Evaluating and enhancing the taxonomic resolution of shark and ray (Subclass Elasmobranchii) catch statistics in the Mediterranean and Black Seas (1950-2014)

by

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Abstract

To sustainably manage fisheries, the stock biology, ecology, and its past and present human exploitation must be known. To monitor fisheries, the Food and Agriculture Organization of the United Nations began collecting and harmonizing country catch reports in the late 1940s. In 1950, it issued its first global annual catch statistics, which have continued until the present. This official reported catch has been shown to vastly underrepresent the entirety of the world's catch. The small-scale fisheries sectors (i.e., artisanal, subsistence, and recreational) are largely unreported, in addition to incidental catches of non-target species, much of which is discarded. The latter component of the catch is often comprised of species that are more biologically vulnerable to overfishing than target species. Sharks and rays (subclass Elasmobranchii) are one such group of species. One in four elasmobranch species are estimated to be threatened with extinction, primarily as a result of overfishing. Unfortunately, elasmobranch catch data are notoriously underreported and imprecise.

This thesis sought to elucidate the elasmobranch catches of 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 catches 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 catch data, and reporting quality has hardly improved. While many countries have improved their reporting since the 1950s, the original leaders (e.g., Malta and Georgia) have seen their position worsening over time.

The species composition of reconstructed historical elasmobranch catch was also investigated. The fishery characteristics of species-specific catches were modeled and used to estimate unknown species-specific proportions within aggregated catch categories (e.g., "sharks and rays"). Over half a million tonnes of species-specific catch was disaggregated, increasing the species-specific proportion of reported catches by over 10%. These results, combined with a literature review, imply weak implementation and enforcement of existing protective regulations, despite precipitous declines of elasmobranchs in the Mediterranean and Black Seas.

Lay summary

Seafood provides three billion people with over 20% of their animal protein, much of it from marine fisheries. Fisheries often use gears that catch species other than those targeted, and such ‘bycatch’ species are often more susceptible to overfishing. Sharks and rays (subclass Elasmobranchii) are commonly bycaught in many fisheries and a quarter are now threatened with extinction. Since 1950, the United Nations has published global fisheries statistics, based on countries’ self-reporting. Elasmobranch catch has been largely unreported or reported with insufficient detail. The Mediterranean and Black Seas are a hotspot of threat for elasmobranchs, yet only 3% of reported catches are species-specific. This work (i) evaluates the taxonomic resolution of reported elasmobranch catches, and (ii) predicts the species composition of elasmobranch catches in the Mediterranean and Black Seas. This thesis contributes to fisheries management and conservation efforts for a region and group of species that suffer from data deficiency.

Preface

This thesis was written by Madeline Cashion under the supervision of Daniel Pauly and is a contribution of the *Sea Around Us*, a research initiative at the University of British Columbia. *Sea Around Us* reconstructed catch data and taxon distributions were used for the analyses in both Chapter Two and Chapter Three. The analysis in Chapter Two also relied on catch data from the Food and Agriculture Organization of the United Nations, extracted using the FishStatJ software (FAO, 2016a).

The original method of calculating the Taxonomic Resolution Index was designed by Daniel Pauly and Reg Watson. In Chapter Three, the model of correlates of species-specific catch and the taxonomic disaggregation algorithm were built by Madeline Cashion with help from Tim Cashion.

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CBD	Convention on Biological Diversity
CHOND	Total domestic elasmobranch catch in metric tonnes
CPUE	Catch per unit effort
EBFM	Ecosystem-based fisheries management
EEZ	Exclusive economic zone
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GFCM	General Fisheries Commission for the Mediterranean
IPOA-SHARKS	International Plan of Action for the Conservation and Management of Sharks
IUCN	International Union for Conservation's (IUCN)
LMM	Linear mixed-effects model
NPOA-SHARKS	National Plan of Action for the Conservation and Management of Sharks
OCCUR	Taxon distribution occurrence value in an exclusive economic zone
OF	Percentage of the number of overfished stocks
RFMO	Regional fisheries management organization
RPOA-SHARKS	Regional Plan of Action for the Conservation and Management of Sharks
SPA/BD	Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean
SpCATCH	Species-specific annual domestic elasmobranch catch
SPP	Species
TRI	Taxonomic Resolution Index
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
USSR	Union of Soviet Socialist Republics

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First, I would like to thank Daniel Pauly for his wisdom, levity, and confidence during my time with the *Sea Around Us.* It has truly been a privilege to work with him. I would also like to acknowledge William Cheung and Nicholas Dulvy who served on my supervisory committee and helped me a great deal throughout my degree.

From database queries to map-making, this work was the combined effort of the many moving parts (people!) of the *Sea Around Us* research group. Thank you to everyone who helped me, in several iterations, to produce the data upon which this thesis relied. In particular, Gordon Tsui and Eric Sy should be recognized for their data science magic. I also want to specifically acknowledge Nicolas Bailly for his patient taxonomist mind and insights on the whole thesis, but in particular for his counsel on the Taxonomic Resolution Index.

This work would not have been possible without the unrelenting support, snacks, and beverages provided by close friends of mine, including my brilliant and hilarious cohort at the Institute for the Oceans and Fisheries. I feel so lucky that we get to begin and share our careers together, what a brilliant group we've built here! I want to acknowledge my desk friend throughout my degree: Santiago De La Puente. Thank you for teaching (and distracting me) with your incredible depth of experience and stories from the Peruvian fisheries world.

My family has somehow always managed to treat me like a hero and that is precisely how I feel as I finish this work. Thank you Nana, Grandad, and Mum. I love you, thank you for your unrelenting support.

Most of all, thank you to my compassionate and ingenious husband, Tim Cashion for showing support by reading, editing, and most of all snuggling. I could not be happier to be sharing this life with him, both in the ocean and on land.

Dedication

This thesis is dedicated to the late Dr. Eugenie Clark, a pioneering shark biologist who inspired generations of shark researchers and enthusiasts.

Chapter 1: Introduction

Extinction is a common phenomenon; on a geologic time scale, individual species are somewhat ephemeral, appearing then disappearing throughout the tree of life. The rate of speciation is generally in balance with the rate of extinction, with rare exceptions of large fluctuations one way or the other. Fossil evidence suggests that there have been five mass extinction events in the history of life on Earth in which the rate of species exceeded the background extinction rate by several orders of magnitude. More recently, however, evidence has mounted suggesting that the Earth has entered its sixth mass extinction event. This characterizes the newly-defined present epoch, dubbed the "Anthropocene" by the Nobel Prize–winning chemist Paul Crutzen in 2002. The Anthropocene is an era of human-induced environmental change triggering waves of extinctions (Zalasiewicz et al., 2008). The current rate of species loss is unprecedented compared to the last five mass extinctions, during which between 75 and 96% of species went extinct over millions of years (Barnosky et al., 2011).

The extent and consequences of current species loss in the marine environment are less clear than in terrestrial ecosystems (Dulvy, Sadovy, & Reynolds, 2003). Confirmed global marine extinctions tend to be species that are relatively easy to monitor such as mammals (e.g., Caribbean monk seal and Steller's sea cow) and shallow-water invertebrates (e.g., white abalone). However, at a local scale, over 50 fish species have gone extinct since the mid- 19^{th} century (Dulvy et al., 2003). It is also clear that most at-risk species have small home ranges and are subject to human exploitation. Since humans preferentially select for large slow-growing fishes, the mean trophic level of marine catches has declined since 1950, a phenomenon Pauly et al. (1998) dubbed "fishing down marine food webs". Marine predators are declining at both the global (Jackson et al., 2001; Pauly et al., 1998) and local scales (e.g., Friedlander & DeMartini, 2002; Hughes, 1994; Reitz, 2004).

