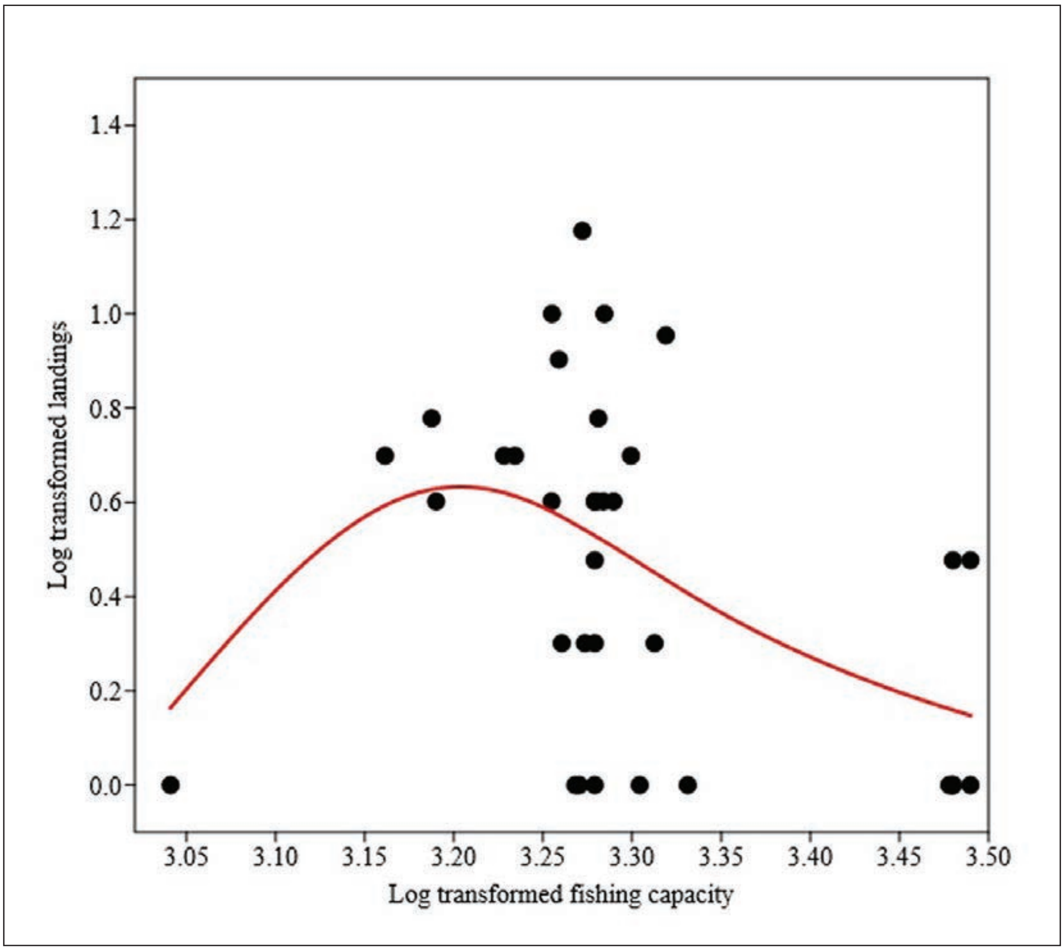

Fig. 5: Estimated smoothing spline of the GLM plot of* H. griseus *landings versus registered fishing capacity in the SoM.
Sl. 5: Ocenjeni izravnalni zlepek grafa GLM, ki prikazuje ulov vrste* H. griseus *v primerjavi z registrirano ribolovno zmogljivostjo v Marmarskem morju.

media posts has significantly increased since 2006 compared to the period from 1967 to 2005.

Bluntnose sixgill shark landings vs. environmental parameters

Incidental catches of *H. griseus* in the continental shelf zones of the SoM indicated a positive correlation with increases in annual loads of dissolved phosphate (PO_4, micromoles per litre) and dissolved nitrogen (NO_3+NO_2, micromoles per litre), but a negative correlation with dissolved oxygen (DO, mg per litre) at bathyal depths (Spearman's r=-0. 11 for DO; p>0.05; r=0.271 for PO_4, p>0.05; and r=0.345 for NO_3+NO_2, p<0.05; Fig. 6). Based on the correlations between captures of *H. griseus* and environmental parameters, it is suggested that the recent increase in catches in continental shelf waters is primarily associated with the annual rise in dissolved organic compounds in bathyal waters, rather than the decline in dissolved oxygen. However, only the annual increase in nitrogen loads showed a statistically significant correlation with catches and landings (Spearman's r=0.345, p<0.05; Fig. 6).

