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Approaching the "real" state of elasmobranch fisheries and trade: A case study from the Mediterranean

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ABSTRACT

Elasmobranchs are sensitive marine species due to their K-strategic life characteristics in combination with the intensification of fisheries. Despite the regulations and conventions protecting several species, elasmobranchs are still caught as bycatch and landed throughout the Mediterranean, a location where the pressure on shark populations is well documented. Severe knowledge gaps still exist regarding their biology, ecology and the exploitation by fisheries, due to limited research and the fact that in almost all Mediterranean countries, elasmobranchs are recorded by the national authorities in aggregated landing categories. To overcome such issues, we contrasted landings and trade of elasmobranchs using an integrative sampling in auction markets, landing sites, and fish markets at three important sites in Greece, combined with DNA analysis to address mislabeling. Five species contributed more than half of the total elasmobranch catches for all fisheries combined (62.5%); *Scyliorhinus canicula* (21.6%) and to a lesser extent *Dasyatis* sp., *Mustelus mustelus*, *Raja radula* and *Dasyatis pastinaca* (12.8%, 11.7%, 9.6%, and 6.9% respectively). Results highlighted that small-scale fisheries underreported catches of threatened elasmobranchs. About 50–60% of the elasmobranch landings were threatened species while in the fish markets the corresponding contribution was reduced to 26%. Mislabeling was common throughout the year with several species sold under different names for increasing profit or to hinder their protection status. The current practices do not satisfy Common Fisheries Policy in terms of treacability, and the fishing of threatened elasmobranchs raises additional concerns as a conservation priority.

1. Introduction

1.1. General perspective on elasmobranch management

Chondrichthyans belong to the most vulnerable marine taxa with a quarter of species facing an elevated extinction risk (Dulvy et al., 2014). Among several areas, the Mediterranean Sea has been identified as one of the three hotspots where the biodiversity of sharks and rays is seriously threatened, with bycatch being the most significant threat for their conservation (Dulvy et al., 2014). At least 50% of the sharks and rays in the Mediterranean are threatened with extinction, extirpations, and steep population declines (Dulvy et al., 2016).

Aggregating taxonomic categories of elasmobranch catches are a major pitfall jeopardising any conservation effort (Cashion et al., 2019),

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given that fisheries exploitation of targeted or bycatch is the major threat to elasmobranchs (Dulvy et al., 2016; Milazzo et al., 2021). To quantify this impact, it is important to taxonomically disaggregate catches and collect species-specific data. However, elasmobranchs are rarely (or incorrectly) identified (Kleitou et al., 2017; Serena et al., 2020) to species level, making the official data less reliable even if they are recorded in species-specific landing categories. Despite the efforts made by the European Union (EU), the General Fisheries Commission for the Mediterranean (GFCM), and the International Commission for the Conservation of Atlantic Tunas (ICCAT) to reduce shark bycatch mortality (i.e., adoption of the European Commission's Action plan for the Conservation and Management of Sharks), and the adoption of several consequent Recommendations, EU goals are far from being achieved, and conservation actions are urgently needed. Under this legislative framework, fisheries management is becoming more multi-disciplinary, and there is an urgent need to have robust monitoring mechanisms and multiple control protocols. Thus, the main challenges to be addressed are: (a) the complexity and heterogeneity of the Mediterranean fisheries, where bycatch levels are uncertain due to the low sampling coverage of the different type of fisheries (FAO, 2018a), (b) the heterogeneity of data provided by national data collection programs, primarily designed to quantify discards of commercial species (Dörner et al., 2018), and (c) the complexity of the Mediterranean ecosystem food webs (Coll and Libralato, 2011).

Mediterranean fisheries are characterized by a highly diverse fishing fleet, mostly consisting of small-scale vessels (less than 12 m) (FAO, 2018a) and targeting numerous fish species with contrasting life-history traits (Stergiou et al., 2009). Presently, fishing vessels smaller than 10 m in length, are not required to transmit fishing logbook data, which has led to an uncertainty on the status of many vulnerable protected fish species, and generated bias in bycatch estimates and problems with the bycatch monitoring in the Mediterranean. Subsequently, assessing bycatch level of elasmobranchs has been problematic and likely underestimated. Therefore, there is a need to implement and ensure gear species-specific monitoring of all components of multi-gear fisheries.

1.2. Elasmobranch in Greek fisheries and trade

In Greece, based on the most recent list, there are records of 62 species of elasmobranchs (Papaconstantinou, 2014), with 42 of them being considered threatened according to the IUCN evaluation (Vulnerable-VU, Endangered-EN, Critically Endangered-CR) (Dulvy et al., 2016). The biology, ecology, exploitation levels and conservation status remain largely understudied. For instance, in 2009 only 13 species were evaluated in the Greek Red Data Book, whereas the data for the remaining 49 were inadequate (Legakis and Maragou, 2009) and in the Mediterranean assessment, 9 out of the 62 elasmobranchs assessed, were listed as Data Deficient. At the same time, national and international legislations as well as international Conventions (including the Barcelona Convention, Bern Convention, CITES) have established measures for 25 species.

According to EU legislation, all marketed fisheries products should be clearly labeled with their nominal scientific name, the common name in the official language of the Member State marketed, the FishBase Information System or the ASFIS database of the Food and Agriculture Organisation (FAO, 2018b), the fishing gear and the state of the product (frozen, fresh, etc.), when relevant Ministry transposed this regulation with specific standards for the labels (see Table 2 of Giovos et al., 2020). Regarding fisheries, several elasmobranchs are discarded due to low commercial value (Damalas and Vassilopoulou, 2011) and those landed are officially reported in the Hellenic Statistical Authority (HELSTAT) in three aggregated categories ((i) Catsharks, nursehounds nei, SCL; (ii) Smooth-hounds nei, SDV; (iii) Raja rays, SKA. Gear species-specific data, especially for more coastal species that are targeted by small scale fishers (SSF), are limited and vague (e.g. Follesa et al., 2020). Misidentification of elasmobranchs is common in Greece with several species commonly misidentified or misreported (Giovos et al., 2020). At the same time, new studies on elasmobranchs reveal illegal trade (Giovos et al., 2020), mislabeling (Pazartzi et al., 2019; Giovos et al., 2020) and illegal fishing (Giovos et al., 2020), although the frequency of occurrence of these phenomena is unknown.

A large proportion of the Greek landings, especially those derived from SSF, are not directed through the official auction markets. The majority of the fish products sold in the Greek fish markets originated from industrial fisheries catches, while landings from the SSF were sold directly to local consumers. Given that SSF are not obliged to land in auction markets, their monitoring took place at the landing sites while elasmobranch catches from the industrial fishery were monitored from auction markets.

1.3. Aim of the study

The Central-North Aegean Sea represents the main hot-spot area of elasmobranch fisheries contributing more than half (for the 1990–2017 period; Hellenic Statistical Authority, HELSTAT, 2019) of the total commercial elasmobranch landings in Greece. Here, we collect and integrate a variety of data sources, to quantify species-specific elasmobranch landings in different ports of the study area, and potential mislabeling of elasmobranchs within local fish markets.

2. Materials and methods

2.1. Study area

The Central-North Aegean Sea is an oligotrophic ecosystem (Lykousis et al., 2002), but one of the highest productivities in the Eastern Mediterranean (Bosc et al., 2004) due to the nutrient influx from the Black Sea and several rivers (Axios, Aliakmon, Evros, Loudias and Nestos) (Lykousis et al., 2002; Karageorgis et al., 2003). The area is also characterized by a diverse coastal and bottom morphology including several gulfs (Strymonikos Gulf, Chalkidiki Peninsula Gulfs, Thermaikos Gulf, Pagasitikos Gulf) and islands (Thassos, Samothraki, Sporades Islands), while the Thracian Sea has an extended continental shelf, primarily covered with seagrass meadows and sandy-muddy bottoms (Fig. 1). These characteristics make the Central-North Aegean Sea one of the most important fishing grounds in Greece, sustaining almost a fifth (20.3%) of the Greek national fleet, with a third (37.5%) of the dynamic gear fleet (i.e., trawls and purse seines) and 19.7% of the SSF fleet (data derived from the official registry of the four major towns; Alexandroupoli, Kavala, Thessaloniki, and Volos) (HELSTAT, 2019). Elasmobranchs, based on the official statistics, are mostly (approximately 90%) caught by bottom trawlers (65%) and SSF gears (23%) and to a minor extent by purse-seiners (Giovos et al., 2020).

