Marine Policy 105 (2019) 1–9

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Official catch data underrepresent shark and ray taxa caught in Mediterranean and Black Sea fisheries

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ARTICLE INFO

Keywords:
Elasmobranchii
Fisheries
Conservation
Data
Reporting

ABSTRACT

One in four fishes of the subclass Elasmobranchii (sharks and rays) is estimated to be threatened with extinction, according to the IUCN Red List. Their primary threat is overfishing, but data deficiency makes stock assessment difficult. Over 50% of shark and ray species are listed as Data Deficient, in part because the taxonomic resolution of existing catch statistics is too low to identify species-level trends of abundance. Less than 25% of the shark catch reported to the FAO is identified below the genus level; the other 75% is lumped into categories such as "sharks", "rays", or "elasmobranchs nei", (not elsewhere included). This study evaluates the taxonomic resolution of domestic elasmobranch landings in the Mediterranean and Black Seas, where over half of shark and ray species are threatened with extinction, but data deficiency and ambiguity consistently limit conservation action. A Taxonomic Resolution Index (TRI) was calculated for the landings of 24 countries over 65 years (1950–2014) to evaluate the quality of catch reporting over time. The TRI revealed that less than a quarter of commercial elasmobranch taxa are represented in Mediterranean and Black Seas landings data, and reporting quality has hardly improved. Conservation and management policy exists for effective fisheries data collection in the Mediterranean and Black Seas, but lacks implementation.

1. Introduction

Detailed fisheries catch statistics are required for effective management of marine resources [1]. When the resolution of a catch time series is low, stock assessments are difficult and may not yield robust results that are representative of true stock dynamics [2–5]. Global fisheries statistics have been officially reported to the Food and Agriculture Organization of the United Nations (FAO) by its member countries since 1950 and continue to be a fundamental data resource for fisheries researchers. However, FAO data typically do not include catches from unregulated fisheries, discarded catches, nor those from the recreational, subsistence, or artisanal sectors, with the latter three collectively referred to as 'small-scale' [6] [7]. estimate that these omissions represent at least half of the world's catch from 1950–2010, based on historic 'catch reconstructions' from all maritime countries (see also www.seaaroundus.org). However, even the catches that are reported to the FAO, herein referred to as 'landings', are not necessarily informative for stock management and conservation. It is important to note that landings data resolution does not always reflect the work of national fisheries departments. In some cases, countries' fisheries statistics are initially recorded at a relatively high taxonomic precision before being aggregated for submission to the FAO, in compliance with the categories given on the FAO data request form [7]. Taxonomically, the resolution of reported landings is highest for commercially-important taxa (e.g., tunas), as one might expect [7].

Elasmobranchii, the subclass of fishes comprised of sharks and rays, is a group of species generally associated with poor catch reporting. While directed fisheries exist for some elasmobranch species, it is estimated that their overall landings are far outweighed by incidental and discarded catches [4,8]. Most elasmobranchs are caught incidentally and then either discarded at sea or landed (when individuals are marketable or in compliance with a discard ban) [9]. The International Union for the Conservation of Nature's (IUCN) Red List of Threatened Species estimates that about a quarter of elasmobranch species are threatened with extinction (i.e., assessed or estimated to be Vulnerable, Endangered, or Critically Endangered) and overfishing is the principal threat behind elasmobranch population declines [8]. The slow life histories of many elasmobranchs (i.e., late maturity, low fecundity, and long lives) render them intrinsically less resilient to exploitation than most other vertebrate lineages [8,10]. Thus, although targeted fisheries for elasmobranchs do exist, they are often characterized by "boom-and-bust" patterns of exploitation, with rapidly increasing yields closely

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https://doi.org/10.1016/j.marpol.2019.02.041
Received 23 April 2018; Received in revised form 5 February 2019; Accepted 22 February 2019

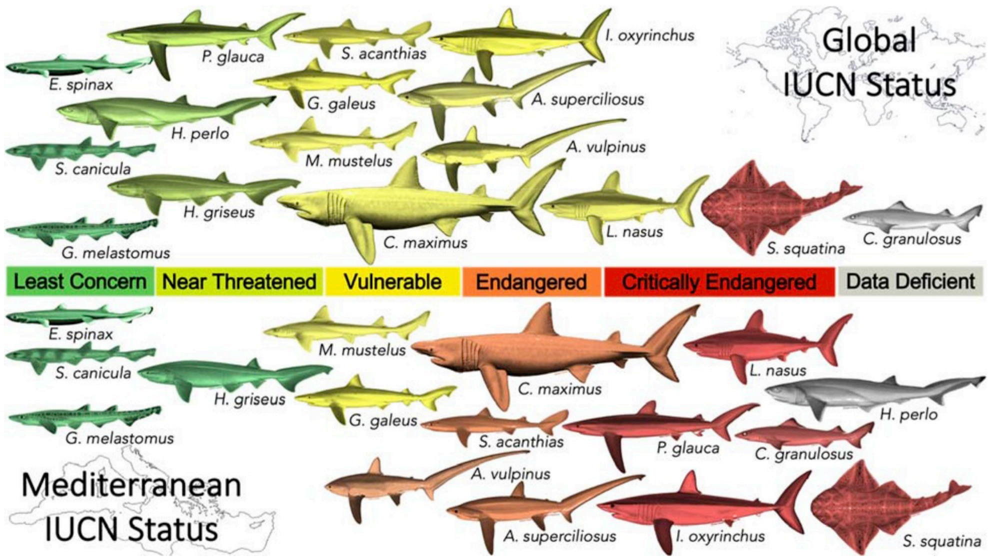

Fig. 1. Global vs. regional (Mediterranean Sea) IUCN Red List statuses of the 16 shark species reported in domestic FAO landings statistics by Mediterranean countries from 1950–2014. At least half of these sharks face an elevated risk of extinction in the Mediterranean Sea than they do globally. Illustrations courtesy of Marc Dando.

followed by precipitous declines in catch [9,11]. Overall, only 4% of global elasmobranch catches derive from sustainably managed stocks [12].