Bluntnose sixgill shark landings vs. depth of capture

Depths of capture were recorded for 69 specimens (50.73%) of *H. griseus*, ranging from 10 to 1,000 m. Fourteen (20.28%) of the 69 specimens were caught at depths spanning the upper continental slope to the deep bathyal zone, while the remaining 55 (79.71%) were caught in continental shelf waters. While most captures from 1967 to 1991 occurred in the deep parts of the continental shelf and upper slope waters (n=9; 13.04%), 46

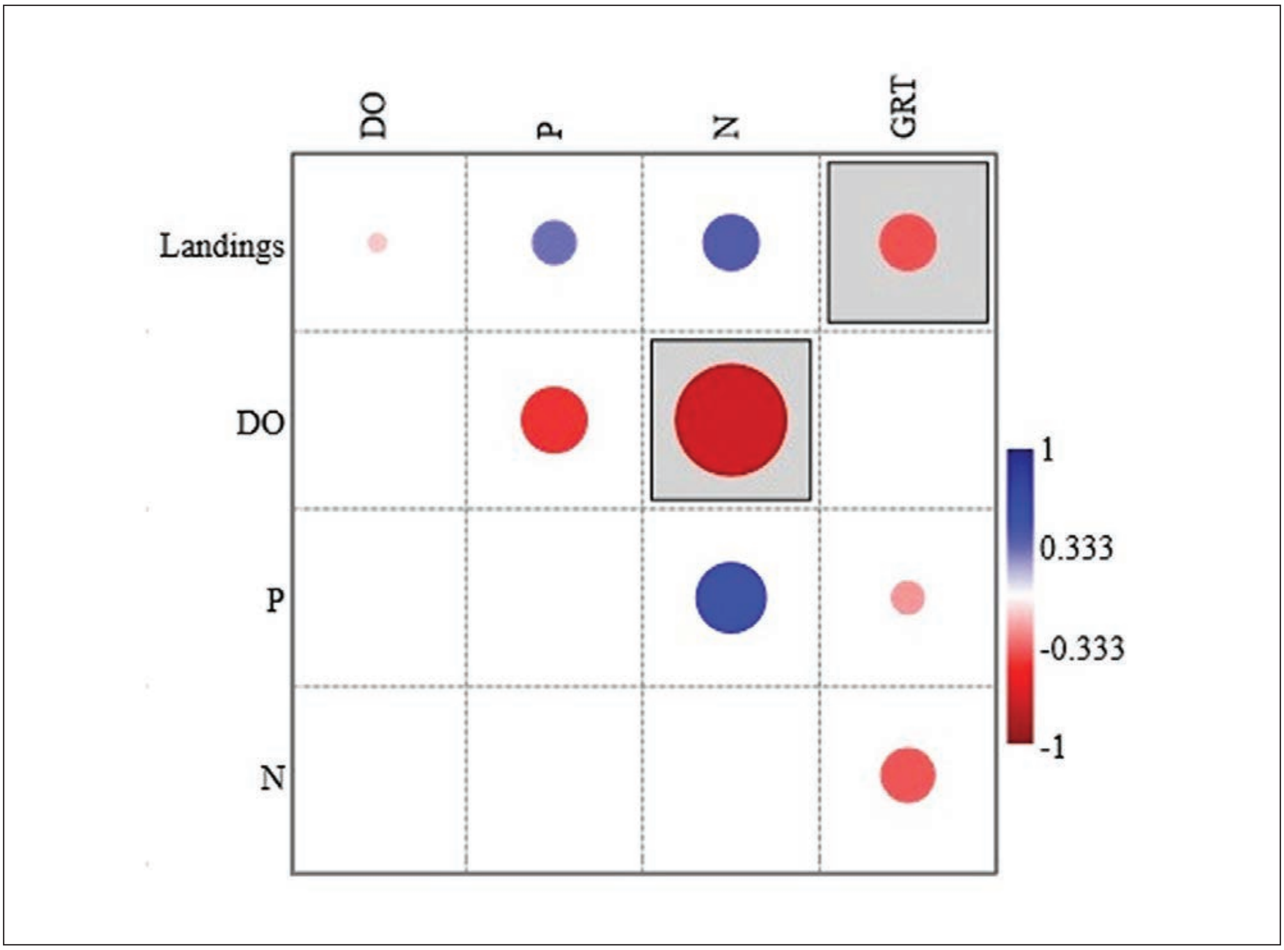

Fig. 6: Spearman's correlation plot between** H. griseus **catches, fishing capacity, and environmental parameters in the SoM. Statistically significant differences are shown in boxes (p<0.05). Abbreviations as follows: DO - dissolved oxygen; P, PO_4 - phosphate; N, NO_3+NO_2 - nitrogen, and GT - fishing capacity as gross tonnage.
Sl. 6: Spearmanov korelacijski prikaz med ulovi** H. griseus**, ribolovno zmogljivostjo in okoljskimi parametri v Marmarskem morju. Statistično pomembne razlike so prikazane v okvirčkih (p<0,05). Okrajšave: DO - raztopljeni kisik; P, PO_4 - fosfat; N, NO_3+NO_2, dušik in GT - ribolovna zmogljivost kot bruto tonaža.

specimens (82.14%) were captured in moderate to shallow shelf depths in 1995 and later (Fig. 7). Only 17.85% (n=10) of the post-1995 captures of *H. griseus* were recorded in the upper slope and deep bathyal zones.

In the early 1990s, in the deep waters (900–1,250 m) of the SoM, dissolved oxygen began to decrease below the hypoxia threshold (2 mg per litre), while dissolved nitrogen (NO_3+NO_2) and phosphate started to increase (Yücel *et al.*, 2023). Using this timeframe as a reference point, the difference in the capture depths of bluntnose sixgill sharks between the 1967–1991 and 1995–2023 periods was not statistically significant (Mann-Whitney test, p=0.05). However, after excluding the depths of the few specimens caught in the upper slope or deep bathyal zones (n=10; 300–1,000 m) during the 1995–2023 period, the difference in the depths of capture between these periods became statistically significant (Mann-Whitney test, p<0.05, p=0.0013).

Type of fishing gear vs. depth of capture

Information on the type of fishing gear was recorded for 58 (42.64%) of the 136 specimens of *H. griseus*. Purse-seine was the main fishing gear used (n=33; 56.9%), followed by a gill- and trammel-net composite (n=21; 36.21%), illegal bottom-trawling (n=3; 5.17%), and recreational hand-lining with a heavy-tackle shark rig (n=1; 1.72%). In addition to the type of fishing gear, information on the depth of capture was available for 46 (79.31%) of these 58 specimens. Although purse-seining was the