2.2. Auction market surveys

During January–December 2019, two observers performed monthly surveys of the auction markets of the four major towns (Fig. 1). All elasmobranch products were recorded following an adapted Rapid Fishery Assessment Market Survey form (White et al., 2014). Recorded information included the total weight per species per trader (measured in situ using the trader's scale), name of the trader, total number of traders in the auction market, date, and other optional information like the name of the vessel, capture location, fishing equipment used, etc. Pictures were taken for all registrations (i.e. records of a species from a trader) to facilitate species confirmation by an additional taxonomic expert at a later stage. The field identification guide produced by Serena (2005) was used for in-situ identification. When macroscopic identification was not possible, tissue samples were collected for genetic species identification. Sampling was conducted for 2 h per month, between 1.00 and 3.00 a.m. when most of the vessels landed their catches.

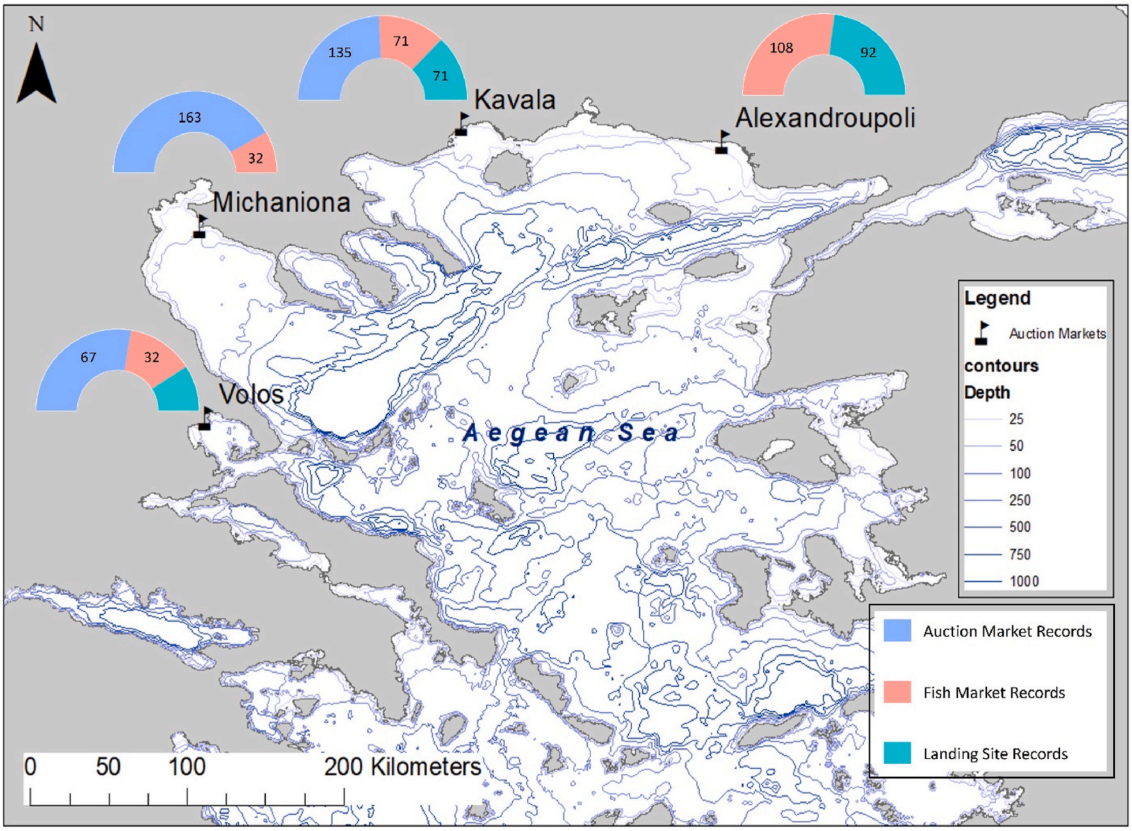

Fig. 1. Sampling sites in the Central-North Aegean Sea. The numbers in the chart pies indicate the number of records per site.

2.3. Small scale surveys

Two observers performed monthly surveys of the landing sites of Alexandroupoli, Kavala, Michaniona, and Volos where small scale fishers (netters and longliners) land and sell their catches (Fig. 1). Surveys took place in the early morning when fishers were returning from the sea. All the elasmobranchs landed and/or discarded were recorded, as fishers arrived at the landing site with the entire catch and then discard unwanted species, together with information on total weight per species, the fishing equipment used, and the location of capture, using the same sampling form developed for the auction markets. When macroscopic identification was not possible, tissue samples were collected for the genetic identification of the species. For all registrations, pictures were taken to confirm identification by an additional taxonomic expert at a later stage.

2.4. DNA analysis in fish market surveys

Fish market surveys took place on a monthly basis in four selected towns; Alexandroupoli, Kavala, Thessaloniki, and Volos (Fig. 1). Through a random selection process, fish markets and fish stores were visited, and pictures and tissue samples of products sold as elasmobranchs (e.g. ray wings, shark fillets etc.) were taken for genetic analysis.

Two different mitochondrial (mtDNA) genes (16S rRNA and COI) were selected as targets for the analysis, as both markers have been repeatedly used in fish DNA barcoding studies (Palumbi, 1996; Ivanova et al., 2007). A universal primer pair (16SH: 5′-CCGGTCTGAACTCAATCACG-3′, 16SL: 5′-CGCCTGTTTAACAAAAACAT-3′) was used for the amplification of a 600 bp fragment from the mtDNA 16S rRNA gene (Palumbi, 1996). Cycling conditions consisted of an initial denaturation step of 94 °C for 3 min followed by 30 cycles of 94 °C for 50 s, 50 °C for 50 s and 72 °C for 50 s, with a final extension at 72 °C for 5 min. A universal primer pair (FishF2: 5′-TCGACTAATCATAAAGATATCGGCAC-3′, FishR2: 5′-ACTTCAGGGTGACCGAAGAATCAGAA-3′) was also used for the amplification of a 670 bp segment of the mtDNA COI gene (Ward et al., 2005). The PCR cycling conditions included an initial denaturation at 95 °C for 2 min, followed by 35 cycles at 94 °C for 30 s, 53 °C for 30 s, 72 °C for 1 min, and a final extension at 72 °C for 10 min.

PCR products were purified and, subsequently, single-stranded sequenced with BigDye Terminator v3.1 (Life Technologies, USA) cycle sequencing methodology, using the same primers as for PCRs (a forward primer for each gene).

All sequences were compared with those available in GenBank using the standard nucleotide BLAST (blastn) against the nucleotide collection (nr/nt) database (http://blast.ncbi.nlm.nih.gov/Blast.cgi). COI sequences were also compared to the BOLD database (Species Level Barcode Records, http://www.boldsystems.org/), through the Identification System (ID's), for verification purposes. For both databases, the identity threshold was set at 99% and sequences with high homology (≥99%) were considered as acceptable and consequently registered, whereas sequences below the threshold were disregarded from further analysis.