The Mediterranean and Black Seas historically harboured a high diversity and abundance of elasmobranchs [13] but has become a region of elevated threat for elasmobranchs and an area of special concern for marine conservation [14,15]. Following centuries of exploitation and the more recent expansion and intensification of fisheries, elasmobranchs have become increasingly rare, with precipitous population declines for mesopredators [16,17]; and [18] and even suspected extirpations for some large coastal species [19,20]. Between 53 and 71% of Mediterranean elasmobranch species are at risk of extinction and many have an elevated and worsening threat status regionally (Mediterranean Sea) compared to their global status [14]. For example, nine of the 16 shark species reported in domestic FAO Mediterranean landings are more threatened regionally than they are at a global level (Fig. 1).

Ambiguous landings statistics represent a lost opportunity for an otherwise critical source of abundance time series, particularly in areas lacking fisheries-independent surveys. In the Mediterranean and Black Seas, data deficiency is a pervasive problem, with respect to both the availability and adequacy of information, and is often cited as an impediment to fisheries research and management (e.g., Refs. [20,21]). Data Deficient species represent the second-greatest proportion (18%, 13 spp.) of assessed elasmobranch species in the Mediterranean and Black Seas. These are second only to those listed as Critically Endangered (28% [14]). Landings data for these species continue to have insufficient coverage and taxonomic resolution due to weak or absent national implementation and enforcement regulations for elasmobranch conservation. Protections in the Mediterranean and Black Seas benefit from strengthened multilateral agreements, as most of the coastal States have not claimed the right to declare and enforce their national maritime zones (past the 12 nautical mile mark) [22]. As such, much of the Mediterranean Sea area remains legally under no national jurisdiction and strength in fisheries management and conservation efforts must come from harmonised region-wide policy for now.

A major intrinsic factor influencing the taxonomic quality of a country's fisheries data is the richness of its marine fauna [23]. The fewer species and interspecific diversity, the simpler it is to identify catch composition. Thus, to compare the taxonomic resolution of landings between countries by counting the number of species-rank records would result in unfair comparisons. This can be illustrated by comparing the number of Indonesia's fishes deemed ‘commercial’ by FishBase [24] (> 702 spp.; highest in the world) against Finland's (~30 spp.; among the lowest in the world), two countries with similar amounts of marine coastline. In 2014, Indonesia reported 52 (7%) of its commercial fish species [25], while Finland reported fewer species, but a much higher percentage of its commercial species (67%) [26]. Even if Indonesia had the fisheries management capacity that Finland does, covering an additional 421 species accurately to match Finland's percentage of reporting is, unfortunately, unrealistic.

Pauly and Watson [23] designed a ‘Context-Adjusted Fisheries Statistics Indicator’ to correct for the bias associated with comparing the taxonomic resolution of landings from low latitude, highly-speciose developing countries with those of higher latitude, low-diversity developed countries. This index scores the taxonomic resolution of a country's reported landings relative to the list of biogeographically present taxa that are reported by other countries in the region. Here, this index is used, but renamed the Taxonomic Resolution Index (TRI). The TRIs are calculated and compared for the FAO elasmobranch landings of 24 countries in the Mediterranean and Black Seas with the aim of identifying trends in taxonomic quality of their statistics over the past 65 years (1950–2014). This paper discusses taxonomic resolution of landings in the context of the usefulness of reported statistics for elasmobranch fisheries management and conservation.

2. Methods

The taxonomic resolution of reported landings statistics can be scored by country for any marine taxon. The taxonomic focus of this study was sharks and rays, the cartilaginous fishes comprising the subclass Elasmobranchii within the class Chondrichthyes. Chimaeroid species of the sister subclass Holocephali are excluded from this study because there were no reported domestic landings of them in the Mediterranean and Black Seas from 1950 to 2014. The TRI was calculated annually for each maritime country and territory (i.e., the Gaza Strip) from 1950 to 2014, following a method adapted from Ref. [23]. Each country-specific annual TRI value is a quotient of the number of taxa reported domestically in a country over the number of taxa on the Mediterranean and Black Sea commercial taxa list that occur in the waters of that country. Many Mediterranean and Black Sea countries have not claimed exclusive economic zones (EEZ), which they are permitted to do under the rules of the United Nations Convention on the Law of the Sea (UNCLOS). As such, this study defines "EEZ-equivalent waters" as delineated by the Flanders Marine Institute (see www.vliz.be; [27].

2.1. Reported elasmobranch landings

Annual domestic landings data were extracted from the FAO FishSTAT database [28] for the Mediterranean and Black Seas (FAO Major Fishing Area 37) by country from the first year of published FAO annual fishery statistics (1950) to the most recent year at the time of this analysis (2014). Six of 24 countries/entities (Croatia, Gaza Strip, Georgia, Montenegro, Russia, and Ukraine) in this study were evaluated using reconstructed landings data (reported domestic landings only) from the *Sea Around Us* database [29]. This was necessary because these entities emerged from the breakup of a larger state (i.e., the dissolutions of Yugoslavia and the USSR) and thus their FAO landings statistics are not complete for the 65-year period. The *Sea Around Us* data treat present day EEZ boundaries as constant over the study period. Additionally, the following countries and territories were omitted from the analysis due to particularly small fishing industries: Bosnia and Herzegovina, Monaco, Slovenia, Gibraltar, and Ceuta and Melilla.

Reported landings taxon categories are not always identified by scientific names, thus landings were associated with the lowest inclusive taxonomic name and rank (i.e., subclass, superorder, order, family, etc.) prior to scoring (Table A.1). The taxonomic classification follows FishBase [24]. A total of 37 unique elasmobranch taxa were reported in the Mediterranean and Black Sea FAO data, 27 of which were identifiable to species.

Annual TRI values are expressed as a percentage and are calculated by dividing the taxonomic resolution score of each country's reported elasmobranch catch by the taxonomic resolution score of the Mediterranean and Black Sea commercial taxa list, described in detail in the following sections. Taxon distribution data were derived from the *Sea Around Us* database to determine the presence of commercial taxa in each country's EEZ [30].