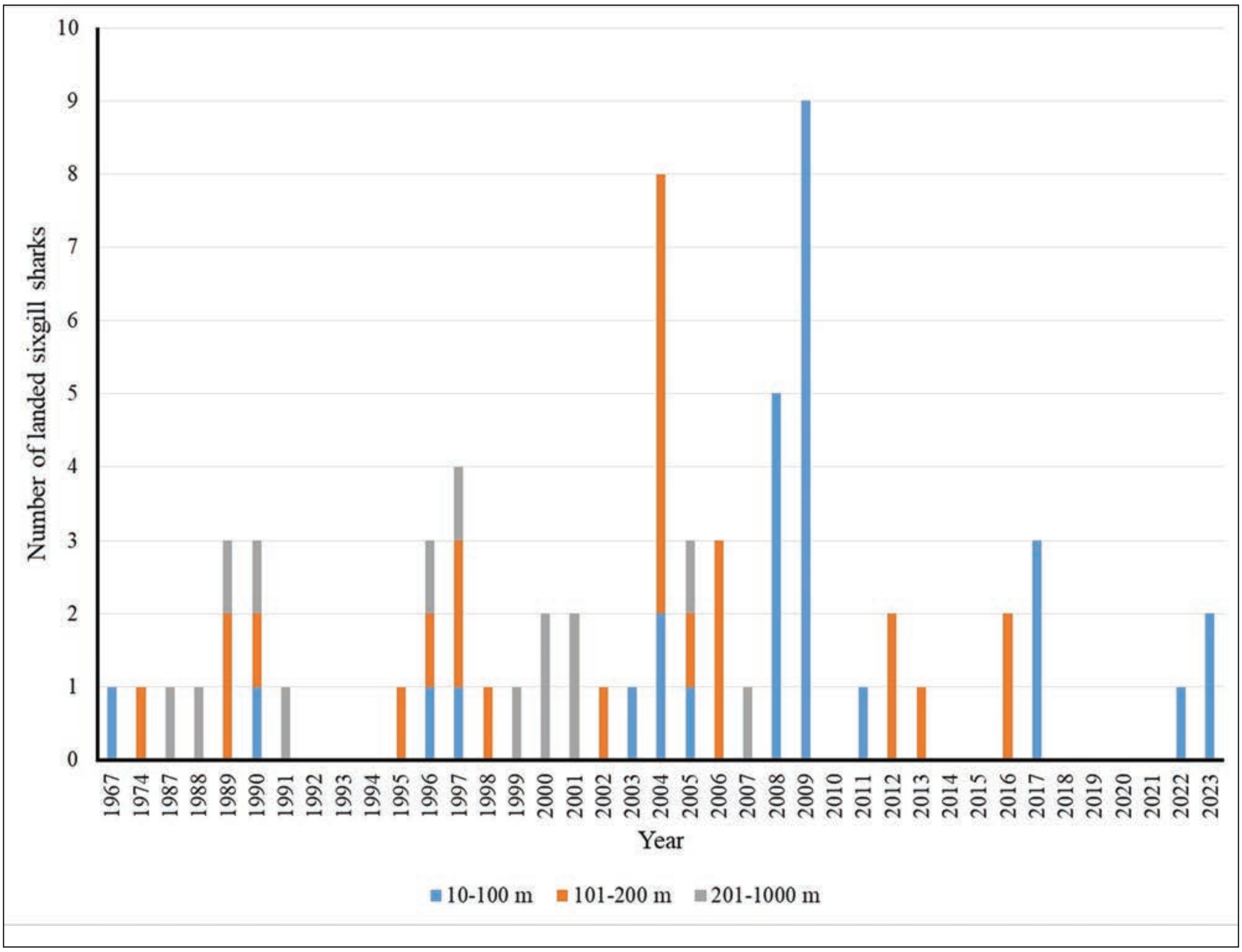

Fig. 7: Depths of capture of landed bluntnose sixgill sharks in the SoM between 1967 and 2023.
Sl. 7: Globine ulova morskih psov šesteroškrgarjev v Marmarskem morju med letoma 1967 in 2023.

primary fishing method in this subgroup as well (n=24; 52.17% vs. n=19; 41.3% for the gill- and trammel-net composite), the majority of captures in slope waters (>200 m depth) were associated with the gill- and trammel-net composite (n=7 vs. n=1 for purse-seining). However, the difference between fishing gear type and depth of capture was not statistically significant (Mann-Whitney test, p=0.38).

DISCUSSION AND CONCLUSIONS

In all geographical sub-regions of the Mediterranean Sea, *H. griseus* is considered a common bycatch species, primarily caught using demersal fishing gear, especially bottom trawls (Carpentieri *et al.*, 2021). A recent study based on local ecological knowledge (Nuez *et al.*, 2023) reported the capture of 2,111 specimens of *H. griseus* between 2007 and 2017, with the majority of captures concentrated in the western basin (n=1,152) and a significantly lower number of records in the eastern basin (n=284). During extensive MEDITS surveys investigating the spatial variation of demersal chondrichthyans in the northern Mediterranean, the frequency of occurrence of *H. griseus* varied from 0.9% (GSA9) to 9.5% (GSA25) from the western to the eastern basin (Follesa *et al.*, 2019). Between 1967 and 2022, a total of 234 specimens of *H. griseus* were recorded in Turkish marine waters, of which 131 were incidentally caught and landed in the SoM (Kabasakal, 2023b). With the recent addition of five bluntnose sixgill sharks, the current number of landed specimens in the SoM has increased to 136. Compared to the Mediterranean Sea, the SoM is a relatively small and semi-enclosed sea; however, the number of landed specimens, representing 6.44% of all Mediterranean records, suggests that a significant subpopulation of *H. griseus* inhabits this region.

Unfortunately, the findings of this study indicate that the bluntnose sixgill shark population in the SoM faces multiple threats.