2.5. Official data

In Greece three categories of elasmobranchs are officially recorded by HELSTAT: (i) Catsharks, nursehounds nei (SCL), (ii) Smooth-hounds nei (SDV), (iii) Raja rays (SKA); (abbreviations from FAO Aquatic Science and Fisheries Information System). However, elasmobranch products can be marketed in 17 categories based on Annex 2 of the Ministerial Decision in the Greek Legislation (Fig. 2A). All auction markets are required to report the marketed products every month by providing information on the total weight and the prices per month. Information is provided by category, based on the list of Annex 2 of the Ministerial Decision. In the context of the study, the reconstructed catch

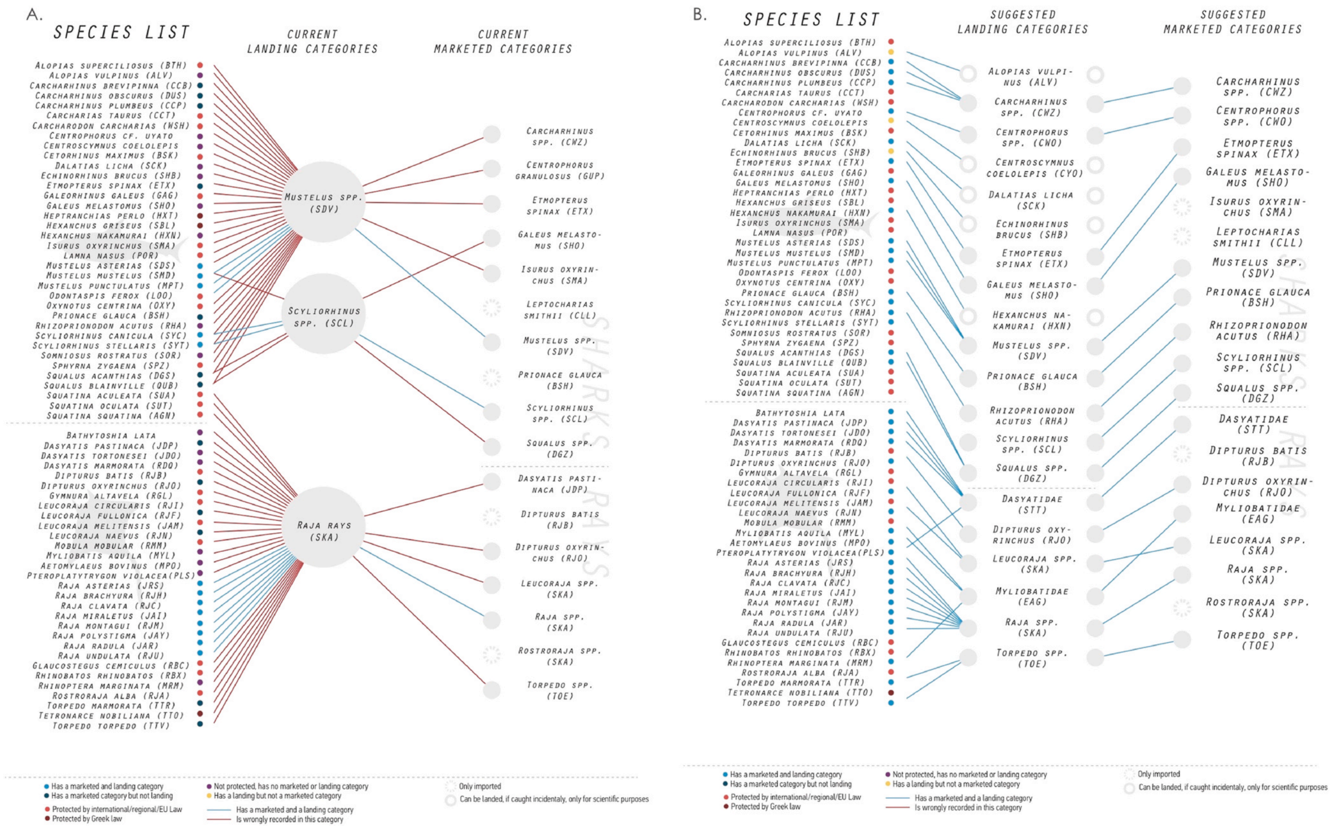

Fig. 2. A. Current situation in the Greek elasmobranch landing and trade. The list of species is based on the species reported in Papakonstantinou (2014) and Chatzispyrou et al. (2020). Current marketed categories are based on those provided by the Ministerial Decision No 1750/32219/2015, while landing categories are based on those reported by HELSTAT. B. Recommendations on elasmobranch catch and marketed categories in Greece.

data of the Sea Around Us (available at www.seaaroundus.org; Pauly and Zeller, 2016) were used for the Greek Seas (Moutopoulos et al., 2015). Reconstructed catches were used instead of the official ones, because the former also include the unreported portion of the catches that are not properly covered by the official national statistics, such as those from SSF vessels (Moutopoulos et al., 2015). The use of such reconstructed data will further enhance our integrated approach to vulnerable species that are not recorded by official authorities.

2.6. Data analysis

A total 48 surveys were conducted in the auction markets, landing sites, fish markets, and fish stores of Alexandroupoli, Kavala, Thessaloniki (Michaniona), and Volos (Fig. 1). Regarding the auction markets, all registrations from Alexandroupoli were not included in the current analysis since the majority of the landings were transferred straight to Kavala auction market. Volos auction market was further excluded from the comparison with the official data because it is not an official auction market managed by CMFO SA and therefore data are not available. Additionally, all registrations from the landing site of Michaniona were excluded due to the small number of vessels and the irregularity of their fishing effort.

The species-specific weight per sampling was used to estimate the monthly landings of each species for the auction markets based on the aggregated official data using the weight proportion of each species recorded in each auction market. This approach fited well for the Volos auction market, because all marketed elasmobranchs were recorded during the surveys. For Kavala and Michaniona auction markets we used the official monthly data provided by Central Market and Fishery Organizations (CMFO SA) in four aggregated categories for elasmobranchs (*Mustelus* spp.-SDV; *Raja* spp-SKA; *Scyliorhinus* spp.-SCL; *Squalus* spp.-DGZ) to correct our recorded daily weights. To increase the accuracy of our analysis, we treated shark and batoid species separately. For each month (January to December) and auction market (Kavala, Michaniona), two weight factors were developed for sharks and for batoids, respectively. For estimating the weight factors, the official weights of sharks (aggregating the official data for Mustelus spp.-SDV; Scyliorhinus spp.-SCL; Squalus spp.-DGZ) and the official weights for batoids (Raja rays-SKA) were respectively divided with our collected monthly aggregated weights for all shark and batoid species, (Official Monthly Sharks (or Batoids) Weights/Observed Daily aggregated Sharks (or aggregated Batoids) Weights*Working Days). The resulting factors were used to extrapolate our monthly data per species and gear type.

For SSF, certain assumptions were made on extrapolating the elasmobranch catches. Table A1 (in Appendix) presents the number of fishing vessels, the number of fishing days per month, and the percentage of the active number of small-scale fishing vessels in the study areas. The number of SSF vessels was derived from the records of the EU Fleet Register for 2019 (https://webgate.ec.europa.eu/fleet-europa/index_en). Fishing days for the professional SSF per area/port were derived from Tzanatos et al. (2005). The percentage of the truly active SSF vessels (i.e., fully dependent on fisheries) per month was derived from Kapantagakis and Laurijsen (2005), which has remained consistent until present day (Tzanatos et al., 2020).

A matrix consisting of the percentage species catch composition by gear and month (January to December) was generated using the data derived from the auction markets and the landing sites. Data were squared root-transformed and converted into a triangular matrix of similarities using the Bray-Curtis coefficient (Bray and Curtis, 1957) to be analyzed using the group-average linking method. Differences between the identified groups formed by the cluster analysis were tested using the non-parametric PERMANOVA test (Anderson and Walsh, 2013). This test statistically determines whether the centers (centroids) between the clusters differed in their ordinations, similar to an ANOVA test. The contribution of each species to the average Bray-Curtis similarity within the aforementioned groups was also identified using SIMilarity PERcentage (SIMPER) analysis (Clarke and Warwick, 2001). Multivariate analyses were all performed using Primer ver 7.0.

3. Results

3.1. Landings by species and fishing gear

Overall, 793 unique registrations (unique observations of elasmobranchs during the surveys) were obtained, 365 from the 3 auction markets, 185 from the 3 landing sites, and 243 from the different fish market and fish stores of the 4 towns, resulting in 224 tissue samples for genetic identification from all locations (Fig. 1). Macroscopic and genetic identification in all cases resulted in the identification of 28 different species, with auction markets displaying the highest species richness (25 different species observed). More than half of the registrations refer to batoid species (65.44%, N = 519), while 58.22% of the total weight (3775.82 kg) resulted from shark species (Table 2).