Cartilaginous fishes of the subclass Elasmobranchii (sharks and rays) have persisted through four of the five mass extinction events, but now a quarter of these ~1200 species may now be at risk of extinction (Dulvy et al., 2014). Elasmobranchs are commercially valued for their meat, fins and wings, gill rakers, liver, and skin, though less than one-third of the world's catch (Worm et al., 2013) and only one-third of threatened species are directly targeted for these products (Dulvy et al., 2014). Incidental capture and exploitation poses the greatest threat to elasmobranchs overall. While a major driver of shark and ray fishing is the international fin trade, regulatory intervention and changing consumer demand has shifted the weight of markets increasingly toward meat products (Dent & Clarke, 2015). Overfishing and habitat loss have reduced some elasmobranch populations to just 10% of their previous abundance (Myers et al., 2007) and their conservative life history strategies limit their recovery potential in the absence of science-based fisheries policies (Simpfendorfer & Dulvy, 2017; Stevens et al., 2000). The loss of top predators can have a cascading impacts in ecosystems (Heithaus et al., 2008; Paine, 1980) particularly after decades of heavy exploitation has reduced trophic web redundancies (Jackson et al., 2001). For example, the loss of large predatory sharks due to overfishing is thought to compromise the resilience of coral reef communities to the myriad pressures that many of them now face (Dulvy, Freckleton, & Polunin, 2004; Hughes, 1994).

Growing concern for elasmobranch populations has spurred conservation and management initiatives worldwide over the past two decades. The United Nations (UN) International Plan of Action for the Conservation and Management of Sharks (IPOA-SHARKS) in 1999 was the first international effort specific to elasmobranchs, designed to encourage and guide shark-fishing nations to adopt plans for elasmobranch management (FAO, 1999). By the most recent count, 31 national and 6 regional plans of actions have been created (IUCN-SSG, 2016). Nearly two-thirds of the elasmobranch landings (i.e., not including discarded catch) reported to the United Nations Food and Agriculture Organization (FAO) are from countries with action plans but only 9% are from countries with plans that meet the objectives specified by IPOA-SHARKS (Davidson, Krawchuk, & Dulvy, 2015). Furthermore, IPOA-SHARKS and its subsidiary plans have been criticized for their lack of specific, actionable guidelines (Davis & Worm, 2013). Arguably, among the most successful tactics for protecting elasmobranchs is the fins-attached policy, the strongest finning policy, whereby fins and wings may not be landed separate from shark and ray carcasses (Biery & Pauly, 2012; Davidson et al., 2015).

Prior to IPOA-SHARKS, the Convention on Biological Diversity (CBD) was signed by 150 governments at the United Nations Rio Earth Summit, 1992. As of January 2018, the CBD had been signed by 196 states including the European Union (EU), and ratified by all UN member states except for the United States (UN, 2018). The Strategic Plan of the CBD, introduced in 2010, outlines 20 specific biodiversity targets, the Aichi Targets, to be met by the year 2020 (UNEP, 2010). The Aichi Targets most relevant to elasmobranchs are:

- **Target 6:** "By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem-based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits."

- **Target 11:** "By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes."

- **Target 12:** "By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained."

Of these three targets, a mid-term assessment found that progress was most advanced toward meeting Targets 6 and 11 (Tittensor et al., 2014). Although, marine protected areas (MPAs; Target 11) may not be providing adequate protection for elasmobranchs; only 12 of the 99 at-risk species with restricted home ranges have at least 10% of their range within a no-take MPA (Davidson & Dulvy, 2017). Additionally, to approach Target 6, ecosystem-based fisheries management (EBFM) needs to be implemented in order to accommodate regulations of bycatch species such as elasmobranchs. Despite a great breadth of literature providing frameworks and policy recommendations, myths and confusion around the interpretation and feasibility of EBFM appear to be preventing widespread implementation (Patrick & Link, 2015; Pitcher et al., 2009; Trochta et al., 2018).

The Mediterranean and Black Sea region is a hotspot of threat for elasmobranchs: between 53 and 71% of species assessed by the International Union for the Conservation of Nature (IUCN) are at an elevated risk of extinction (Dulvy et al., 2016). The uncertainty in these assessments is due to a lack of reliable data on species' biological parameters (e.g., age of maturation and fecundity) and exploitation patterns. A species' or population's risk of extinction is a function of intrinsic biological sensitivity and exposure to threat (Dulvy et al., 2014). Thus, recent and ongoing intensification and spatial expansion of fishing in the Mediterranean and Black Seas is likely exacerbating elasmobranch threat level. Additionally, there is evidence of major structural changes to Mediterranean ecosystems, including a reduction in elasmobranch abundance, that predate the start of official fisheries statistics (Fortibuoni et al., 2017).

The aim of this thesis was to evaluate and improve the taxonomic resolution of elasmobranch catch statistics in the Mediterranean and Black Seas. This research addresses the questions: (1) How informative are the reported catch data for elasmobranch management and conservation in the Mediterranean and Black Seas? (2) What is the species composition of elasmobranch catches in the Mediterranean and Black Seas? These questions were guided by a need for detailed elasmobranch fisheries data in this region (Dulvy et al., 2016).

Chapter 2 of this thesis provides an analysis of the taxonomic resolution of domestic elasmobranch catches reported by each country to, and harmonized by, the Food and Agriculture Organization of the United Nations (FAO). The taxonomic resolution of elasmobranch catches was compared spatially and temporally to evaluate changes and trends within in the Mediterranean and Black Seas. Chapter 3 uses data from the *Sea Around Us* database of "reconstructed" catches (Pauly & Zeller, 2015) to estimate the species composition of ambiguous catch categories such as "Sharks, skates, and rays not elsewhere included", which contain a large proportion of elasmobranch tonnage. Additionally, Chapter 3 uses a novel method of taxonomic disaggregation and discusses its benefits, limitations, and potential for future applications. Chapter 4 combines the results from Chapters 2 and 3 and discusses them in the context of elasmobranch management and conservation on a broader scale.

The analyses and discussions of this research could be used to prioritize future efforts to conserve and manage sharks and rays in the Mediterranean and Black Seas. In particular, the region would benefit from a greater emphasis on monitoring and documentation of the implementation, by country, of existing regulations. Additionally, the taxonomic disaggregation provides the first basin-wise estimates of the species composition of historical shark and ray catches. The resultant catch time series may be used to better understand the exploitation patterns and population effects for elasmobranchs in the Mediterranean and Black Seas.

Chapter 2: Less than a quarter of Mediterranean and Black Seas commercial shark and ray taxa are reported in official catch data

2.1 Introduction

Detailed fisheries catch statistics are requisite to effective management of marine resources. 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 (Cavanagh, Fowler, & Camhi, 2009; Chen, Chen, & Stergiou, 2003; Clarke et al., 2006; Zhou, Smith, & Fuller, 2011). 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' (Camhi et al., 1998) Pauly and Zeller (2016) 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 when catches are reported, they are not necessarily informative for stock management and conservation. Taxonomically, the resolution of reported catches is highest for commercially-important taxa, as one might expect (Pauly et al., 2016). 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 (Pauly & Zeller, 2016).

Elasmobranchii, the subclass of fishes comprised of sharks and rays, is a group of species associated with poor fisheries reporting. While directed fisheries exist for some elasmobranch species, it is estimated that their overall catch is far outweighed by incidental and discarded catches (Clarke et al., 2006; Dulvy et al., 2014). The International Union for Conservation's (IUCN) Red List of Threatened Species estimates that about a quarter of elasmobranch species are threatened with extinction (i.e., assessed as Vulnerable, Endangered, or Critically Endangered) and overfishing is the principal threat behind elasmobranch population declines (Dulvy et al., 2014). The 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 (Dulvy et al., 2014; Musick, 1999). Although targeted fisheries for elasmobranchs do exist, they are often characterized by "boom-and-bust" patterns of exploitation, with rapidly increasing yields closely followed by precipitous declines in catch (Holden, 1973; Stevens et al., 2000) Only 4% of global elasmobranch catches derive from sustainably managed stocks (Simpfendorfer & Dulvy, 2017). Most elasmobranchs are caught incidentally and either discarded at sea or landed (when individuals are marketable or in compliance with a discard ban) (Stevens et al., 2000).