2.2. Regional and Country Taxa Lists: commercial elasmobranchs in the Mediterranean and Black Seas

A list of all the elasmobranch taxa reported in domestic Mediterranean and Black Sea landings were compiled by year from 1950 to 2014, herein referred to as the Regional Taxa List (37 taxa). Each country was evaluated based only on the Regional Taxa that are biogeographically present in its waters, defined as the distributions which overlapped with at least 10% of its EEZ area; this list is herein referred to as the Country Taxa List. Elasmobranchs on each Country Taxa List were assumed to have been caught by that country, even if they were not reported to the FAO, due to these taxa being commercially unimportant or appearing in incidental, discarded, or small-scale catches [23]. While many elasmobranchs are depleted in the Mediterranean and Black Seas, all are still caught incidentally by some fishery [13]. Furthermore, the Regional Taxa List contained far fewer taxa than are biogeographically present in the Mediterranean and Black Seas (i.e., 27 species reported versus at least 80 species occurring [21]) and was therefore a conservative representation of the number species that were caught.

Some elasmobranchs are considered locally extinct in certain Mediterranean and Black Sea subareas (defined in GFCM/31/2007/2; [14,31]). A review of studies in the region indicated that the time of last sighting for most of these species is uncertain and a year of local extinction has yet to be determined; a delay between last sighting and extinction reporting is typical for marine species [32]. Of the 27 elasmobranch species reported in landings, only two could be confirmed absent from subareas within the Mediterranean and Black Seas: the angelshark (*Squatina squatina*) and the common guitarfish (*Rhinobatos rhinobatos*). Where relevant, these species were excluded from the analysis to reduce the introduction of commission errors (species assumed present in an EEZ when in fact they are not) [33]. Omissions were based on both IUCN and literature estimations of date and location of extinction (Table A.2).

2.3. Taxonomic resolution score for each country's reported landings

Once Country Taxa Lists were compiled for all 24 countries, the taxonomic resolution of their reported elasmobranch landings was scored. Each country's annual taxonomic score for reported landings was the sum of unique elasmobranch taxa appearing in its data, weighted by their positions in the taxonomic hierarchy so that more precise taxonomic reporting received higher scores. There were six taxonomic ranks/levels included in this scoring scheme: subclass, superorder, order, family, genus, and species. Each rank/level received 1/6 of a point (0.167), with species earning 1 point, as the most precise rank/level. In cases when a country reported both a taxon and a higher taxon above it (e.g., reports of thornback ray (*Raja clavata*) as well as Batoidea) in the same year, points were counted only for the most precise taxon. This was necessary because otherwise a country that reported both a species and a less-precise higher taxon would receive more points overall than a country that reported only that species.

2.4. Taxonomic Resolution Index

To calculate TRI, each country's taxonomic score for reported taxa was divided by the taxonomic score of its Country Taxa List (calculated using the procedure explained in section 2.3) (Equation (1)).

$$TRI_{Country/Year} = \frac{Taxonomic\ score\ of\ reported\ catch}{Taxonomic\ score\ of\ Country\ Taxa\ List} \quad (1)$$

The lowest possible TRI is 0% and indicates that no elasmobranchs were reported in a country's landings in a given year, while the highest possible TRI is 100% and indicates that a country reported all elasmobranchs on its Country Taxa List. For an example of scoring, Spain's landings for the year 2000 are presented (Table 1).

3. Results

3.1. Composition of reported landings: elasmobranchs vs. other organisms

Mediterranean and Black Sea countries reported 37 different shark and ray taxa in official FAO landings statistics from 1950 to 2014 (Table 2; see Table A.1 for full taxon list). There were 27 species (73% of all reported elasmobranch taxa), one genus (3%), six families (16%), two orders (5%), and one subclass (3%) (Table 2). This distribution of taxonomic ranks is roughly similar to those of the non-elasmobranch taxa reported in the Mediterranean and Black Seas over the same time period: 183 species (70% of all non-elasmobranch taxa), 30 genera (11%), 32 families (12%), six orders (2%), five classes (2%), and eight categories of miscellaneous landings (3%) (Table 2). By tonnage amount however, only 3% (0.03 million t) of reported elasmobranch landings were species-specific, compared to the majority (74%; 62 million t) of non-elasmobranch landings reported by species (Table 2). The genus and order ranks each represented one-third (0.32 million t) of the total elasmobranch catch, attributed to one genus ("Smooth-hounds nei", *Mustelus* spp.) and two orders ("Stingrays, butterfly rays nei", order Myliobatiformes, and "Rays, stingrays, manta nei", superorder Batoidea) (Table 2).

Elasmobranchs also appear more recently and less often in reported landings statistics compared to other organisms. Over two-thirds (25/37) of all elasmobranch taxa were reported for less than half the time series (i.e., < 32 years) and only four of the remaining ten taxa were species (i.e., gulper shark, *Centrophorus granulosus*; porbeagle, *Lamna nasus*; picked dogfish, *Squalus acanthias*; and longnosed spurdog,

Table 1
An example of the calculation method of the Taxonomic Resolution Index using the landings data for Spain in the year 2000.