Bottom trawlers and to a lesser extent gillnets caught a wide range of the reported species (22 and 14, respectively). The number of elasmobranchs that approximately contributed 75% of the elasmobranch catches in weight was highest for bottom trawls (seven species) and lowest for longlines (three species for both drifters and bottom longlines). Purse seiners, however, showed high selectivity for elasmobranchs with only one species landed (*Dasyatis pastinaca*) (Table 1). Five species contributed more than half of the total catches for all fishing gears combined (62.5%); *Scyliorhinus canicula* (21.6%) and to a lesser extent *Dasyatis* sp., *Mustelus mustelus*, *Raja radula* and *Dasyatis pastinaca* (12.8%, 11.7%, 9.6%, and 6.9% respectively) (Table 1). Most of the gillnet catches were composed of *D. pastinaca* and *Dasyatis* sp. (cumulative 56.9%), pelagic longlines mostly caught *M. mustelus* (50%), bottom longlines *R. radula* (54.5%), trawls *S. canicula* and *M. mustelus* (cumulative contributed 40%) and purse seines *D. pastinaca* (97.4%). Almost two-thirds (65.6%) of all elasmobranchs were caught during October–December and in August (Fig. 3), a pattern observed for four of the five most abundant species (Fig. 3); *S. canicula*, *Dasyatis sp., M. mustelus* and *R. radula*. In contrast, *D. pastinaca* was mostly caught during summer (May to July) displaying a clear seasonality (Fig. 3).

Multivariate analysis on the species composition per fishing gear and month (36 total combinations) revealed, at 21.85% significance level, four significant (PERMANOVA test: pseudo F-ratio = 44.60; $p < 0.05$) groups primarily dependent on gear type. Six gear-month combinations were identified (Supporting Fig. A1). SIMPER analysis identified the most representative species that cumulatively contributed to the average

Table 2
Species specific extrapolated landing weight (in KG) in the auction markets and the landing sites in the Central-North Aegean for 2019.

Row Labels	Auction	Landing	Total
Aetomylaeus bovinus	9664	804	10468
Centrophorus cf. uyato	115		115
Dasyatis marmorata	214		214
Dasyatis pastinaca	5147	996	6143
Dasyatis sp.	79010	1209	80219
Dasyatis tortonesei	20085	124	20209
Dipturus oxyrinchus	2706		2706
Galeus melastomus	999		999
Gymnura altavela	6820	670	7490
Heptranchias perlo	39		39
Isurus oxyrinchus	1593		1593
Malacoraja clavata		149	149
Mustelus asterias	6649		6649
Mustelus mustelus	175759	240	175999
Mustelus punctulatus	6236		6236
Myliobatis aquila	13102	204	13306
Prionace glauca	12056		12056
Pteroplatytrygon violacea	48		48
Raja brachyura	100		100
Raja clavata	33801	182	33982
Raja miraletus	12637	40	12676
Raja polystigma	25		25
Raja radula	21842	1814	2366
Raja sp.	2401	122	2523
Raja spp.	21553		21553
Rostroraja alba	4807		4807
Scyliorhinus canicula	43926	1080	45007
Scyliorhinus stellaris	598	42	640
Squalus blainville	20917		20917
Torpedo marmorata	125	390	515
Uknown elasmobranch species	53840	20	53859
Total	**556814**	**8086**	**543608**

Table 1
Percentage contribution of the species to the average Bray–Curtis similarity (Av%) of the groups identified by the multivariate analysis for the fishery in the Central-North Aegean 2019. Comp% is the species composition, C%, is the percentage contribution to the Bray–Curtis similarity within groups (see Fig. 3); Contrib%, is the cumulative contribution of SIMPER analysis.

Species	Gillnet			Bottom Trawlers			Longlines			Purse seiners		
	Av.: 45.26%				Av.: 52.77%		Av.: 43.55%			Av.: 71.03%		
	Comp%	C%	Contrib%	Comp%	C%	Contrib%	Comp%	C%	Contrib%	Comp%	C%	Contrib%
Aetomylaeus bovinus	9.9	15.0	3.9	2.9	8.0	1.5	1.3	12.0	1.6			
Centrophorus cf. uyato				0.0	3.0	0.3						
Dasyatis pastinaca	22.5	19.0	6.0	1.5			1.5	16.0	3.5	97.4	92.0	100.0
Dasyatis sp.	35.4	21.0	8.4	7.7	14.0	5.2	0.1					
Dasyatis tortonesei	1.4			3.2	6.0	0.2	0.2					
Dipturus oxyrinchus				0.7	4.0	0.8	4.1					
Gymnura altavela	9.5	4.0	0.3	2.5	3.0	0.8	0.3					
Raja clavata	1.1	15.0	3.2	10.2	25.0	17.0	0.6	9.0	1.5			
Mustelus asterias				0.2			7.5	12.0	0.9			
Mustelus mustelus	3.9			10.2	16.0	4.5	77.0	72.0	87.4			
Mustelus punctulatus				0.5			1.3	9.0	0.6			
Myliobatis aquila	0.5	6.0	0.5	4.0	7.0	2.0	1.7					
Raja miraletus	0.1			0.5	8.0	1.8	0.0					
Raja radula	4.4	61.0	57.8	5.5	19.0	7.4	4.1	14.0	4.5			
Raja sp.	2.1	6.0	0.5	0.1	12.0	3.3						
Scyliorhinus canicula	0.1	6.0	0.7	37.6	70.0	50.0	0.1			2.6		
Squalus blainville				5.4	19.0	5.3						
Torpedo marmorata	7.6	35.0	18.7	0.2	8.0			12.0				
Number of species/group	**13%**			**18%**			**14%**			**2%**		
Cumulative contribution (%)	**98.7%**			**93.0%**			**99.8%**			**100.0$**		