The Mediterranean basin is a region of elevated threat for elasmobranchs and has become an area of special concern for marine conservation (Dulvy et al., 2016; Fernandes et al., 2017). The Mediterranean and Black Seas historically harboured a high diversity and abundance of elasmobranchs (Cavanagh & Gibson, 2007). Following centuries of over-exploitation and the more recent expansion and intensification of fisheries, elasmobranchs have become increasingly rare, with population declines of up to 99% for some large coastal species (Farrugio, Oliver, & Biagi, 1993; Ferretti et al., 2008). At least 53% of Mediterranean elasmobranch species are at risk of extinction and many have an elevated and worsening threat status regionally compared to their global status (Dulvy et al., 2016). For example, ten of the 16 shark species reported in Mediterranean catches are more threatened regionally than they are at a global level (Figure 2.1).

Unfortunately, there is a lack of population and fisheries data for many elasmobranchs worldwide. 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., Ferretti et al., 2008). Data Deficient species represent the second-greatest proportion (18%) of assessed elasmobranch species in the Mediterranean and Black Seas. These are second only to those listed as Critically Endangered (27%; Dulvy et al., 2016). Ambiguous catch statistics represent a lost opportunity for an otherwise critical source of abundance time series, particularly in areas lacking fisheries-independent surveys. So far, regulations for elasmobranch conservation in the Mediterranean and Black Seas have proven insufficient due to weak or absent national implementation and enforcement, despite the Mediterranean being one of the first to adopt a Regional or National Plan of Action for Sharks (NPOA) (Cavanagh & Gibson, 2007). 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) and as such, much of the Mediterranean Sea area remains legally under no national jurisdiction high seas (Chevalier, 2005).

A major intrinsic factor influencing a country's taxonomic data quality is the diversity in its marine fauna (Pauly & Watson, 2008). Thus, to compare the taxonomic resolution of catches between countries by simply counting the number of species-rank records would result in unfair comparisons, as illustrated by comparing the number of Indonesia's fishes deemed 'commercial' by FishBase (Froese & Pauly, 2017) (> 702 spp.; highest in the world) against Finland's (~ 30 spp.; among the lowest in the world). In 2014, Indonesia reported 52 (7%) of its commercial fish species (Pauly & Budimartono, 2015), while Finland reported fewer species, but a much higher percentage of its commercial species (67%) (Rossing, Bale, Harper, & Zeller, 2010). 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 likely unrealistic.

Pauly and Watson (2008) designed a 'Context-Adjusted Fisheries Statistics Indicator' to correct for the bias associated with comparing the taxonomic resolution of catches from low latitude, highly-biodiverse developing countries with those of higher latitude, low-biodiversity developed countries. This index scores the taxonomic resolution of a country's reported catch data relative to the list of biogeographically present taxa reported by other countries in the region. In the present study, this index is adapted and renamed the Taxonomic Resolution Index (TRI). The TRIs are calculated and compared for the FAO elasmobranch catches 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. This paper discusses taxonomic resolution of catches in the context of the usefulness of catch statistics for elasmobranch fisheries management and conservation.

2.2 Methods

The taxonomic resolution of reported catch statistics can be scored by country for any marine taxa. The taxonomic focus of this study was sharks and rays, the cartilaginous fishes comprising the subclass Elasmobranchii. Chimaeroid species of the subclass Holocephali are excluded from this study because there were no reported domestic catches of them in the Mediterranean and Black Seas from 1950 to 2014. The TRI was calculated annually for each maritime county and territory (i.e., Gaza Strip) from 1950 to 2014, following a method adapted from Pauly and Watson (2008). 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 are biogeographically present in the waters of that country. Many Mediterranean and Black Sea countries have not claimed their exclusive economic zones (EEZ), as they are permitted to under the rules of the United Nations Convention on the Law of the Sea (UNCLOS). As such, throughout this study defines country EEZs by their "EEZ-equivalent waters" as delineated by the Flanders Marine Institute (see www.vliz.be) (Zeller & Pauly, 2016).

2.2.1 Reported elasmobranch catches

Annual domestic landings data were extracted from the FAO FishSTAT database (FAO, 2016a) 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). The reported elasmobranch catch categories are not always identified by scientific names, thus catches were associated to the lowest inclusive taxonomic name and rank (i.e., subclass, superorder, order, family, etc.) (Table A.1). The taxonomic classification follows FishBase (Froese & Pauly, 2017). A total of 37 unique elasmobranch taxa were reported in the Mediterranean and Black Seas 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 the country's EEZ (Palomares et al., 2015).

FAO data were used for this study in order to evaluate taxonomic resolution of catches as they appear in this widely-used resource. However, six countries (Croatia, Gaza Strip, Georgia, Montenegro, Russia, and Ukraine) were evaluated using reconstructed catch data (reported domestic catches only) from the *Sea Around Us* database (Pauly & Zeller, 2015). This was necessary because these countries emerged from the breakup of a larger state (i.e., the dissolutions of Yugoslavia and the USSR) and thus their FAO catch statistics are not complete for the 65-year 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.

2.2.2 Regional Taxa List: commercial elasmobranchs in the Mediterranean and Black Sea

A list of all elasmobranch taxonomic names reported in domestic Mediterranean and Black Seas catch data were compiled by year from 1950 to 2014, herein referred to as the Regional Taxa List. Throughout the analysis, each country was evaluated based on the taxa in the Regional Taxa List that overlapped with at least 10% of its EEZ, 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 commercial unimportant or appearing in incidental, discarded, or small-scale catches) (Pauly & Watson, 2008). This I supported by evidence that while many elasmobranchs are depleted in the Mediterranean and Black Seas, all are still caught incidentally by some fishery (Cavanagh & Gibson, 2007). Furthermore, the Taxa List contained far fewer taxa than are biogeographically present in the Mediterranean and Black Seas (i.e., 27 species reported in catches versus at least 80 species occurring; Bradai, Saidi, & Enajjar, 2012) 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; GFCM, 2017) (Dulvy et al., 2016). 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 (Dulvy et al., 2003). Of the 27 elasmobranch species reported in catches, 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) (Davidson & Dulvy, 2017). Omissions were based on both IUCN and literature estimations of date and location of extinction (Table A.2).

2.2.3 Taxonomic resolution score for each country's reported catches

Once Country Taxa Lists were compiled for all 24 countries, the taxonomic resolution of their reported elasmobranch catches were scored. Each country's annual taxonomic score for reported catch was the sum of unique elasmobranch taxa appearing in FAO statistics, weighted by the position in the taxonomic hierarchy. 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) so that more precise taxa received higher scores, 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., reported catches 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.

2.2.4 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 2.2.3) (Equation 2.1).

$$\mathrm{TRI}_{\mathrm{Country/Year}} = \frac{Taxonomic\ score\ of\ reported\ catch}{Taxonomic\ score\ of\ Country\ Taxa\ List}$$

(Equation 3.1)

The lowest possible TRI is 0% and indicates that no elasmobranchs were reported in a country's catch 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, the catch statistics for Spain for the year 2000 are presented (Table 2.1).

2.3 Results

2.3.1 Composition of reported catches: elasmobranchs vs. other organisms

Mediterranean and Black Seas countries reported 37 different shark and ray taxa in official FAO catch statistics from 1950 to 2014 (Table 2.2; see Table A.1 for full taxa list). There were 27 species (73% of all elasmobranch taxa), one genus (3%), six families (16%), 2 orders (5%), and one subclass (3%) (Table 2.2). 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%), 6 orders (2%), five classes (2%), and eight categories of miscellaneous catch (3%) (Table 2.2). By catch amount however, only 3% (0.03 million t) of reported elasmobranch catches were species-specific, compared to the majority (74%; 62 million t) of non-elasmobranch catch reported by species (Table 2.2). The genus and order ranks each contributed 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 2.2).