Taxonomic hierarchy of the Country Taxa List						Reported?	Points toward score	
Subclass	Superorder	Order	Family	Genus	Species		Country Taxa List	Reported Taxa
Elasmobranchii	*NA*	*NA*	*NA*	*NA*	*NA*	Y	0.00*	0.00*
Elasmobranchii	Batoidea	*NA*	*NA*	*NA*	*NA*	Y	0.00**	0.33**
Elasmobranchii	Batoidea	Myliobatiformes	Dasyatidae	*Dasyatis*	*pastinaca*	N	1.00	0.00
Elasmobranchii	Batoidea	Rajiformes	Rajidae	*Raja*	*clavata*	N	1.00	0.00
Elasmobranchii	Selachimorpha	Carcharhiniformes	Carcharhinidae	*Prionace*	*glauca*	Y	1.00	1.00
Elasmobranchii	Selachimorpha	Carcharhiniformes	Scyliorhinidae	*NA*	*NA*	Y	0.00**	0.67**
Elasmobranchii	Selachimorpha	Carcharhiniformes	Scyliorhinidae	*Scyliorhinus*	*canicula*	N	1.00	0.00
Elasmobranchii	Selachimorpha	Carcharhiniformes	Triakidae	*Mustelus*	*NA*	Y	0.00**	0.83**
Elasmobranchii	Selachimorpha	Carcharhiniformes	Triakidae	*Mustelus*	*mustelus*	N	1.00	0.00
Elasmobranchii	Selachimorpha	Hexanchiformes	Hexanchidae	*Hexanchus*	*griseus*	N	1.00	0.00
Elasmobranchii	Selachimorpha	Lamniformes	Alopiidae	*Alopias*	*vulpinus*	N	1.00	0.00
Elasmobranchii	Selachimorpha	Lamniformes	Lamnidae	*Isurus*	*oxyrinchus*	Y	1.00	1.00
Elasmobranchii	Selachimorpha	Lamniformes	Lamnidae	*Lamna*	*nasus*	N	1.00	0.00
Elasmobranchii	Selachimorpha	Squaliformes	Centrophoridae	*Centrophorus*	*granulosus*	N	1.00	0.00
Elasmobranchii	Selachimorpha	Squaliformes	Squalidae	*NA*	*NA*	Y	0.00	0.00
Elasmobranchii	Selachimorpha	Squaliformes	Squalidae	*Squalus*	*acanthias*	Y	1.00	1.00
Elasmobranchii	Selachimorpha	Squaliformes	Squalidae	*Squalus*	*blainville*	N	1.00	0.00
Elasmobranchii	Selachimorpha	Squatiniformes	Squatinidae	*Squatina*	*squatina*	N	1.00	0.00
Taxonomic score							**13.00**	**4.83**
TRI $= \left(\frac{\sum \textit{Country Taxa List points}}{\sum \textit{Reported Taxa points}}\right)$							**37%**	

* If landings were reported for a taxon as well as a more precise taxon within that higher taxon, the country only received points for the more precise taxon.
** If landings were reported for a taxon but not for any more-precise taxa within that taxon, points were given for that reported taxon despite it receiving zero points in the Country Taxa List scoring.

Table 2
Taxonomic breakdown of reported (FAO) domestic elasmobranch landings compared to non-elasmobranch landings in the Mediterranean and Black Seas from 1950–2014.

Taxonomic rank	Number of taxa: elasmobranch (other)	Landings (millions t): elasmobranch (other)	Percentage of total landings: elasmobranch (other)
Class and subclass	1 (5)	0.2 (0.21)	20 (0.002)
Order	2 (6)	0.32 (1.6)	33 (2)
Family	6 (32)	0.11 (3.06)	11 (4)
Genus	1 (30)	0.32 (8.89)	33 (11)
Species	27 (183)	0.03 (61.65)	3 (74)
Misc. categories*	0 (8)	0 (7.86)	0 (9)
Total	**37 (264)**	**0.98 (83.22)**	**100 (100)**

*Note that the category "Marine fishes not elsewhere included", grouped within "Misc. categories", is known to include elasmobranch species.

Squalus blainville) (Table A.1). In contrast, over half (142/264) of non-elasmobranch taxa were reported for at least half of the 1950 to 2014 period, and more than two-thirds (179/264) were species-specific (not shown). In absolute terms, Spain reported the most elasmobranch taxa (21) over the time series and in the final year (2014), while being the third-largest elasmobranch-fishing nation in the Mediterranean and Black Seas, behind Italy and Turkey. While Spain lead in number of reported taxa overall, prior to 1996 it only reported two low-resolution taxa (i.e., Elasmobranchii and Batoidea).

3.2. Taxonomic Resolution Index by country

The taxonomic detail of elasmobranch reporting in the Mediterranean and Black Seas is low but has improved as a region, rising from 12% (1950–1960 average TRI) to 16% (2004–2014 average TRI) of commercial elasmobranch taxa reported to the FAO (Table 3). Of 24 countries in this study, 15 improved their TRI over the 65-year period (Table 3). The taxonomic resolution of Spanish and French reporting improved the most, by 60 and 35% respectively (Table 3), but ranked 8th and 9th (out of 24) by mean overall TRI from 1950 to 2014 due to poor initial reporting (Table 4). Eleven entities (Albania, Bulgaria, Cyprus, Gaza Strip, Lebanon, Libya, Romania, Russia, Syria, Tunisia, and Ukraine) did not report any elasmobranchs in 1950s landings, but reported as much as 30% of their Country Taxa Lists by the final decade (Table 3). In fact, eight of these countries ranked among the top ten highest TRI scores by the final decade (Table 3).

Table 3
Change in mean TRI (%) over time, in descending order, from the initial (1950–1960) to the final (2004–2014) decades of reported elasmobranch landings by country in the Mediterranean and Black Seas. Positive values of change indicate an overall improved taxonomic resolution of data while negative values indicate an overall decline.

Country	Initial mean TRI (1950–1960)	Final mean TRI (2004–2014)	Change in mean TRI (Final – Initial)
Spain	5.2	65.1	59.9
France	2.2	37.6	35.4
Bulgaria	0.0	30.4	30.4
Ukraine	0.0	24.6	24.6
Tunisia	0.0	17.6	17.6
Albania	0.0	17.5	17.5
Romania	0.0	10.8	10.8
Libya	0.0	8.8	8.8
Russia	0.0	7.7	7.7
Gaza Strip	0.0	7.5	7.5
Cyprus	0.0	2.7	2.7
Morocco	1.1	3.5	2.4
Syria	0.0	1.6	1.6
Lebanon	0.0	1.1	1.1
Turkey	10.3	10.6	0.3
Egypt	2.0	1.0	−0.9
Israel	5.7	3.6	−2.1
Algeria	11.4	8.2	−3.1
Greece	20.5	13.9	−6.6
Malta	55.7	46.1	−9.6
Italy	35.8	22.3	−13.6
Croatia	34.1	10.8	−23.3
Montenegro	45.5	11.8	−33.7
Georgia	65.5	11.3	−54.1
Mean across all countries	**12.3**	**15.7**	**3.4**

Table 4
Overall mean TRI values, in descending order, and components from 1950–2014 by country in the Mediterranean and Black Seas. The mean taxonomic score of reported landings is the mean sum of taxonomically-weighted unique elasmobranch taxa reported to the FAO by each country from 1950 to 2014 (TRI numerator). The taxonomic score of the Country Taxa List is the sum of taxonomically-weighted unique elasmobranch taxa on the Regional Taxa List that are biogeographically present in each country (TRI denominator).