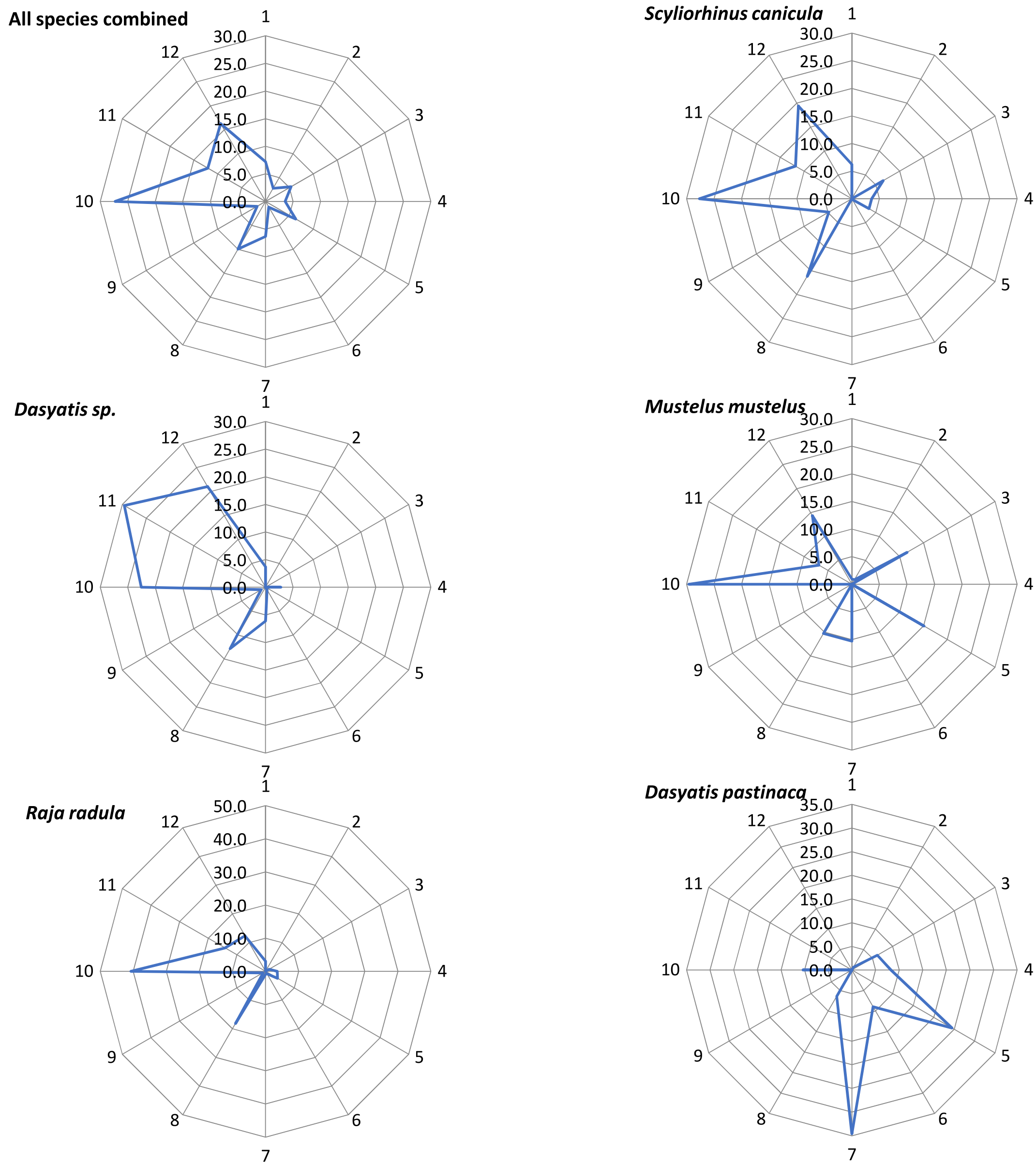

Fig. 3. Seasonality of the most abundant elasmobranch species caught by all gear types combined in the Central-North Aegean, 2019. The vertical lines indicated the monthly species composition (%) and the integer numbers the months (1 = January, …., 12 = December).

Bray-Curtis similarity within the different groups identified by the cluster analysis (Table 1). These species generally differed between the different fisheries with *R. radula* being the most representative species caught in gillnets, *S. canicula* and to a lesser extent *R. clavata* in trawls, *M. mustelus* in longlines (both for bottom and driftners) and *D. pastinaca* in purse seines (Table 1).

3.2. Auction market surveys

Most auction market registrations were collected from Michaniona (44.65%, N = 163) and Kavala (36.98% N = 135), followed to a lesser extent from Volos (18.35%, N = 67) (Fig. 1). In 58 records (15.89%), species were identified to the genus level (a high proportion were *Dasyatis* sp. Due to the identification issues with these species; Serena et al., 2005) while in 19 cases (5.20%) identification was not possible. About 58% of the registrations recorded in the auction markets were referring to species whose Mediterranean populations are listed as threatened (Vulnerable (VU) = 38.73%; Endangered (EN) = 8.09%; Critically Endangered (CR) = 4.91%) by the IUCN Red List of Threatened Species, with Michaniona having the highest percentage of threatened species (61.04%) followed by Volos (59.68%) and Kavala (40.68%) (Figs. 3 and 4). However, in Volos the highest percentage of CR species detected (8.06%) was due to the landings of *Gymnura altavela* and *Aetomylaeus bovinus,* that were the most commonly CR species found both in Michaniona and Kavala. Additionally, landings of *Prionacea glauca* and *Isurus oxyrinchus* were recorded in Michaniona and Kavala, respectively (Table 2). The most common species recorded were *M. mustelus, Dasyatis sp., R. clavata, R. radula* and *S. canicula* in Michaniona, *S. canicula, M. mustelus, R. clavata, Squalus blainville* in Kavala and *Dasyatis* sp. and *R. clavata* in Volos (Fig. 4). The majority of the registrations were obtained during October, November, and December (16.99%, 12.33%, and 11.78%, respectively), while the highest diversity of species was also recorded during the same period (Fig. 3, Table A2).

In the auction markets, several of the elasmobranch registrations were labeled as imported products from Turkey (in terms of weight: 32.54%-Michaniona, 22.55%-Kavala, and 3.27%-Volos) frequently occurred in March and October–December.

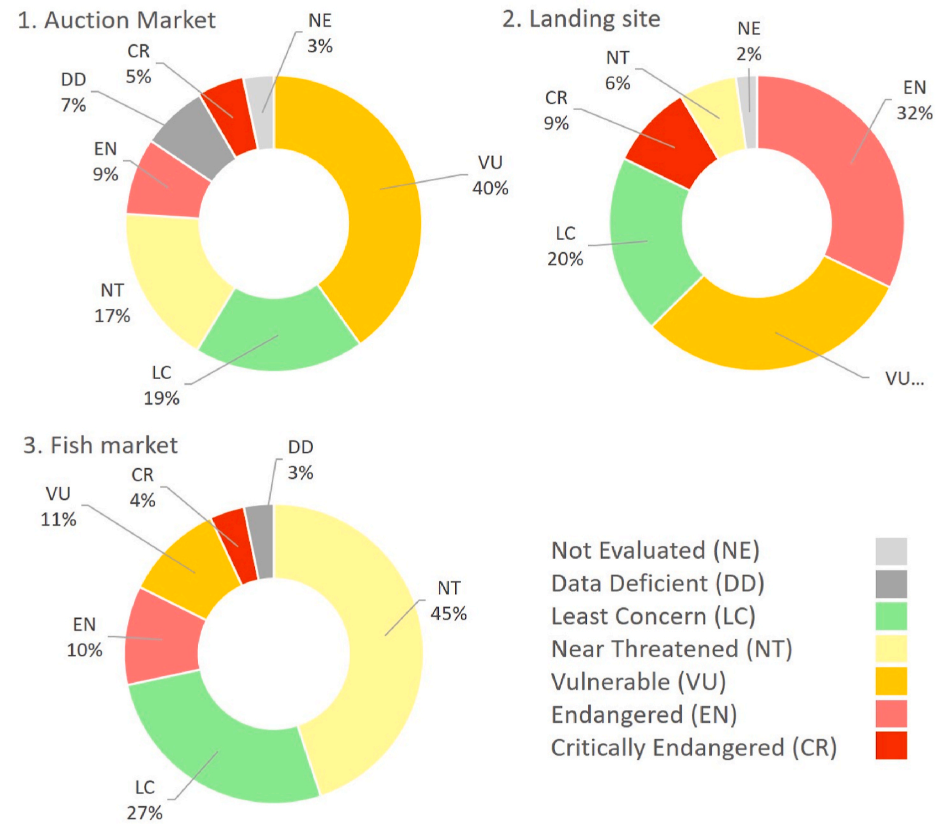

Fig. 4. Conservation status of the Mediterranean population of all elasmobranch specimens found in the sampling sites.

3.3. Small scale surveys

Most surveys were conducted from Alexandroupoli fishing port (49.73%, N = 92) followed by Kavala (38.38%, N = 71) and Volos (11.89%, N = 22) (Fig. 1, Table A2), and most registrations were collected from Alexandroupoli (45.27%, N = 91), followed by Kavala (39,80%, N = 80) and Volos (14,93%, N = 30). Ten elasmobranchs were observed in Alexandroupoli and Kavala, and five in Volos (Table A2). Kavala exhibited the highest proportion of threatened elasmobranchs (VU = 1.43%; EN = 67.14%; CR = 5.71%) due to the high occurrence of *R. radula*, followed by Alexandroupoli (VU = 49.40%; EN = 8.43%; CR = 14.46%), attributed to the high percentages of *R. radula* and *A. bovinus* (Table 2) and to a lesser extent by Volos (VU = 52.38%; EN = 9.52%), due to the high percentages of *Dasyatis spp.* (Figs. 4 and 5). Alexandroupoli exhibited the highest percentage of CR elasmobranch landed, due to the high occurrence of *G. altavela* (protected species) and *A. bovinus*, while Kavala exhibited the highest percentage of EN elasmobranchs due to high occurrence of *R. radula* (Figs. 4 and 5). Most specimens were caught in August (31.35%, N = 58), with the highest number of elasmobranch species caught in October (8) (Fig. 3, Table A2).