Although *H. griseus* was not considered a commonly encountered shark species in the initial assessment of the MEDLEM database (Mancusi *et al.*, 2020), in the second phase of the MEDLEM project, covering the period from 2017 to 2022, it accounted for 20.5% of all reported large shark records from the Mediterranean (Gallo *et al.*, 2022). Therefore, as indicated in Lipej *et al.* (2022), it can be assumed that the population declines observed in many large shark species in the Mediterranean are not affecting *H. griseus*. Although both GLM regression and the Mann-Kendall trend analysis indicated an increasing trend in landings of *H. griseus* in the SoM, the smoothing spline model of the GLM regression revealed a dramatic decrease after 2017. Notably, the rise in *H. griseus* landings observed in the SoM between 2009 and 2016 started to decline in the following years, even as fishing capacity increased. Similar dramatic reductions in the biomass of elasmobranchs landed as a result of increased fishing capacity have been observed in other regions of the Mediterranean, such as the Adriatic, where an extraordinary decline in the abundance of demersal elasmobranchs has occurred (Barausse *et al.*, 2014). Therefore, although the registered fishing capacity in the SoM was lower from 2009 to 2016 than after 2017, the higher number of bluntnose sixgill shark landings can be explained by a greater recognition of the landed specimens.

In parallel with the growing use of social media, citizen science, and local ecological knowledge, there has been a notable rise in records of elasmobranch bycatch in commercial fisheries and sightings (Kabasakal & Bilecenoğlu, 2020; Bargnesi *et al.*, 2020, 2022; Mancusi *et al.*, 2020; Gallo *et al.*, 2022). Compared to the period from 1967 to 2005, the likelihood of finding information on the capture and/or landing of a bluntnose sixgill shark has increased with statistical significance since 2006, due to the rise of Internet media and social media posts. However, this increase did not reach the extent predicted by the accumulation curve model in this study, which was based on registered fishing capacity in the SoM and *H. griseus* landings per year.

As one of the deepest dwelling sharks, *H. griseus* can reach depths of at least 2,500 m, but is commonly found between 200 and 1,100 m (Ebert *et al.*, 2021). In terms of bathymetric distribution, *H. griseus* generally inhabits continental slope habitats; however, in certain parts of the world, such as the Flora Islets (Strait of Georgia, Canadian Pacific) or Puget Sound, bluntnose sixgill sharks are known to regularly visit very shallow reefs for unknown reasons (Dunbrack & Zielinski, 2003; Griffing *et al.*, 2014). In the present study, bluntnose sixgill sharks for which capture depth data were recorded (n=69) were caught incidentally at depths ranging from 10 to 1,000 m (Fig. 7). It has been observed in the SoM that bluntnose sixgill sharks can leave their usual depths on the continental slope and ascend to the very shallow waters of the continental shelf, and while the reasons for their migration may not be well understood in the Canadian Pacific, in the SoM, it is most likely due to progressive deoxygenation caused by the deterioration of environmental conditions in the bathyal region, or even the anoxia that is beginning to be observed in some regions of the SoM bathyal.

Over the last 40 years, the influx of excessive organic matter from terrestrial sources has caused nitrogen-phosphorus levels in the SoM to reach alarming heights, leading to conditions of hypoxia and even anoxia (Yücel *et al.*, 2023). Although dissolved oxygen levels remained above the hypoxia threshold (>80 μmol/L), which was tolerable for the survival of oxygen-dependent marine life up to the early 2000s, oxygen is now depleted in the deep zones (>500 m depth) of the SoM, and low levels of hydrogen sulphide (3–10 μM) have been observed (Yücel *et al.*, 2023). If the early 1990s is taken as a reference point, when dissolved oxygen in the deep waters (900–1,250 m) of the SoM began to fall below the hypoxia threshold (80 μmol/L) and a sudden, continuous increase in nitrogen and phosphorus levels was recorded, the observed increase in incidental catches of *H. griseus* in the shallow continental shelf, where dissolved oxygen levels remain higher than in deep waters, may be attributed to the deterioration of the bathyal ecosystem. Furthermore, the exclusion of records of bluntnose sixgill sharks caught above the continental slope at depths between 300 and 1,000 m (n=10) resulted in a statistically significant difference in the depth of capture of *H. griseus* between the 1967–1991 and 1995–2023 periods (Mann-Whitney test, $p<0.05$, $p=0.0013$), suggesting a bathymetric shift response to environmental degradation in the bathyal ecosystem. However, *H. griseus* is known to occur in deep-water oxygen minimum zones and has even spent daylight hours in hypoxic deep habitats (Comfort & Weng, 2015). The deepest capture of *H. griseus* in the SoM (1,000 m) was recorded in June 2005, coinciding with beginning of the drastic deterioration of environmental conditions in the bathyal ecosystem, and a few bluntnose sixgill sharks were caught in hypoxic regions during the 2000s. This suggests that *H. griseus* may still inhabit the bathyal zone of the SoM despite oxygen depletion. However, the increasing number of captures in the upper continental slope indicates that this region of the SoM is becoming a more frequently used habitat for *H. griseus* (Kabasakal, 2017). As an active demersal predator, *H. griseus* can ascend to shallower waters where dissolved oxygen concentrations are higher and exhibit more active foraging behaviour (Comfort & Weng, 2015). Ram-ventilating sharks often respond to environmental degradation, particularly deoxygenation, with vertical habitat compression (Sims, 2019). The results of the present study suggest that the bluntnose sixgill shark may be experiencing vertical habitat compression for the first time, throughout its Mediterranean range in the SoM. However, the fact that it is still recorded on the upper continental slope suggests that habitat compression has not yet reached a critical level and may have only recently begun.