Country	Mean taxonomic score of reported landings	Mean taxonomic score of Country Taxa List	Mean TRI (% reported)
Malta	5.3	8.0	72.0
Georgia	0.8	3.3	35.8
Ukraine	1.2	3.8	31.7
Montenegro	1.5	8.2	25.2
Turkey	1.5	7.9	23.4
Romania	0.6	3.8	22.4
Italy	1.7	8.9	21.1
Spain	3.3	8.9	21.0
France	2.6	9.0	20.9
Croatia	1.2	8.0	19.5
Greece	1.6	8.7	19.1
Tunisia	1.8	9.1	18.0
Bulgaria	0.8	3.6	16.6
Russia	0.5	3.5	14.8
Algeria	0.7	8.0	9.1
Albania	1.0	8.1	7.5
Gaza Strip	0.5	7.2	6.0
Morocco	0.4	8.1	5.4
Israel	0.3	7.6	3.7
Egypt	0.2	7.6	2.5
Cyprus	0.2	8.6	2.2
Libya	0.3	8.6	1.5
Syria	0.1	7.7	1.4
Lebanon	0.1	7.3	0.7
Mean across all countries	**1.2**	**7.2**	**16.7**

Bulgaria improved the most, out of the countries that began by reporting no elasmobranchs (Table 3). In 2014, Bulgaria reported 3 of the 12 species on its Country Taxa List: piked dogfish, thornback ray (*Raja clavata*), and common stingray (*Dasyatis pastinaca*). Bulgaria, along with many of the countries that improved, appeared to have a decreasing trajectory of TRI by the end of the 65-year period (Fig. 2A-D).

The TRIs of nine countries (Algeria, Croatia, Egypt, Georgia, Greece, Israel, Italy, Malta, and Montenegro) worsened over the time series (Table 3). Georgia's TRI declined the most, with a −54% change since the 1950s, at which time it had the highest taxonomic resolution of any country, reporting 66% of its Country Taxa List (Table 3). However, the TRI is a relative index and Georgian elasmobranch landings data only contained spiny dogfish (*Squalus acanthias*) from 1951–1987, then just "sharks, rays, skates, etc. nei" until 2000, with a single record of "rays, stingrays, mantas nei" in 1991. During most of the 2000s, Georgia reported a curious alternating pattern of "sharks, rays, skates, etc. nei" and piked dogfish landings annually until 2013, at which point it began reporting both. Thus, Georgia's dramatic drop in TRI is not attributed to fewer taxa reported (i.e., decreasing numerator). Rather, it occurred because the quality of its landings data lagged behind improvements made by countries with which it has taxa in common. The analysis suggests this is a common trend: countries that initially led the region in TRI showed no improvement or even declining TRI over time (Fig. 3). In fact, only countries reporting fewer than 10% in the 1950s showed any overall improvement (Fig. 3). Interestingly, some countries exhibited a pattern of falling TRI surrounding the years of secession from a larger entity, especially those affected by the fall of the Soviet Union (Fig. 2A–D). The most precipitous declines occurred in Romania (1989 collapse of the Communist Eastern Bloc), Bulgaria (1989 collapse of the Communist Eastern Bloc), and Georgia (1991 independence from USSR), while Russia (1990 independence from USSR) showed a less steep decline.

3.3. Leading countries in TRI overall

While many Mediterranean and Black Sea countries improved their elasmobranch TRI from 1950 to 2014, mean scores over the time period were low (Table 4). Only 2 out of 10 of the most improved countries reported more than a quarter of their Country Taxa List on average (Table 4). In fact, Malta was the only country to report at least half of its Country Taxa List, on average, with a mean TRI of 72% (Table 4) and was the leading country for 45 of the 65 years, finishing second to Spain (Fig. 2A and D). Malta and Georgia's leading overall scores, at odds with their vastly differing number of commercial taxa (Malta has more than twice that of Georgia), demonstrate that the definition of commercial taxa (Country Taxa Lists), as intended, avoids 'penalizing' countries for having a higher species richness than others.