3.4. Official data analysis

Elasmobranchs contribute approximately 1.1% of the total Greek official landings and 1.0% of the Central-North Aegean landings during 1990–2017 (HELSTAT 2019). More than half of the official total elasmobranch landings were represented by *Raja* rays nei (SKA) (59.5%), one third approximately by Smooth-hound nei (SDV) (30.1%) and the remaining by the Catsharks, nursehounds nei (SCL) (10.4%). The annual reconstructed catch data of elasmobranchs were 8 times higher than the official landings and depicted a consistently declining trend for the 1990–2017 period, decreasing from 3358 t, in 1991, to 843 t, in 2017.

3.5. Genetic analysis in fish market surveys

In total, 224 samples were collected for genetic analysis from the fish market, auction markets, and landing sites (Table A3). Amplification and sequencing were successful for all DNA samples. In most cases, amplification of the 16S rRNA gene failed to provide sufficient resolution to species level, especially for *Raja* and *Mustelus* genera. For that reason, only 18 samples were identified solely with the 16S marker and all the remaining tissue samples (N = 206) were analyzed using the COI gene. The identification results for COI marker were verified through sequence comparisons using the BOLD database.

Most common labels used for the sold batoids were “Vatos” (refers to all *Raja* spp.) (26.75%, N = 65), “Salachi” (common name for all batoids) (11.52%, N = 28), “Rina Vatos” (Rina is the Greek common name for Angel Sharks and Vatos the common name for all *Raja* spp.) (5.76%, N = 14) and “Rinovatos” (the Greek common name for guitarfish) (4.12%, N = 10) and sharks wer “Galeos” (referring to all *Mustelus* spp.) (25.93%, N = 63). Almost half (44.19%, N = 57) of the batoid products sold, were mislabeled, and 14.73% (N = 19) had no label. For sharks, 78.95% (N = 60) were mislabeled and 10.53% (N = 8) had no label. *R. clavata* was the most mislabeled species of batoid (26.36%) and sold either as “Rina Vatos” or as “Salachi”, which according to the applied legislation must be sold under the label “Vatos, SKA”. For sharks, *S. canicula* was the most commonly mislabeled species (53.95%) often sold as “Galeos” which refers to all species of *Mustelus* genus, while according to the applied legislation must be sold as “Skylopsaraki” or “Scyliorhinus sp., SCL”. *Rostroraja alba* was the only illegal species found during our surveys although in few cases fishmongers did not allow us to record specimens of *G. altavela*, as they were aware of the legal status of the species. Interestingly, a tissue sample genetically identified as *Squalus cubensis* was collected from a fish market in Thessaloniki. The species is present only in the Western Atlantic.

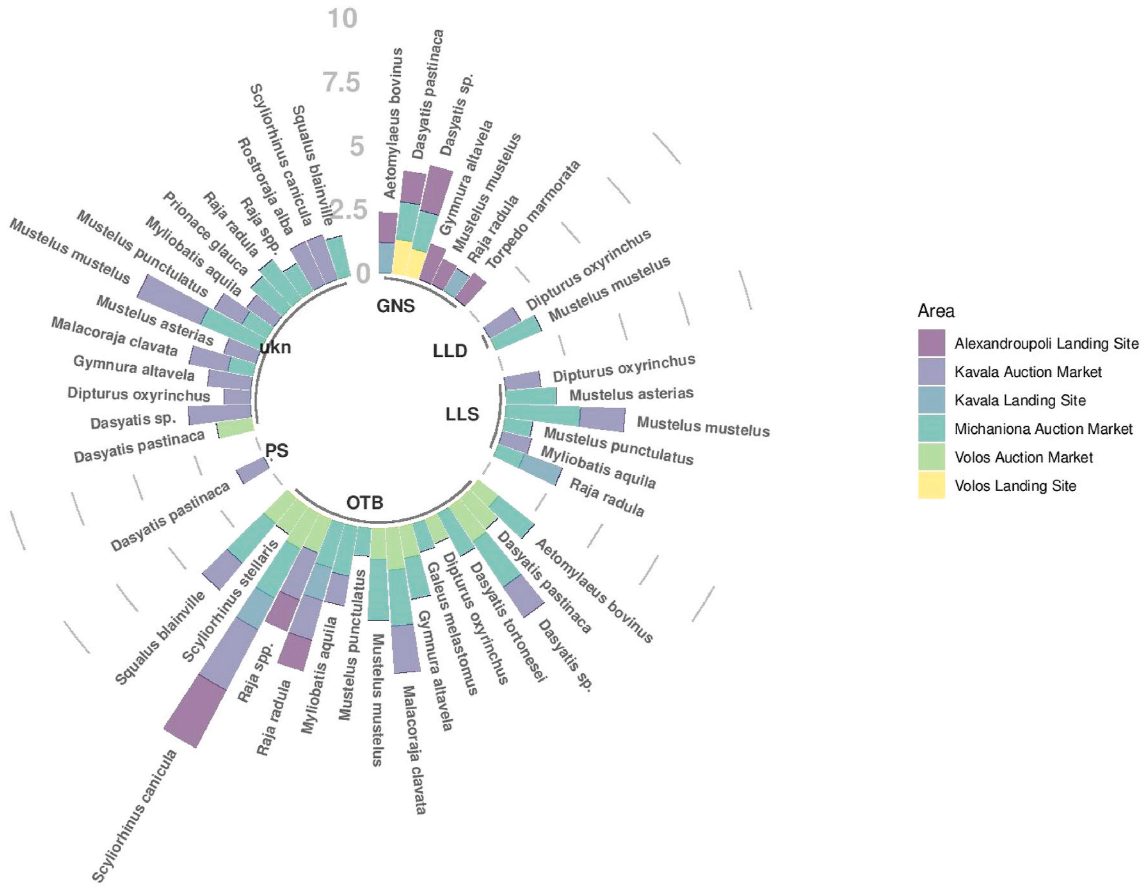

Fig. 5. Gear specific data of elasmobranchs observed at each site. Values were log transformed (log base 10) and only the species with the highest contribution (log10 = >1) are included.

4. Discussion

This is the first species-specific study of the landings and trade of elasmobranchs in Greece based on integrative approach from samplings in auction markets, landing sites, and fish markets as well as through genetic analyses on marketed samples. Due to data limitations in our study it is worth noting that we do not estimate (i) the diversity and abundance of elasmobranchs in the Central-North Aegean, or (ii) the interaction with fisheries, only for the marketed species. The approach used in this study for extrapolating *in-situ* observations masks potential inaccuracies, especially towards rare species and incidental captures, but presents a good picture of the overall situation, especially for more abundant species. The present study also cannot be considered generic for the entire Greek Seas, because the different fisheries examined in the North Aegean Sea, and especially SSF, are highly heterogeneous in terms of spatial and temporal activity when compared to those operating in other areas (longline fishery in the South Aegean Sea: Megalofonou et al., 2005; Peristeraki et al., 2008). Yet, with the data currently available, this study represents the best approximation to date of an integrative understanding of the elasmobranch fisheries and trade in Greece.

4.1. Discrepancies in the official fisheries and trade statistics for elasmobranchs

Elasmobranch conservation in the Mediterranean region is hampered by a lack of detailed fisheries catch statistics (Cashion et al., 2019; Giovos et al., 2020). Fisheries catch of this taxa is usually lumped in large commercial categories, thus hampering the assessment of the status of exploited populations. In Greece, as with many other Mediterranean areas (Garibaldi, 2012), fisheries statistics are generally incomplete and have low reliability (Moutopoulos and Koutsikopoulos, 2014), because it is not uncommon for fishermen to deliberately misreport their catches to avoid stricter regulations, especially for certain protected elasmobranchs, as has been also observed in our study area (pers. communication with captains from the area).

False estimates of elasmobranch landings exist due to inconsistencies in the sampling scheme followed by the HELSTAT and changes in the taxonomic resolution of the recorded species; in 2014 a reduction of elasmobranch recorded categories from five (1982–2013) to three categories took place. In addition, the lack of harmonization between different policies (e.g. market policy, fisheries policy, environmental policy) further enable/foster fragmented information as well as illegal fishing and trade. The present study revealed that fishmongers, fish suppliers and even the Central Market and Fishery Organizations exhibited low compliance with the Greek law, reporting or selling their products in any possible way, sometimes even labeling them as protected species (e.g. angel sharks, guitarfish etc.; Fig. 5). This situation is aggravated by the absence of any fishing control in the fish markets by the corresponding authorities (i.e., Veterinary, Fisheries, and Finance offices). Previous studies found that about 60% of all elasmobranch products were mislabeled in the Greek markets, with several protected species being sold (Pazartzi et al., 2019; Giovos et al., 2020). Our results also confirmed the large numbers of mislabeled elasmobranch products (≈64%) throughout the year with ≈10% of the products sold without any label.