Elasmobranchs also appear more recently and less often in reported catch 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, *Squalus blainville*) (Table A.1). To compare, over half (142/264) of non-elasmobranch taxa, reported for at least half of the 1950 to 2014 period, and more than two-thirds (179/264) were species-specific (not shown here). In absolute terms, Spain reported the most elasmobranch taxa (21) over the time series and in the final year (2014), although prior to 1996 it only reported two low-resolution taxa (i.e., Elasmobranchii and Batoidea).

2.3.2 Taxonomic Resolution Index by country

The taxonomic detail of elasmobranch catch reporting in the Mediterranean and Black Seas has improved as a whole, rising from 12% (1950-1960 average TRI) to 16% (2004-2014 average TRI) of commercial elasmobranch taxa reported to the FAO (Table 2.3). Of 24 countries in this study, 15 improved their TRI over the 65-year period (Table 2.3). The taxonomic resolution of Spanish and French reporting improved the most, by 60 and 35% respectively (Table 2.3), but ranked 8th and 9th (out of 24) by mean overall TRI from 1950 to 2014 (Table 2.4). Eleven countries (Albania, Bulgaria, Cyprus, Gaza Strip, Lebanon, Libya, Romania, Russia, Syria, Tunisia, and Ukraine) did not report any elasmobranch catch in the 1950s, but reported between 1 and 30% of their Country Taxa Lists by the final decade (Table 2.3). Eight of these countries ranked among the top ten highest TRI scores by the final decade (Table 2.3). Bulgaria improved the most, out of the countries that began by reporting no elasmobranchs (Table 2.3). 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 (Figure 2.2.A-D).

The TRIs of nine countries (Algeria, Croatia, Egypt, Georgia, Greece, Israel, Italy, Malta, and Montenegro) worsened over the time series (Table 2.3). Georgia's TRI declined the most, with a -54% change since the 1950s, at which time it had the highest taxonomic resolution, reporting 66% of its Country Taxa List (Table 2.3). Georgian elasmobranch catch statistics included only spiny dogfish from 1951-1987, then only "sharks, rays, skates, etc. nei" until 2000, with a single record of "rays, stingrays, mantas nei" in 1991. During most of the 2000s, the Georgia reported a curious alternating pattern between "sharks, rays, skates, etc. nei" and spiny dogfish annually until 2013, at which point they began reporting both. Thus, Georgia's dramatic drop in TRI is not attributed to fewer taxa reported (i.e., decreasing numerator), but rather that the quality of its catch statistics lagged behind improvements made by countries with which it has domestically-occurring taxa in common. Our results suggest this is a common trend: countries that initially led the region in TRI showed no improvement or even declining TRI over time (Figure 2.3). In fact, only countries reporting fewer than 10% in the 1950s showed any overall improvement (Figure 2.3).

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 (Figure 2.2A-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.

2.3.3 Leading countries in TRI overall

While many Mediterranean and Black Seas countries improved their elasmobranch TRI from 1950 to 2014, mean scores over the time period were low (Table 2.4). Only 2 out of 10 of the most improved countries reported more than a quarter of their Country Taxa List on average (Table 2.4). 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 2.4). Malta was the leading country in the Mediterranean and Black Seas for 45 of the 65 years, but finished second to Spain (Figure 2.2 A & D). Malta and Georgia's leading overall scores, at odds with their vastly differing number of commercial taxa (Malta has more than twice as many as

Georgia), demonstrate that our definition of commercial taxa (Country Taxa Lists), as intended, avoids ‘penalizing’ countries for having a higher species richness than others.

2.4 Discussion

This is the first study to measure the taxonomic resolution of reported elasmobranch catch statistics, relative to the biogeographic composition of commercial taxa found in each country. The results suggest that fisheries data quality for elasmobranchs in the Mediterranean and Black Sea has improved slightly over time but remains alarmingly low for many countries and in the region as a whole. There is apparently no 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 (Abella, 2011). Indeed, data deficiency and inadequacy continues to be cited as one of the hindrances for taking action to protect Mediterranean elasmobranchs (Cavanagh & Gibson, 2007; Ferretti et al., 2008; Kebe, Restrepo, & Palma, 2002). This is also reflected by the fact that 24% of Mediterranean and Black Sea shark species are listed as Data Deficient (Dulvy et al., 2016) and yet some are still landed (e.g., *Heptranchias perlo*).

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

2.4.1 The Mediterranean and Black Seas fisheries in a global context

At least 90% of Mediterranean fish stocks are overexploited (Colloca, Scarcella, & Libralato, 2017; Fernandes et al., 2017) and many of the fisheries are not managed in compliance with scientific advice (Vasilakopoulos, Maravelias, & Tserpes, 2014). A recent study found that nearly all of the fish stocks in the Mediterranean Sea (with sufficient data for assessment) were being subjected to fishing mortality higher than at maximum sustainable yield and none had sustainable sizes of spawning stock biomasses (Fernandes et al., 2017). This is the legacy of a centuries-long history of human impacts and, more recently, unregulated development of unselective fisheries (Farrugio et al., 1993). As a semi-enclosed sea with a dense coastal human population, the Mediterranean and Black Seas ecosystem are also experiencing accelerated warming, acidification, and pollution (Piroddi et al., 2015).

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 (Fernandes et al., 2017). Despite shrinking stocks, Mediterranean and Black Seas fishing effort has been increasing and practices have become less selective (Vasilakopoulos et al., 2014). This is particularly true for non-European fisheries that have industrialized and spatially expanded in the Mediterranean (Colloca et al., 2017). Collectively, non-European elasmobranch catch has tripled from in the last 20 years while European catches have been steadily declining since the mid-1990s following two peaks in previous decades (Colloca et al., 2017). Growing yields followed by precipitous declines, or the boom-and-bust pattern, characterizes many elasmobranch fisheries (Camhi et al., 1998).

2.4.2 Mediterranean and Black Seas elasmobranch catch 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 if this is reflected by TRI by comparing the results of the present study to those of the first use of the TRI by Pauly and Watson (2008). They evaluated catches of all exploited marine taxa (fish and invertebrates) for 53 countries, including several in the Mediterranean and Black Seas. 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 (Pauly & Watson, 2008). In both studies, Spain and France were two of the highest-ranking countries for TRI and Egypt was among the lowest. Pauly and Watson (2008) also found that countries with high initial TRI values did improve relative to those with poorer initial reporting, which contrasts to the result in the present study. This suggests that countries may not be as motivated, or perhaps pressured, to improve the quality of their catch reporting for elasmobranchs relative to other species in the catch.

One aspect of catch reporting that is not addressed by TRI is the amount of elasmobranch catch in each country and whether or not that influences the taxonomic resolution of the data. This and other studies indicate that the amount and resolution of elasmobranch catches may not be related. On a global scale, elasmobranch landings are declining due to reduced populations rather than improved fisheries management (Davidson et al., 2015). Davidson et al. (2015) 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 catch 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 the a much greater proportion (90%) of Mediterranean and Black Sea elasmobranch landings are from countries with less than a quarter of their landings identified to species. In total from 1950 to 2014, an overwhelming 97% of Mediterranean and Black Sea elasmobranch landings were not species-specific. Thus, a higher proportion of Mediterranean and Black Seas elasmobranch catch is inadequately reported as compared to global catches.