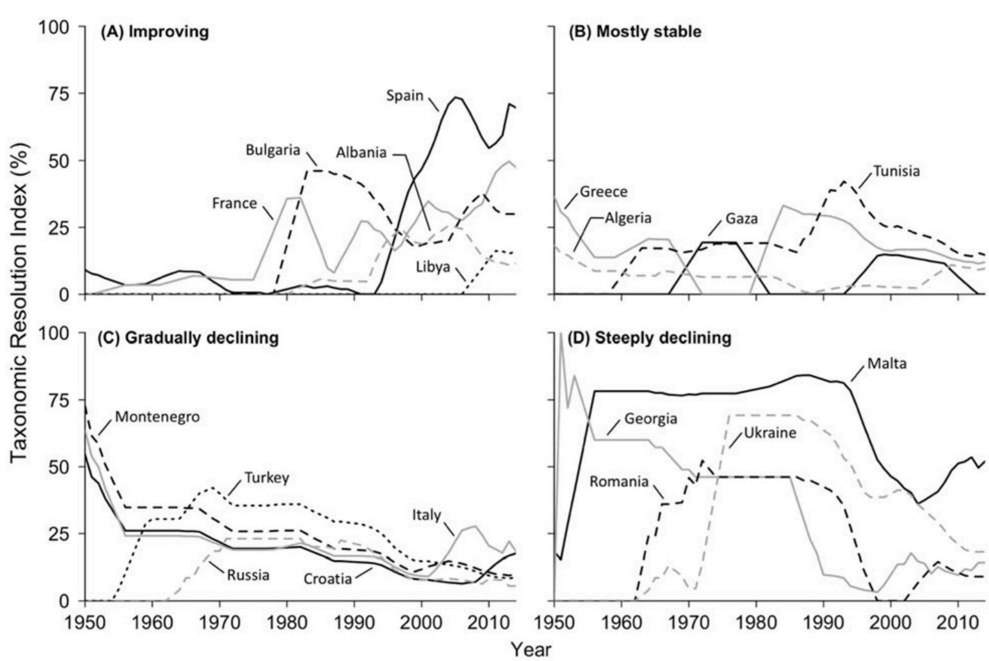

Fig. 2. Annual taxonomic resolution (proportion of commercial taxa reported) of FAO elasmobranch landings data for the Mediterranean and Black Sea countries (1950–2014), plotted by general trend: (A) Improving, (B) Mostly stable, (C) Gradually declining, (D) Steeply declining. Six countries are not shown because their scores were consistently low (< 10%): Cyprus, Egypt, Israel, Lebanon, Morocco, and Syria.

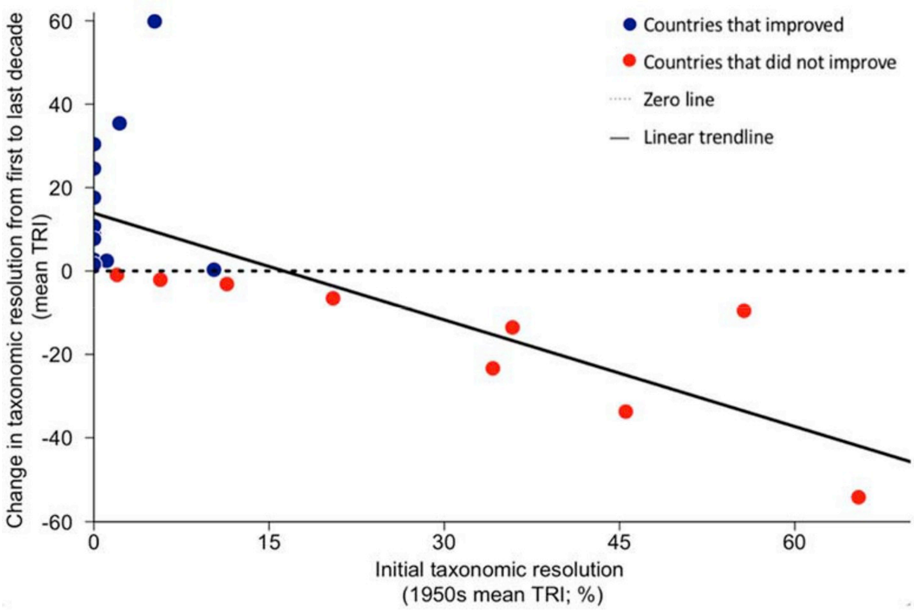

Fig. 3. Countries that initially (1950s mean TRI) reported elasmobranch landings with high taxonomic resolution did not improve overall. Only countries with an initial TRI of < 10% improved at all. Countries with a higher mean TRI in 2004–2014 vs. 1950–1960 are shown in blue (i.e., improved), countries with a lower score are shown in red (i.e., declined). $R^2 = 0.55$, $p < 0.001$. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4. Discussion

This is the first study to measure the taxonomic resolution of reported elasmobranch landing statistics, relative to the biogeographic composition of commercial taxa occurring in each country. The reported fisheries data quality for elasmobranchs in the Mediterranean and Black Seas has improved slightly over time but remains alarmingly low for many countries and in the region as a whole. There is apparently no suggested definition in the literature for data *sufficiency* in terms of fisheries management or elasmobranch conservation; however, even methods of stock assessment for data-poor fisheries require data with high taxonomic resolution [34] and managing species in groups can mask declines of the more vulnerable species [35]. The FAO's Code of Conduct for Responsible Fisheries [36] contains principles for effective data collection which urge the precautionary approach including accounting for "… the impact of fishing activities, including discards, on non-target and associated or dependent species …", which certainly includes elasmobranchs. It also emphasizes that "[t]he absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures". Yet, data deficiency and inadequacy continue to be cited as one of the hindrances for taking action to protect Mediterranean elasmobranchs [13,20,37].

This study raises three main issues about reporting quality and elasmobranch species in the Mediterranean and Black Seas: (1) How does the reporting of elasmobranch landings in the Mediterranean and Black Seas compare to the rest of the world? (2) Has TRI changed in response to either changes in elasmobranch exploitation or new conservation and management initiatives? (3) How could elasmobranch reporting be improved in the Mediterranean and Black Seas?

4.1. The Mediterranean and Black Sea fisheries in a global context

At least 90% of Mediterranean fish stocks are overexploited [15,38] and many of the fisheries are not managed in compliance with scientific advice [39]. A recent study found that nearly all of the fish stocks in the Mediterranean Sea (with sufficient data for assessment) are being subjected to fishing mortality higher than that at maximum sustainable yield and none have sustainable spawning stock biomasses [15]. This is the legacy of a centuries-long history of human impacts and, more recently, unregulated development of unselective fisheries [19]. As semi-enclosed seas with dense coastal human populations, the Mediterranean and Black Seas are also experiencing accelerated warming, acidification, and pollution [40].

While Europe's previously overfished stocks in the Northeast Atlantic are now largely recovering, its Mediterranean stocks continue to be overexploited, suggesting a region-specific paucity of data and enforcement [15]. Despite shrinking stocks, Mediterranean and Black Sea fishing effort has been increasing and practices have become less selective [39]. This is particularly true for non-European fisheries that have industrialized and spatially expanded in the Mediterranean [38]. Collectively, non-European elasmobranch landings have tripled from low levels in the last two decades while European landings have been steadily declining since the mid-1990s, following two peaks and troughs in previous decades [38]. These patterns are indicative of boom-and-bust yields and ineffective management.