Species-specific composition of the elasmobranch fishery is largely consistent with previous works in the Mediterranean (Bradai et al., 2018 and all references within). In fact, otter bottom trawl fisheries in Greek waters have been reported to catch at least 30 different species of elasmobranchs (Damalas and Vassilopoulou, 2011). In the present study, 23 species were identified in the landings of bottom trawlers with slightly different abundance compared to Damalas and Vassilopoulou (2011). The differences in the species abundance and species number observed may be attributed to the different areas studied (Central-North Aegean vs South Aegean), and the fact that Damalas and Vassilopoulou (2011) reported the catches and not only the landings. Regarding batoids, *R. clavata* and *R. radula* were found to be the most commonly landed species observed during our surveys, similar to the bottom trawl reported landings in other Mediterranean regions (e.g. Balearic Islands, Iskenderun Bay, Viareggio, Italy; Bradai et al., 2018), while in Greece *R. clavata* (Damalas and Vassilopoulou, 2011) was the most common batoid catch.

For purse seiners, the dominance of *D. pastinaca*, is also consistent with previous studies (Tsagarakis et al., 2012). Occasional captures of pelagic sharks are reported on purse seiner catches, including *Isurus oxyrinchus*, *Alopias vulpinus* or *Carcharodon carcharias* (Fromentin and Farrugio, 2005; Saidi et al., 2005). These species are sometimes discarded, but in most cases do not enter the auction markets, because fishers are, to a large extent, aware that they are protected through national/international legislations (e.g. *I. oxyrinchus* or *H. griseus* (Fig. 5). Based on the available official data in Greece, purse seiners contribute up to 23.3% of the landings of *Mustelus* spp. (Giovos et al., 2020). This might be due to the multiple licensing systems (e.g. a trawl vessel that operates as purse seine during summer), allowing fishers to overcome the temporal and/or local (i.e. especially in enclosed gulfs) closures (Moutopoulos and Koutsikopoulos, 2014).

For SSF, Stergiou et al. (2002) reported that approximately 6–10% of the total catch weights in the trammel net fishery of Cyclades is due to Rajidae, predominantly represented by *R. clavata* and *R. radula*. In the Balearic Islands, *D. pastinaca*, *R. radula* and *T. marmorata* cumulatively represented 87% of the elasmobranch catches (Morey et al., 2007), while Tiralongo et al. (2018), studying the cuttlefish fishery in the southeastern coast of Sicily found *T. torpedo, R. radula, D. pastinaca* and *T. marmorata* as the most common bycaught species (47.32%, 32.53%, 18.85%, 1.29% respectively). Our findings mirror those from the Balearic Islands and those from Sicily, except for *T. torpedo*, which is a rare species in the Central-North Aegean waters. Our findings regarding the longline fisheries cannot be compared to the rest of the *in-situ* studies that have been conducted for Greek waters (Megalofonou et al., 2005; Peristeraki et al., 2008) due to the relatively low number of registrations occurring from longlining fishing.

4.2. Fishery impact on elasmobranchs

Knowledge on the status of elasmobranchs populations in Greece remains elusive, because only a few studies addressed either elasmobranch fisheries in the area (i.e., Megalofonou et al., 2005; Damalas and Vassilopoulou, 2011) or species presence and abundance (i.e., Maravelias et al., 2012; Tserpes et al., 2013; Follesa et al., 2020; Giovos et al., 2020; Chatzispyrou et al., 2020; Peristeraki et al., 2020). Although elasmobranchs only depict low landings in Greece (less than 1000 tons per year during 2000–2017: HELSTAT, 1984–2019) and revenues thereof, consumer preference for sharks is high (Mylonaki, 2007), compared to the preference for other fish species groups. To meet the demand for elasmobranch's products, Greece imports annually almost 2000 tn, which is more than double the amount of local elasmobranchs' landings (Giovos et al., 2020). Thus, Greece exhibits the 3rd largest elasmobranch market in southern Europe and is among the top 20 elasmobranchs' import countries globally (Dent and Clarke, 2015; Okes and Sant, 2019; Giovos et al., 2020). For example, we detected *S. cubensis* a species that does not occur in the Greek waters. Genetic analysis detect illegal trade and mislabeling of elasmobranch trade highlighting the deregulation of the Greek fish market and the lack of controls.

Threatened elasmobranchs represented 50–60% of the total elasmobranch landings in the auction markets and the landing sites, whereas when the fish end up in the fish markets, the proportion of threatened species declines to 26%. Based on anecdotal evidence, rare and/or protected elasmobranchs are sold directly to restaurants or hotels (personal communication of the first author with several captains from the area) in order to avoid control and exposure to the fish markets. Particularly, large-scale fishing vessels, which are required to sell their landings in the auction markets, might approach isolated and small ports to illegally land large sharks directly to trucks, before entering the auction markets. Occasionally, some of these species, predominantly members of the Hexanchidae family, may also be used by fishmongers to gain media and consumer's attention due to their large size (Giovos et al., 2020). Evidence on these issues are preliminary approached in the context of this work (Fig. 6), and more research is required to confirm and quantify these illegal practices.

The seasonality observed for the most abundant elasmobranchs (Fig. 3) may be due to species-specific gear effect (Fig. 5). *D. pastinaca* depicted higher catch rates during summer, the period during which small-scale activity peaked because of high touristic activity, favorable weather conditions, and the absence of competition with bottom trawls due to seasonal closure of that fishing gear (Tzanatos et al., 2005). Immediately after the temporal allowance of the trawl fishery (October), bottom trawls exhibited the highest fishing activity (Stergiou et al., 2007) likely resulting in the peak of catches for the remaining elasmobranch species (i.e., *S. canicula*, *Dasyatis* sp., *M. mustelus* and *R. radula*), which are mostly bycaught by this fishery.

In Greece, 24 species are protected, but illegal fishing and trade is still existent (Giovos et al., 2020). Several critically endangered species were confirmed by DNA barcoding in this study (e.g. *G. altavela*, *R. alba)*. These species are considered to be among the most vulnerable elasmobranchs due to their life-history characteristics, habitat degradation and susceptibility to bycatch (Dulvy et al., 2016). Illegal incidents were related to the landings of *G. altavela* caught by netters in Alexandroupoli port. In many cases these individuals were alive when landed. In a few cases, landings of *R. alba* were detected mostly caught by bottom trawlers and on rare occasions *I. oxyrinchus* (N = 1) and *H. griseus* were landed in Kavala auction market and sold as "Galeos" which refers to *Mustelus spp.*. In several cases, fishmongers and employees of the auction markets were showing to us pictures of protected species landed when the team was not visiting the location (Fig. 6). Such incidents occurred both from offshore (trawls) and inshore (small-scales) fishing vessels. Until 2019, no infringement was recorded by the patrol authorities regarding illegal shark landing and trade (Moutopoulos et al., 2017), although several cases took place, often publicly in Greek media (Giovos et al., 2020).

4.3. Approaching the real" state of elasmobranch fisheries and trade

The lack of knowledge about the exploitation level and conservation status of elasmobranchs, also hinders the ability to obtain reliable stock assessments and provide catch advice (STECF, 2020) for these threatened species. This is because stock assessments are based on fisheries data derived only from fisheries statistics, which in most cases are erroneously placed or recorded (Pauly et al., 2014). This is particularly relevant for Greek waters where several issues related to fisheries data quality are encountered (i.e., abrupt changes of the recorded species and species landings, and spurious correlations of landings among different species groups: Moutopoulos and Koutsikopoulos, 2014). This study addresses a timely issue for elasmobranch conservation in the area, providing possible solutions to improve catch statistics. The data errors reported here should be addressed and where possible cross-checked with data collected from the official authorities under Data Collection Framework in order to beneficially improve fisheries data quality.