Overfishing combined with environmental degradation in the northern Adriatic Sea have caused dramatic declines (≥ 80%) in elasmobranch stocks since the 1940s (Barausse *et al.*, 2014). Another example of a shark whose vulnerability to fishing is increased by deoxygenation is *Prionace glauca*, which has been linked to increased blue shark bycatch in the Atlantic Ocean due to oceanic habitat compression from deoxygenation (Vedor *et al.*, 2021). Captures of the deep-sea shark *Echinorhinus brucus* in shallow waters (<120 m) in the SoM have increased in recent years (Kabasakal *et al.*, 2023), suggesting that the deterioration of environmental conditions in the SoM bathyal zone is forcing sharks to migrate to shallower areas. Furthermore, a study investigating the demersal fish fauna in the SoM, reported the maximum CPUE value of *H. griseus* (29.89 kg/km^2) at depths between 100 and 200 m (Daban *et al.*, 2021). So how might the vertical habitat compression that *H. griseus* appears to be experiencing in the SoM affect the bycatch of this species in commercial fisheries?

A recent study has linked increased catches of *H. griseus* in the Mediterranean between May and October to a higher likelihood of bycatch as the species migrates into shallower waters during the warmer months (Nuez *et al.*, 2023). According to previous studies in the SoM, *H. griseus* is a bycatch shark, typically caught in multimodal demersal and purse seine fisheries (Kabasakal, 2023b). In two studies assessing large shark captures in Turkish commercial fisheries, *H. griseus* was reported as the primary bycatch species, with frequencies ranging from 38.6% to 51.8% (Kabasakal e*t al.*, 2017; Kabasakal & Bilecenoğlu, 2020). Until the early 2000s, *H. griseus* was primarily caught as bycatch in the SoM where fishing gears were deployed in the deep waters of the continental shelf and the continental slope (Meriç, 1995; Kabasakal, 2023b); however, since 2002, the depth of capture has decreased significantly and, with few exceptions, the species has become bycatch in the shallow waters of the continental shelf. Although *H. griseus* is thought to have a high tolerance to hypoxia (Comfort & Weng, 2015), environmental shifts in the bathyal zone of the SoM are pushing the area towards anoxic conditions, gradually making it uninhabitable for the bluntnose sixgill shark.

H. griseus is a viviparous shark with large litters ranging from 47 to 108 pups (Ebert *et al.*, 2021). Despite larger litter size in comparison to most other shark species, *H. griseus* is a typical example of a K-selected species with a notable generation length (53 years), which makes it vulnerable to overfishing and subsequent population declines (Finucci *et al.*, 2020). Incidental captures of pregnant females (e.g., Ounifi-Ben Amor *et al.*, 2017) or schools of individuals (e.g., Ben Amor *et al.*, 2019) may exacerbate the already existent vulnerability of bluntnose sixgill sharks throughout their distribution range. Therefore, in accordance with Annex 1 of Highly Migratory Species listed in UNCLOS, a bycatch limitation warning has been added for *H. griseus* in the Mediterranean Sea (Barone *et al.*, 2022), as most captured individuals tend to be immature (e.g., in Tunisian waters) or the average total length gradually falls below the length required for attaining sexual maturity (e.g., in Turkish waters). It has been emphasised that fishery managers should prioritise a better conservation plan and sustainable exploitation of this species, which is considered to have a very fragile stock, like in Tunisian waters (Mili *et al.*, 2021), Otherwise, a complete ban on the catch of the species may be necessary (Kabasakal, 2023b). According to Mili *et al*. (2021), landings of *H. griseus* are not abundant in the Mediterranean, which is an alarming situation, and the drastic reduction in landings in the SoM further jeopardises the future presence of the species in the region.