4.2. Mediterranean and Black Sea elasmobranch reporting in a global context

Among exploited taxa, the quantity and quality of fisheries reporting is generally lowest for non-target and low-value species, such as many elasmobranchs. It is possible to test, albeit with limited scope, if this is reflected by TRI by comparing the results of the present study to those of the first use of the TRI by Ref. [23]. They evaluated landings of all exploited marine taxa (fish and invertebrates) for 53 countries, including several Mediterranean and Black Sea countries. The TRIs of Egypt, France, Italy, Morocco, Spain, and Turkey were between 3 and 46% lower for elasmobranchs than for all species from 2000–2004 [23]. In both studies, Spain and France were two of the highest-ranking countries for TRI and Egypt was among the lowest [23]. Contrary to the results of the present study, Pauly and Watson [23] found that countries with high initial TRI values improved relative to those with poorer initial reporting. This conflicting point likely manifested from the vastly differing scopes of these analyses, both taxonomically (i.e., elasmobranchs vs. all fishes) and geographically (i.e., regional vs. global).

One aspect of fisheries reporting that is not directly addressed by TRI is the varying amount (i.e., tonnage) of elasmobranchs landed by countries and whether this influences the taxonomic resolution of their data. This and other studies indicate that the amount and resolution of elasmobranch landings may not be closely correlated; on a global scale, elasmobranch landings are declining due to reduced populations rather than improved fisheries management [41]. Davidson et al., [41] used the proportion of species-specific reporting as an indicator of suitable management and found that from 2003–2011 three-quarters of chondrichthyan landings worldwide were from countries with poor reporting (defined as < 25% of chondrichthyan landings identified to species) while the remaining quarter was attributed to countries with no species-specific reporting of chondrichthyans at all. Similar to the latter case, the present study found that over a quarter (29%) of elasmobranch landings in the Mediterranean and Black Seas from 2003–2011 were from countries with no species-specific reporting. More concerning, however, is that a much greater percentage (90%) of Mediterranean and Black Sea elasmobranch landings is from countries with less than a quarter of their landings identified to species. In total from 1950–2014, an overwhelming 97% of domestic Mediterranean and Black Sea elasmobranch landings were not species-specific. Thus, elasmobranch reporting in the Mediterranean and Black Seas is lagging behind the global average.

4.3. Reporting quality in relation to conservation and management efforts

In the last two decades, the number of commitments to elasmobranch management and conservation have increased, both globally [41] and within the Mediterranean and Black Seas [42]. It is unclear whether the TRI method detected potential influence of these commitments on reporting quality. Any relationship is obscured by the fact that only landed catch, without discards, is reported in FAO statistics and that the TRI is a relative index. Since TRI is a ratio of the number of taxa reported to the number of commercial taxa in a country's waters, this method does not explain why a country has a high or low reporting quality. For example, many countries exhibit changes in TRI trajectory in the 1990s, but while countries like Georgia and Romania reported fewer taxa and had declining TRIs, other countries with declining TRIs such as Greece and Italy had no change in the number of taxa. Rather, the TRIs of these latter countries reflect improved reporting in countries such as France and Spain that each expanded their commercial taxa lists by 2 or 3 species. The first elasmobranch commitment with the potential to influence conservation and management was the International Plan of Action for the Conservation and Management of Sharks in 1999 [43], a few years after the French and Spanish TRIs improved. Other potential drivers of shifting TRI of landings may include changes in commercial interest for elasmobranchs [44] and regional differences in exploitation traditions. Information on these subtleties is scarce for the Mediterranean and Black Seas.

Another limitation of this study is that the reporting quality trends only depict the proportion of catch that is *landed*, as the FAO statistics provide. These data are the main official source of fisheries data, yet they are incomplete. This paper shows how researchers and decision-makers are limited by the data they have: to understand the trends of elasmobranch exploitation and abundance, we need to know what is discarded at sea. Policies that forbid retention of protected species, such as in the EU Common Fisheries Policy [45] and the General Fisheries Commission for the Mediterranean (GFCM)'s Recommendation 36/2012/3 [46] require that countries report discards of protected species, but these data are largely absent in FAO statistics. This is critical information as discarding often results in elasmobranch mortality and while mortality rates are highly variable, they can be very low. For example, in trawl surveys, at-vessel mortality rates are up to 98% for scalloped hammerheads (*Sphyrna lewini*) [47] but only about 2% for thornback rays [53].

There are foundational commitments to support more complete reporting in the Mediterranean and Black Seas. The GFCM includes the “ecosystem approach to fisheries” as a component of its mandate and cites this in the preamble to its binding resolutions [31]. However, it falls short in at the implementation phase, at least in respect to elasmobranchs. In fact, in a performance assessment of RFMO bycatch and discard management, the GFCM ranked 10th (out of 13) and earned only 1 of 47 possible points for the “Data Collection” criteria [48]. The point it did receive was awarded for satisfying the criterion: “All countries with fisheries under the RFMO's mandate are Members or Cooperating Non-Members”.

4.4. On improving elasmobranch catch reporting

The policies are in place for effective management and conservation of elasmobranchs in the Mediterranean and Black Seas. The problem now lies in the feasibility of implementation. The most useful GFCM resolution to date, in terms of improving fisheries data quality, is GFCM/35/2011/1 concerning the establishment of a catch logbook [31]. If implemented, compiled logbook data could be the ideal resource for fisheries management since it would collate all catches by species, including targeted and incidental landings as well as discarded catches. Evidently, these data are either (a) not being collected and reported by vessel masters, or (b) they are not being made publicly available by the GFCM, and the reality may be a combination of the two. Since the Mediterranean fleet is comprised of 85% small-scale artisanal vessels, it is unlikely that they have the capacity to identify and record every species hauled on board: this is a daunting task even for the trained fishery observer [38]. For some countries in this region the governance structures are not in place to design and maintain accurate reporting. It is particularly difficult for countries with limited capacity to assert their territorial fishing rights; jurisdictional conflicts are common and complex in the Mediterranean and Black Seas. The GFCM is certainly aware of the marginalization of some of its member states. To help build fisheries management capacity, the GFCM launched a five year programme in 2013 through which it aimed to help design and fund plans to address five thematic areas including “Strengthening national capacity in the field of data collection and support of the establishment of regional databases” [46]. Insights from this programme will be available in the end of 2018. Another solution to explore could be a rapid development of automatized image analyses through recent improvements in Artificial Intelligence (neural networks, deep machine learning).