2.4.3 Elasmobranch conservation and management in the Mediterranean and Black Seas

In the last two decades, the number of commitments to elasmobranch management and conservation have increased, both globally (Davidson et al., 2015) and within the Mediterranean and Black Seas (FAO, 2016b)(Table 2.5). The first international elasmobranch conservation initiative was the International Plan of Action for the Conservation and Management of Sharks (IPOA-SHARKS) in 1999 that encouraged all shark-fishing nations to adopt a national plan of action and greater regions to adopt regional plans of action (RPOA-SHARKS) to reduce shark mortality (FAO, 1999). In 2003, the Mediterranean Sea became the third entity to adopt a plan (UNEP, 2003) (note that the Black Sea is not included) and six years later the European Union (EU) adopted a plan (European Commission, 2009). Both of these RPOA-SHARKS resemble the IPOA-SHARKS in that they are not legally binding, but rather serve as proposals for countries to implement their own plans. So far, no Mediterranean and Black Seas countries have their own NPOA-SHARKS; however, under the auspices of the EU Action Plan, EU countries are often considered to have individual plans (Fischer et al., 2012). Although these plans represent important conservation foundations, legally binding instruments paired with adequate enforcement are crucial to the successful protection of Mediterranean and Black Sea elasmobranchs (Davidson et al., 2015; Gilman, Passfield, & Nakamura, 2012).

Three binding resolutions for elasmobranch protection have been establish by the regional fisheries management organization (RFMO) for the Mediterranean and Black Seas, the General Fisheries Commission for the Mediterranean (GFCM) (Table 2.5). The most comprehensive GFCM resolution is Recommendation GFCM/36/2012/3, which prohibits the retention and marketing of all 24 elasmobranch species listed as endangered or threatened (i.e., Annex II) in the Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean (SPA/BD), and emphasizes the live release of tope shark (*Galeorhinus galeus*) in particular (GFCM, 2017). Unfortunately, all species, with the exception of the basking shark (*Cetorhinus maximus*), protected by this resolution have been landed since 2012 by the same countries that caught them prior, according to reported landings until 2014. It is possible that this may have changed from 2014-2017 but no evidence of this was found in the literature. The effectiveness of other measures to reduce elasmobranch mortality such as finning bans, gear bans, and restricted areas have also been difficult to discern in the Mediterranean and Black Seas, generally due to data inaccessibility (Cavanagh & Gibson, 2007; Gilman et al., 2012) In fact, there is no evidence in the present study or otherwise to suggest that the GFCM resolutions to protect elasmobranchs have been implemented (Cavanagh & Gibson, 2007; Ragonese et al., 2013).

Despite the fact that the “ecosystem approach to fisheries” is a component of the GFCM mandate and is cited in the preamble to its resolutions (GFCM, 2017), it falls short in at the implementation phase, at least in respect to elasmobranchs. In fact, in a performance assessment of RFMO bycatch and discards management, the GFCM ranked 10th (out of 13) and earned only 1 of 47 possible points for the “Data Collection” criteria (Gilman et al., 2012). 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”.

2.4.4 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 (GFCM, 2017). 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 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 trained fishery observers (Colloca et al., 2017). Fisheries with low capacity, particularly those in developing countries, may need financial assistance to improve catch recording through training and hiring on-board observers. Another solution to explore could be a rapid development of automatized image analyses through recent improvements in Artificial Intelligence (neural networks, deep machine learning).

2.5 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 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.

2.6. Figures

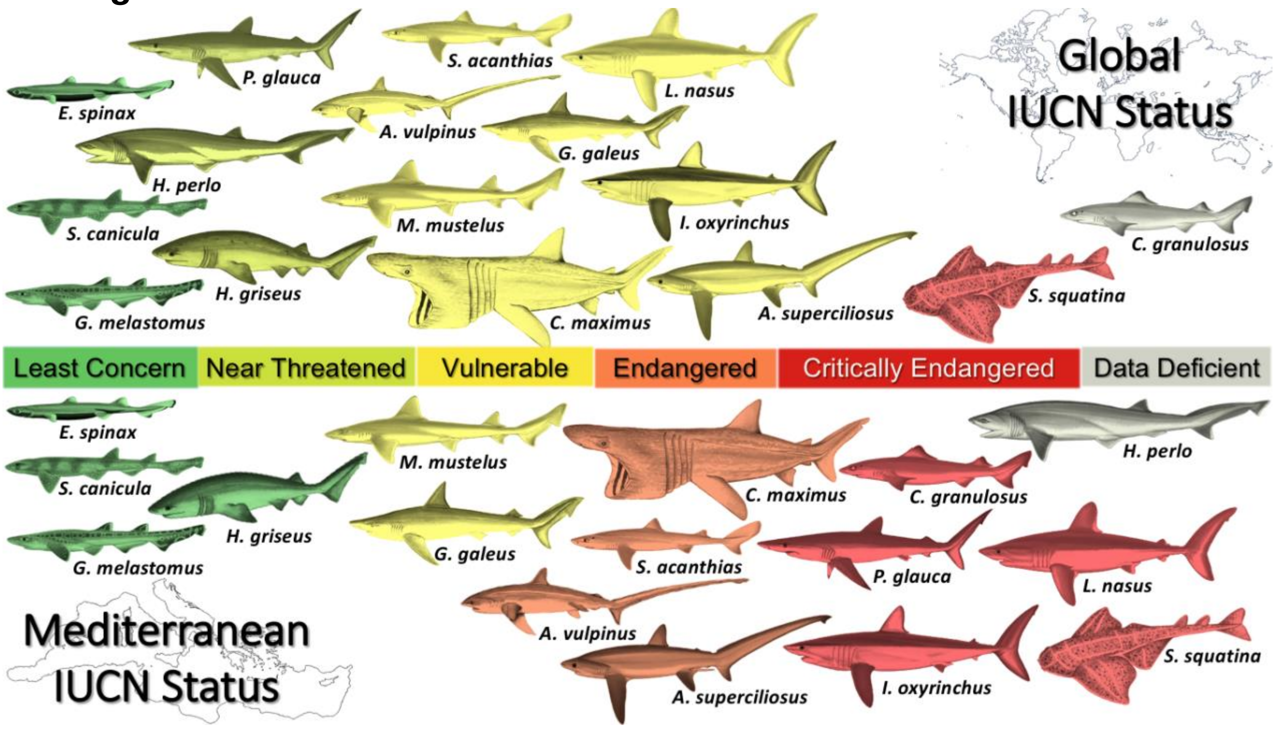

Figure 2.1. Global vs. regional (Mediterranean Sea) IUCN Red List statuses of the 16 shark species reported in domestic FAO catch statistics by Mediterranean countries from 1950-2014. At least half of these sharks face an elevated risk of extinction in Mediterranean Sea than they do globally.