In conclusion, the triple threat of overfishing, habitat degradation or loss, and pollution now poses a significant threat to all elasmobranchs (Dulvy *et al.*, 2021; Pacoureau *et al.*, 2023) and represents a serious challenge for the *H. griseus* population in the SoM. Considering that the current organic matter load in the sea must be reduced by at least 50%, particularly in the deep regions, restoring suitable conditions for marine life will take at least six years (Yücel *et al.*, 2023). It is evident that the return of *H. griseus* to its safe habitat in the SoM bathyal will not be a quick or easy process. It is therefore vital to educate and encourage fishermen to release individuals of *H. griseus* (and other sharks, such as *E. brucus*) caught as bycatch in continental shelf fisheries, back to the environment alive and unharmed.

Unfortunately, in line with the old axiom that 'bad news sells', incidentally captured sixgill sharks, which have never had any economic importance in Turkish marine fisheries, have been landed for many years solely to create striking headlines in the newspapers (Kabasakal, 2010). Moreover, many individuals, often still alive when landed, are displayed for a few days to attract customers and then carelessly discarded, exploited by fishmongers just to increase their sales (Kabasakal, 2010). Recently, *H. griseus* has been declared a protected shark species in Turkish waters, and the statements regarding the dramatic declines in regional landings support this decision. However, educating fishermen remains a key issue to ensure the shark's proper handling and survival after release into the sea. As emphasised in the literature (Pacoureau *et al.*, 2023), the risk of shark extinction increases in seas with high fishing pressure, and it is only possible to overcome this situation with strong fisheries management. Fisheries management plans, also known as 'shark plans' could halt the decline of elasmobranch stocks, subsequently increasing them or slowing down the ongoing decline (Pacoureau *et al.*, 2023). Therefore, a holistic management plan should be prepared and implemented without delay to successfully protect *H. griseus* and other elasmobranchs occurring in the SoM.

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VPLIV RIBOLOVNE ZMOGLJIVOSTI IN OKOLJSKIH PARAMETROV NA ULOV VRSTE *HEXANCHUS GRISEUS* V MARMARSKEM MORJU

Hakan KABASAKAL
Istanbul University, Institute of Science, Fisheries Technologies and Management Program, Istanbul, Türkiye
e-mail: kabasakal.hakan@gmail.com

Uğur UZER
Istanbul University, Faculty of Aquatic Sciences, Department of Fisheries Technologies and Management, Istanbul, Türkiye

F. Saadet KARAKULAK
Istanbul University, Faculty of Aquatic Sciences, Department of Fisheries Technologies and Management, Istanbul, Türkiye

POVZETEK

Med julijem 1967 in decembrom 2023 je bilo v Marmarskem morju (SoM) ujetih 136 morskih psov šesteroškrgarjev, Hexanchus griseus. *Čeprav sta tako generalizirani linearni model (GLM) kot Mann-Kendallov test trenda pokazala porast ulova vrste* H. griseus*, so ocenjeni izravnalni zlepki regresijske trendne črte GLM razkrili močan upad ulova po letu 2017. Medtem ko so se globine ulova od začetka leta 2000 gibale med 10 in 1000 m, je bila večina osebkov ujetih v plitvih vodah epikontinentalnega pasu. Slabše okoljske razmere in vse večja deoksigenacija v globokih vodah SoM sovpadajo z zmanjšanjem globine ulova morskih psov šesteroškrgarjev v epikontinentalnem pasu. Ugotovitve kažejo na stalen proces navpičnega krčenja habitatov, za katerega se zdi, da povečuje ranljivost* H. griseus *za komercialni ribolov v Marmarskem morju.*

Ključne besede: morski pes šesteroškrgar, prelov, ranljivost, onesnaževanje okolja, kisikove razmere, upad

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