Port authorities lack training in species identification and at the same time, the Fisheries Directorate avoids enforcing the applied legislation and improving the data collection especially for sensitive species

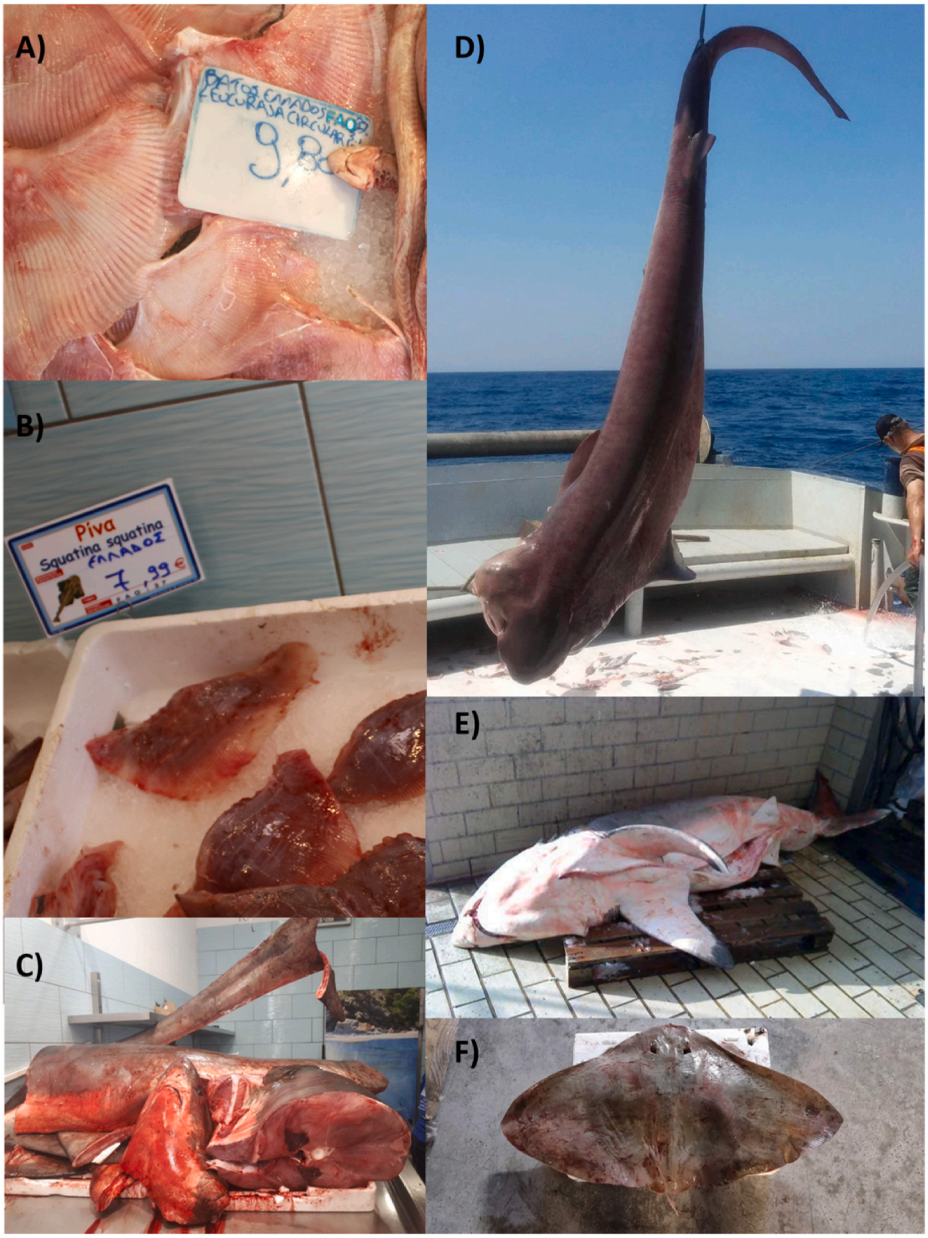

Fig. 6. Anecdotal information of elasmobranch catches reported to the observers by the fishers and employees in the auction markets of the Central-North Aegean and not recorded through the surveys. A. *Raja radula* wings were sold and labeled as *Leucoraja circularis*, which is protected under the Recommendation GFCM/42/2018/2 and Regulation 2102/2015. B. *Dasyatis pastinaca* wings were sold as *Squatina squatina*, which is not listed among the possible marketed species based on the Ministerial Decision No 1750/32219/2015, while *S. squatina* is protected based on the Recommendation GFCM/42/2018/2 and Regulation 2102/2015. C. A picture of a sliced *Alopias vulpinus* observed in a fish store in Kavala city. The individual was captured by purse seiner and landed in Kavala auction market. D. *Hexanchus griseus* was captured by bottom trawler between Lesvos and Ai Stratis Islands. The species is protected based on the Presidential Decree no 67/1981. E. *Carcharodon carcharias* was captured by purse seiner in the Thracian Sea and landed in Kavala auction market. The species is strictly protected by the Recommendation GFCM/42/2018/2 and Regulation 2102/2015. F. *Gymnura altavela* was captured by bottom trawler and landed in Volos auction market. The species is protected based on the Recommendation GFCM/42/2018/2 and Regulation 2102/2015.

(Giovos et al., 2020). Based on our results, 50–60% of the landings for the large- and small-scale fisheries of the Central-North Aegean belonged to species from Mediterranean populations assessed as threatened by the IUCN Red List of Threatened Species, while the majority of species have not been assessed in the Greek Red Book (Legakis and Maragou, 2009).

A revision and harmonization of the species lists reported by the Ministry of Commerce and fisheries authorities (Fig. 2A) should be conducted. This will increase the resolution of the data provided and the traceability of the elasmobranch products sold in the Greek markets. We recommend that the corresponding landings be reported in 19 categories; 13 for sharks and 6 for rays. From those, six landing categories (*Alopias vulpinus*-ALV, *Centroscymnus coelolepis*-CYO *Dalatias licha*-SCK, *Echinorhinus brucus*-SHB, *Hexanchus nakamurai*-HXN, *Somniosus rostratus*-SOR) are solely referring to threatened or data deficient species. For the commercial species categories, we suggest changing the marketed category of *Dasyatis pastinaca* to Dasyatidae and adding the category of Myliobatidae (EAG), which are landed and marketed in Greece. This will progressively increase the resolution of the landings in Greece, providing valuable information to managers and scientists, but will also increase the traceability in the elasmobranch trade, fulfilling the goal of the Common Fisheries Policy (EU 2015/1962). This can be the starting point for assessing the species conservation status in Greek waters that would elaborate further legislative changes and guide conservation priorities.

Legislation for the protection of nature in Greece will be updated soon, while international Conventions are always in the process of amendments and improvements (e.g. CITES, Convention on the Conservation of Migratory Species of Wild Animals, etc.) as are the IUCN Assessments. Greece needs to provide more accurate data, empowering policymakers to produce better future policies and safeguarding elasmobranch population status. To this end, changes in the monitoring of elasmobranch fisheries and trade should be adopted for unraveling the current situation, improving data collection, and increasing traceability in all market supply chains (auction markets, fish markets, and fish stores) (Fig. 2B). These suggestions are based on four criteria: (i) increasing the resolution of the landing data, (ii) adding only the minimum required effort to the monitoring authorities and to the fishers,

(iii) incorporate the applied legislation to the protection of some species, and (iv) harmonize the landing and the marketed categories for increasing traceability.

A future study on the bycatch of the Central-North Aegean fisheries (or in other hot-spot areas for elasmobranchs) per métier is further required to complement this work and to provide a definite picture of the exploitation status of all elasmobranchs in the region. In addition, our dataset would feed the future assessments of IUCN, providing a better picture of the exploitation status of some elasmobranch species in the Aegean. Finally, it is important to note than any effort needs engagement and proper training of fishers, fishmongers, and monitoring authorities in species identification and on the applied legislation.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2021.105743.

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