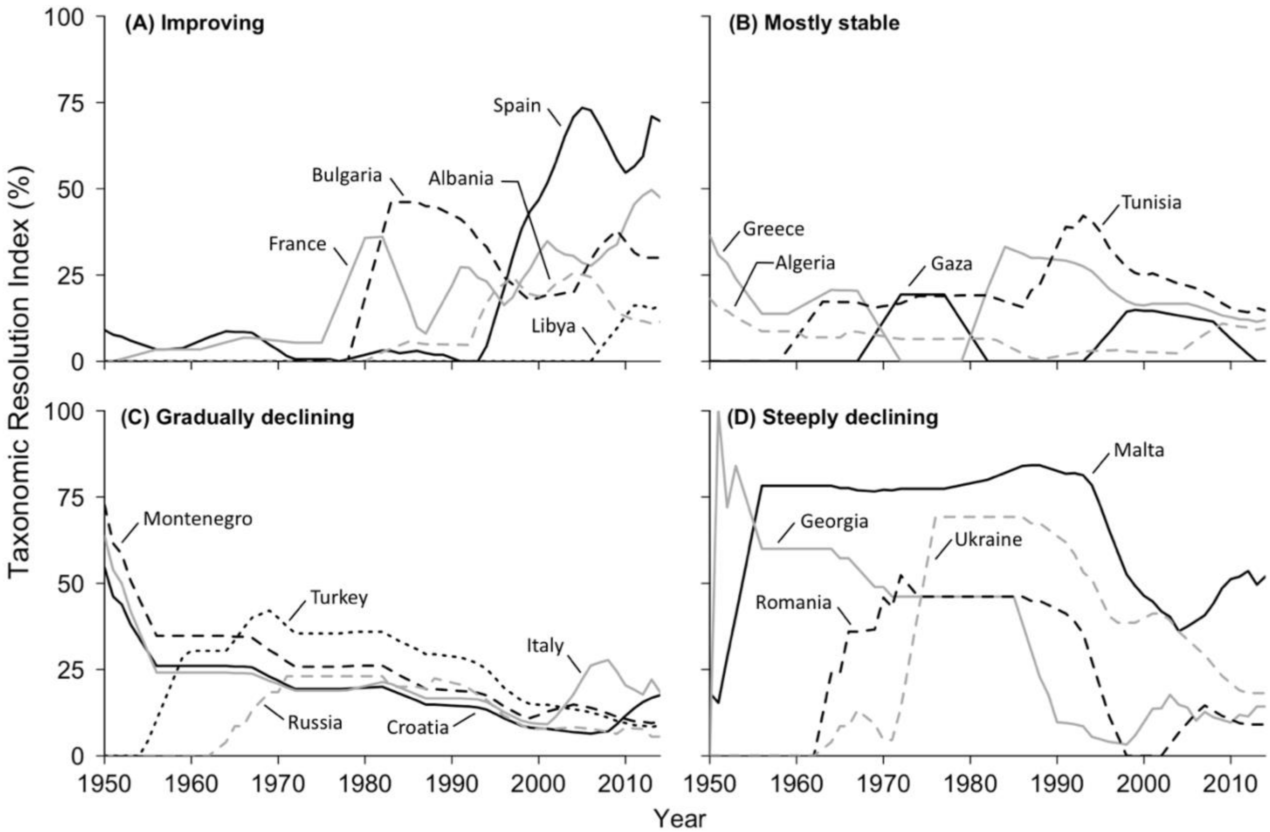

Figure 2.2. Annual taxonomic resolution (proportion of commercial taxa reported) of FAO elasmobranch catch data for the Mediterranean and Black Sea countries (1950-2014), plotted by general trend: (A) Improving, (B) Mostly stable, (C) Gradually declining, (D) Steeply declining. Six countries are not shown, since their scores were consistently low (< 10%): Cyprus, Egypt, Israel, Lebanon, Morocco, and Syria.

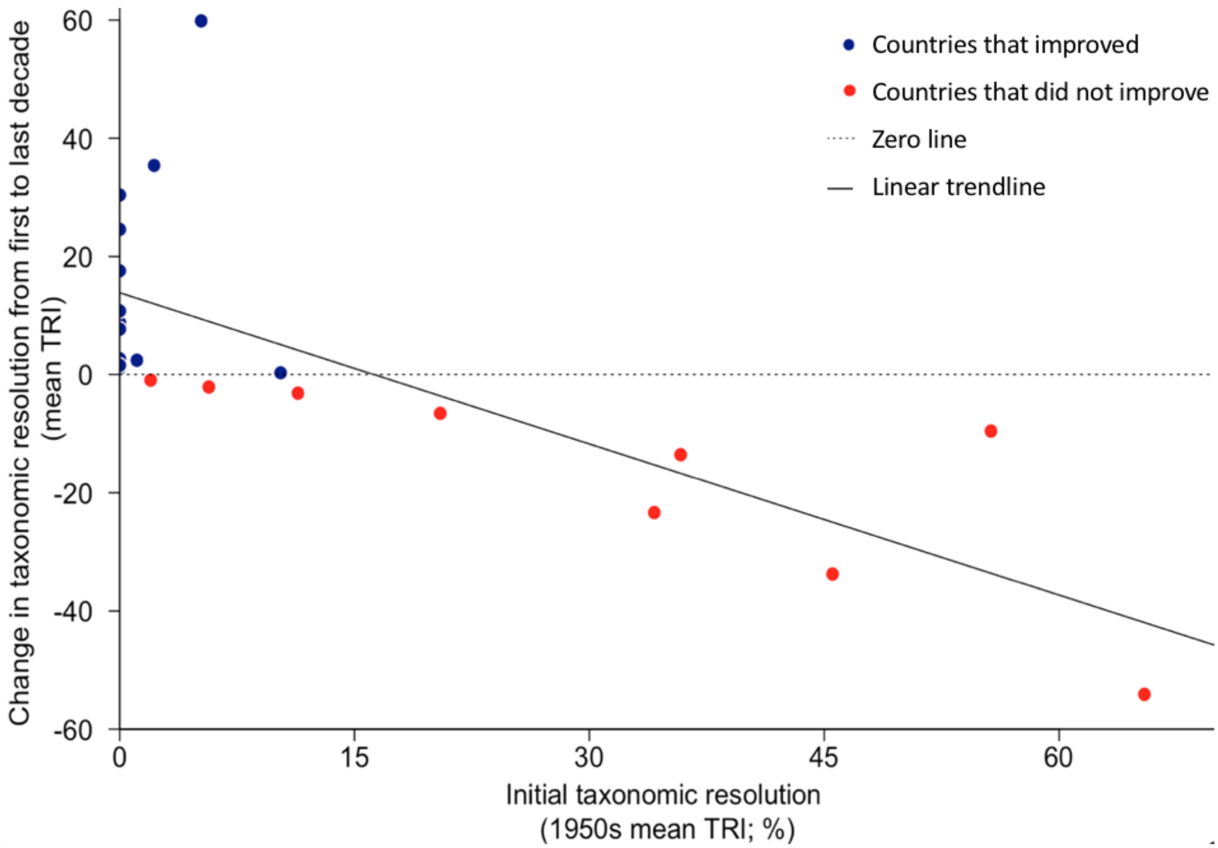

Figure 2.3. Countries that initially (1950s mean TRI) reported elasmobranch catches to a high taxonomic resolution did not improve overall. Only countries with an initial TRI of < 10% improved at all. Countries with a higher mean TRI in 2004-2014 vs. 1950-1960 are shown in blue (i.e., improved), countries with a lower score are shown in red (i.e., declined). $R^2 = 0.55$, $p < 0.001$

2.7. Tables

Table 2.1. An example of the calculation method of the Taxonomic Resolution Index using the data for Spain in the year 2000.

Taxonomic hierarchy of the Country Taxa List							Points toward score	
Subclass	**Superorder**	**Order**	**Family**	**Genus**	**Species**	**Reported?**	**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 = $\left(\frac{\sum Country\ Taxa\ List\ points}{\sum Reported\ Taxa\ points}\right)$							**37%**	

***** If catch was 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 catch was reported for a taxon but not for any more-precise taxa within that taxon, points were given for the more precise taxon.

Table 2.2. The taxonomic breakdown of reported (FAO) domestic elasmobranch catches compared to non-elasmobranch catches in the Mediterranean and Black Seas from 1950-2014.

Taxonomic rank	Number of taxa: elasmobranch (other)	Catch (millions t): elasmobranch (other)	Percentage of total catch: 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.

Table 2.3. The mean TRI (%) and change over time from the initial (1950-1960) and final (2004-2014) decades of reported elasmobranch catch by country in the Mediterranean and Black Seas, arrange from greatest to least change in mean TRI: positive values of change indicate an overall improved taxonomic resolution of catches 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 (Black Sea)	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 2.4. Overall mean TRI values and components from 1950-2014 by country in the Mediterranean and Black Seas. The mean taxonomic score of reported catch is the sum of taxonomically weighted unique elasmobranch taxa (TRI numerator). The taxonomic score of the Country Taxa List (TRI denominator) is the sum of taxonomically weighted unique elasmobranch taxa on the Regional Taxa List that are biogeographically present in each country.

Country	Mean taxonomic score of the reported catch	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 (Black Sea)	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**

Table 2.5. Timeline of existing conservation and management instruments for elasmobranchs in the Mediterranean and Black Seas.