5. Conclusions

The foundation of sustainable resource use is a progressive understanding of exploitative patterns and consequences. Centuries of heavy fishing and cumulative contemporary impacts have deteriorated the Mediterranean and Black Sea ecosystems, including dramatically reducing resident predator populations including many species of elasmobranchs. A chronic paucity of catch data on exploited elasmobranch fishes is preventing the stock assessments necessary to set science-based fishery input controls. However, these species would benefit in the meantime from the implementation and enforcement of the precautionary approach, since Mediterranean elasmobranchs are in the midst of an extinction crisis. Countries with less management capacity need resources from regional bodies such as the GFCM to monitor, and in particular to enforce, current protective instruments that, if practiced, may reduce further harm to these highly threatened populations.

Acknowledgements

We would like to thank the *Sea Around Us* researchers for their support and data provision, and Nick Dulvy and William Cheung for their thoughtful feedback on previous versions of the manuscript. We are also very appreciative to Marc Dando for allowing us to use his beautiful illustrations for Fig. 1. This is a contribution of the *Sea Around Us*, a research initiative at the University of British Columbia, supported by the Oak Foundation, the Paul M. Angell Family Foundation, the Marisla Foundation and the MAVA Foundation. Additional funding was provided by the Natural Sciences and Engineering Research Council of Canada.

Appendix

Table A.1
Elasmobranch taxa reported in FAO Mediterranean and Black Sea domestic catch statistics from 1950–2014. Bolded numbers indicate the 10 taxa reported in at least half of years.

FAO name reported	Scientific name	(Author)	Taxon rank	# Years reported
Sharks, rays, skates, etc. nei.	Elasmobranchii	Unknown	Subclass	**65**
Batoidea (skates and rays)				
Blonde ray	*Raja brachyura*	(Lafont, 1871)	Species	2
Common eagle ray	*Myliobatis aquila*	(Linnaeus, 1758)	Species	9
Common guitarfish	*Rhinobatos rhinobatos*	(Linnaeus, 1758)	Species	6
Common stingray	*Dasyatis pastinaca*	(Linnaeus, 1758)	Species	10
Cuckoo ray	*Leucoraja naevus*	(Müller &; Henle, 1841)	Species	6
Eagle rays nei	Myliobatidae	(Bonaparte, 1835)	Family	11
Guitarfishes, etc. nei	Rhinobatidae	(Bonaparte, 1835)	Family	**33**
Longnosed skate	*Dipturus oxyrinchus*	(Linnaeus, 1758)	Species	2
Mediterranean starry ray	*Raja asterias*	(Delaroche, 1809)	Species	6
Rays, stingrays, mantas nei	Batoidea	Unknown	Superorder	**65**
Spotted ray	*Raja montagui*	(Fowler, 1910)	Species	5
Stingrays, butterfly rays nei	Myliobatiformes	Unknown	Order	11
Thornback ray	*Raja clavata*	(Linnaeus, 1758)	Species	19
White skate	*Rostroraja alba*	(Lacepède, 1803)	Species	5
Selachimorpha (sharks)				
Angelshark	*Squatina squatina*	(Linnaeus, 1758)	Species	24
Angelsharks, sand devils nei	Squatinidae	(de Blainville, 1816)	Family	**61**
Basking shark	*Cetorhinus maximus*	(Gunnerus, 1765)	Species	11
Bigeye thresher	*Alopias superciliosus*	(Lowe, 1841)	Species	3
Blackmouth catshark	*Galeus melastomus*	(Rafinesque, 1810)	Species	13
Blue shark	*Prionace glauca*	(Linnaeus, 1758)	Species	18
Bluntnose sixgill shark	*Hexanchus griseus*	(Bonnaterre, 1788)	Species	30
Catsharks, etc. nei	Scyliorhinidae	(Gill, 1862)	Family	25
Catsharks, nursehounds nei	Scyliorhinidae	(Gill, 1862)	Family	30
Dogfish sharks nei	Squalidae	(de Blainville, 1816)	Family	**65**
Gulper shark	*Centrophorus granulosus*	(Bloch &; Schneider, 1801)	Species	**61**
Longnose spurdog	*Squalus blainville*	(Risso, 1827)	Species	**60**
Picked dogfish	*Squalus acanthias*	(Linnaeus, 1758)	Species	**48**
Porbeagle	*Lamna nasus*	(Bonnaterre, 1788)	Species	**44**
Sharpnose sevengill shark	*Heptranchias perlo*	(Bonnaterre, 1788)	Species	6
Shortfin mako	*Isurus oxyrinchus*	(Rafinesque, 1810)	Species	18
Small-spotted catshark	*Scyliorhinus canicula*	(Linnaeus, 1758)	Species	21
Smooth-hound	*Mustelus mustelus*	(Linnaeus, 1758)	Species	4
Smooth-hounds nei	Mustelus	(Linck, 1790)	Genus	65
Thresher	*Alopias vulpinus*	(Bonnaterre, 1788)	Species	18
Tope shark	*Galeorhinus galeus*	(Linnaeus, 1758)	Species	11
Velvet belly	*Etmopterus spinax*	(Linnaeus, 1758)	Species	13

Table A.2
The angelshark (*Squatina squatina*) and common guitarfish (*Rhinobatos rhinobatos*) were excluded from this study in specific years and countries, based on sources citing them as locally extinct in parts of their previous ranges. Entire EEZs were excluded in cases when species were found to be extinct in only part. For example, angelshark was omitted from Spain from 1959 to 2014 since it is considered extirpated from the Catalan Sea.

Species	Years excluded	Countries	Reference
Squatina squatina	1959–2014	Spain	[49]
Squatina squatina	1980–2014	Italy	[49,50]
Squatina squatina	2000–2014	Bulgaria, Georgia, Romania, Russia, Ukraine	[28,42,51]
Rhinobatos rhinobatos	1950–2014	Croatia, France, Italy, Spain,	[52]

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