Year	Acronym/ Title (Enacting Body)	Details	Legally binding?
1997	**Recommendation GFCM/22/1997/1** on the limitation of the use of driftnets in the Mediterranean (GFCM)	• *Driftnets >2.5 km in length banned in the GFCM area*	**Yes**
1999	**IPOA – SHARKS** International Plan of Action for the Conservation and Management of Sharks (FAO)	• *Signatories should implement regional/national shark action plans: harvest of chondrichthyans should be biologically and economically sustainable, utilizing all body parts, and well-managed to conserve biodiversity and ecosystem function.*	No
2002	**EU Council Regulation 1239/98** Driftnet Ban (Council of the European Union)	• *Driftnets banned when intended for the capture of species listed in Annex VIII and landing those species is prohibited if caught in driftnets* • *Annex VIII:* H. griseus, C. maximus, *Alopiidae spp., Carcharhinidae spp., Sphyrnidae spp., Isuridae spp., and Lamnidae spp.*	**Yes**
2003	**Mediterranean NPOA-SHARKS** Plan of Action for the Conservation and Management of Cartilaginous Fishes (Chondrichthyans) in the Mediterranean Sea (UNEP)	• *Mediterranean-specific proposal for the development of national/regional strategies.* • *Suggested priorities: legal protections for Endangered species, risk assessments for Data Deficient species, management programs for commercially important species, finning bans, discouragement of wasteful fishing practice identification of critical habitats, and development of stock-monitoring systems, capacity-building, and public education/awareness programs.*	No
2003	**EU Council Regulation 1185/2003** Removal of shark fins (Council of the European Union)	• *Removal, retention, transshipment or landing of shark fins on board vessels in prohibited and fins which have been removed on board may not be purchased* • *Exemption permits may be issued, in which case retained fin-weight must not exceed 5% of total live shark catch weight*	**Yes**

Continued: **Table 2.5.** Timeline of existing conservation and management instruments for elasmobranchs in the Mediterranean and Black Seas.

Year	Acronym/Action Title (Enacting Body)	Details	Legally binding?
2005	**Recommendation GFCM/29/2005/1** on deep-sea fishing and a restricted area <1000 m. (GFCM)	• *Demersal trawl nets must have a cod-end mesh size of > 40 mm* • *Towing dredges and trawl nets deeper than 1000 m in prohibited*	**Yes**
2009	**EU Action Plan** for the Conservation and Management of Sharks (Council of the European Union)	• *Broaden the knowledge both on chondrichthyan fisheries and on species and their ecosystem roles* • *To ensure directed chondrichthyan fisheries are sustainable and bycatch of chondrichthyans are properly regulated* • *To encourage a coherent approach between the internal and external community policy for chondrichthyans*	No
2011	**Recommendation GFCM/35/2011/1** concerning the establishment of a GFCM Logbook (GFCM)	• *Fishing vessels over 15m in length must maintain a logbook of, among other things, species-specific catches.*	**Yes**
2012	**Recommendation GFCM/36/2012/3** on fisheries management measures for conservation of sharks and rays (GFCM)	• *Chondrichthyans listed in Annex II* of the SPA/BD cannot be retained on board, transshipped, landed, transferred, stored, sold or displayed or offered for sale.* • *Tope sharks (*G. galeus*) must be released unharmed.*	**Yes**
2015	**Recommendation GFCM/39/2015/4** on management measures for piked dogfish (*S. acanthias*) in the Black Sea (GFCM)	• *Minimum size limit for retention 90cm, unless country has a discard ban in place, then all piked dogfish must be retained regardless of size but cannot be sold or consumed* • *Information on fishing, all catches, release and/or discarding events for piked dogfish are to be reported to national authorities.* • *Contracting parties will engage in capacity-building, research, and collaborations to improve knowledge on piked dogfish.* • *By 2018, the Scientific Advisory Committee shall evaluate the effectiveness of the measures adopted and define stock status and target reference points for MSY of Black Sea piked dogfish.*	**Yes**

Chapter 3: Improving the taxonomic resolution of elasmobranch catches in the Mediterranean and Black Seas

3.1 Introduction

Fisheries researchers and managers use historical catch data as a primary resource to assess stock size and recruitment to set reference limits that inform future exploitation. To assess stock status, trends in abundance are often inferred using catch per unit effort (CPUE). CPUE standardizes catch by the intensity of fishing to ensure that fluctuations in catch due to changing fishing pressure are not incorrectly attributed to fluctuations in stock biomass, or vice versa. Estimating a stock's CPUE from fisheries statistics requires that the data include a measure of the fishing effort (e.g., hauls, sets, hours fished) as well as species-specific tonnage, including zeroes when a species is not caught (Gulland, 1964). In countries such as the United States or Norway, catch data are robust for the majority of fisheries and are supplemented with fishery-independent survey data to spatially and temporally standardize sampling data (Chen, Chen, & Stergiou, 2003; Pauly & Zeller, 2016a). For many countries, however, the only available fishery statistics are those reported by national governments to, and harmonized by, the Food and Agriculture Organization of the United Nations (FAO). The FAO has collated fishery statistics in an annual 'yearbook' since 1950 (Garibaldi, 2012). These data are typically landings from large-scale industrial fisheries, while discards and catches from small-scale fisheries, comprised of subsistence, recreational, and artisanal fisheries, often go unreported.

To account for the missing catch in FAO statistics, the *Sea Around Us* research group at the University of British Columbia has comprehensively reconstructed marine fisheries catches starting with the first year of annual FAO statistics (1950) using as many sources as possible including official statistics as anchoring points (Zeller & Pauly, 2016). The *Sea Around Us* database contains annual catches by exclusive economic zone (EEZ), sector (industrial, artisanal, subsistence, or recreational), landing status (landed vs. discarded), and by gear type (e.g., otter trawl, purse seine, longline). Where possible, these statistics are taxonomically disaggregated to the lowest possible rank (i.e., ideally species) but as in FAO data, taxonomic resolution is highest for commercially important targeted species. Species that are incidentally caught and especially those that are discarded at sea are lumped into aggregate categories, with "marine fishes nei (not elsewhere included)" being one of the most ambiguous category of fishes. The act of discarding undermines sustainable fisheries management, while the ambiguity or absence of discards data undermines these efforts, as many discard species are thought to be more vulnerable to overfishing than the corresponding target species (Zhou et al., 2011).

Cartilaginous fishes, of the subclass Elasmobranchii (sharks and rays), are intrinsically vulnerable to overfishing because they are long-lived and have low reproductive capacity (Musick, 1999). A quarter of elasmobranch species worldwide are estimated to be threatened with extinction, with varying regional and taxonomic threat levels (Dulvy et al., 2014). The Mediterranean and Black Seas are a hotspot of elasmobranch threat with over half of their species at risk of extinction (Dulvy et al., 2016). Species such as the angelshark (*Squatina squatina*) and sawfishes (Pristidae spp.) are suspected to be locally extinct in some areas already (Maynou et al., 2011) while species such as porbeagle (*Lamna nasus*) and hammerhead (*Sphyrna* spp.) sharks declined by >99% over the 20th century.

The fisheries of the Mediterranean and Black Seas are generally considered ‘multi-target’ and the majority of domestic vessels are small-scale, making the management of its marine resources complex (FAO, 2016b). Fisheries management on a regional level is overseen by the General Fisheries Commission for the Mediterranean (GFCM) which, in a 2012 performance review, ranked among the worst regional fisheries management organizations for bycatch and discards governance (Gilman et al., 2012). From 1950-2014, elasmobranchs are estimated to have comprised an average of 4% year^{-1} of all reported and unreported catch in the region, and 2% year^{-1} of the landed value (Zeller & Pauly, 2016). Only 30% of this catch was reported in official statistics and an additional 30% was discarded at sea (Zeller & Pauly, 2016). For the vast majority of elasmobranch catches, whether reported or unreported, the identity of the species is unknown (see Chapter 2).

Clearly, elasmobranch populations in the Mediterranean and Black Seas would benefit from a tailored management plan to account for bycatch and discarding. However, data deficiency and ambiguity hamper the analyses needed to move forward. For example, one study from 2008 attempted to quantify changes in abundance of 20 large predatory shark species in the Mediterranean Sea, but data were only sufficient for the assessment of 5 (Ferretti et al., 2008).

This study uses a new method of catch disaggregation to improve the taxonomic resolution of existing *Sea Around Us* domestic catch statistics for Mediterranean and Black Seas elasmobranchs from 1950-2014. In the first stage of the procedure, species-specific catch characteristics (e.g., gear type and EEZ) are modeled to predict missing species catches. The second stage feeds the predicted species-specific catches into an algorithm that reassigns tonnage from higher taxa to species. The final catches are then synthesized spatially, temporally, and taxonomically to contextualize the results and identify trends in relation to stock statuses.

3.2. Methods

To characterize the predictors of species-specific elasmobranch catches in the Mediterranean and Black Seas, a linear mixed-effects model (LMM) was fit to fisheries data representing catches from 65 years, 25 EEZs (i.e., "EEZ-equivalent waters; Zeller & Pauly, 2016), 8 gear types, and 35 species. The predicted relationships between the variables were used to estimate the species catch amounts comprising aggregated categories of such as "Elasmobranchii" or "Batoidea".

3.2.1. Catch data

Annual domestic elasmobranch reconstructed catches by species (both landings and discards) from 1950-2014 were extracted from the *Sea Around Us* database (Pauly & Zeller, 2015). These data were used because in addition to FAO catches they contain small-scale and discarded catches. For two countries, Albania and Croatia, the FAO and *Sea Around Us* data differed considerably in the number of reported elasmobranch catches due to a retroactive update by the FAO. For example, for Croatia this disparity was the difference between 143 and 0 records in the FAO and *Sea Around Us* databases, respectively. Thus, FAO data were deemed more accurate and used in place of *Sea Around Us* data for the Albanian and Croatian catches, with Yugoslav data used for Croatia pre-1992.

Further, preliminary data exploration revealed that catches of spiny dogfish (*Squalus acanthias*) from the Black Sea would skew parameterization, since their peak tonnages exceed the next greatest species' yield by 25,000 tonnes. These were excluded from the model, because otherwise the subsequent estimates of species-specific catches as informed by the model, would underestimate spiny dogfish catches while overestimating catches of other species (Zuur et al., 2009). Likewise, an anomalously large catch of angelshark (*Squatina squatina*) in 1967 was removed, as it is an order of magnitude higher than other angelshark catch records and is suspected to be an unresolved data entry error originating from Turkish official statistics. The final catch dataset contained 8412 catch records of 35 species caught in 25 countries over 65 years (Table 3.1). The following sections describe in detail the explanatory variables tested in the model-fitting procedure.

Species occurrence

The historical abundance of a species in a fished area is a fundamental predictor of the likelihood of a species having been caught. Combined with fishing effort and gear efficiency (i.e., catchability), CPUE can be used as a predictor of abundance (Arreguín-Sánchez, 1996). However, in the context of characterizing predictors of mostly incidental elasmobranch catch, neither effort data nor stock-specific abundances are currently available for the Mediterranean and Black Seas. This analysis required standardized abundance estimates, comparable between species, at the minimum resolution of EEZs. In the absence of stock assessments, predicted relative abundance based on biogeographic data and species distribution models was used. The *Sea Around Us* combined range extents with modelling gradients of relative abundance by overlaying six spatial data filters at the scale of ½ degree latitude and longitude cells (Palomares et al., 2016); from first to last applied, these filters are: FAO area, latitudinal range, range-limiting polygon, depth range, habitat preferences, and equatorial submergence.

For the present study, the spatial cells of species occurrence were summed by EEZ and thus reflect the size of each EEZ (e.g., given the same species abundance per cell, Malta would have a far lower occurrence value than Spain's Mediterranean EEZ) and each species occurrence value within each EEZ is static over time.

Gear Types

The species composition of catches varies by the gear type deployed. If a species is present and within reach of a suitable fishing method, it may be captured by the fishery. For the model of species-specific catch, large-scale (i.e., industrial) fishing gears associated with each catch record were extracted from the *Sea Around Us* database (Cashion et al., 2018). The gear data were reconstructed using as many sources as possible, such as national fisheries databases, independent studies, and fishing company data. Of this dataset, the domestic fleet used 12 gear types to catch sharks in the Mediterranean and Black Seas from 1950-2014. Some large-scale gear types function similarly in terms of their reach and efficiency in catching elasmobranchs (e.g., different bottom trawl gears) and were therefore aggregated into seven main gear types for this study (Table A.1). The gear type 'small-scale' was assigned to small-scale catches, since these fisheries use numerous and varying gear types with little or no documentation associated with them (Chuenpagdee et al., 2006). The *Sea Around Us* designates small-scale fisheries using country-specific definitions.

Proportion of stocks overfished

Annual stock status data by EEZ were extracted from the *Sea Around Us* database (Kleisner et al., 2013). These data represent the fraction of each EEZ's number of stocks (of all taxa meeting the inclusion criteria described in Pauly et al., 2008) that are assessed as: (i) developing, (ii) exploited, (iii) over-exploited, (iv) collapsed, and (v) rebuilding. The majority of the taxa represented in the fisheries profiles are teleost fishes and therefore the stock statuses are likely conservative compared to those that would characterize the exploitation patterns of elasmobranchs. Most elasmobranch populations are more sensitive to fishing pressure relative to most commercial target species (Stevens et al., 2000). Thus, species abundance declines are often more extreme and accelerated, particularly for large coastal elasmobranchs that are more exposed to combined threats such as overexploitation and habitat degradation (Dulvy et al., 2014). Additionally, stock status is most reflective of biomass for areas that are heavily fished by unregulated fisheries, which is the case for much of the Mediterranean and Black Seas (see Section 2.4).

The species distribution range maps used in this analysis are static. Hence, the annual proportion of stocks that were overfished in each EEZ was included as a proxy for changes in general species abundance over the 65-year period. In this study, the proportion of stocks that are overfished was the sum of the overexploited and collapsed proportions.

Total elasmobranch catch

Preliminary analyses of the Mediterranean and Black Seas catch data suggested that the countries that catch more elasmobranchs as a whole also catch more per individual record. This assumption was supported by the significant positive relationship between countries' mean species-specific catches and mean annual total elasmobranch catch in the *Sea Around Us* dataset (p = 0.005; Figure 3.1). To ensure that species catches in the database did not bias the relationship between taxonomically aggregated catches and species-specific catches, the species catch was omitted from the total elasmobranch catch value associated with that record. For example, if the total elasmobranch catch of Algeria in 1995 was 1000 t, a catch record of 50 t of starry ray (*Raja asterias*) would have 950 t as its associated total elasmobranch catch value.

3.2.2 Modelling the predictors of species-specific catch

An linear mixed-effects model (LMM) was built using the lme4 package in the R statistical software language (Bates et al., 2015) to model species catches. The response variable was the species-specific catch within each year-EEZ-gear combination (hereafter referred to as a 'group'; see Figure 3.2). This response was assumed to follow a lognormal distribution (Figure 3.3; Equation 3.1). The left-handed skew of the data distribution was subsequently minimized by the integration of a random nested classification structure.

An LMM was appropriate for these data because they were log-normal with heterogeneous variances across EEZs, gear types, and species, requiring that these variables be incorporated as random effects rather than fixed (Bolker et al., 2009). Additionally, since this model was subsequently used to interpolate the 'masked' species catches (see Section 3.2.3), it was not possible to use a single-level model structure such as a linear model (Zuur et al., 2009). An LMM structure also enhances the precision of parameterization for clustered data containing unequal observations between clusters, as is the case in this study. Random factors are typically used for factors within which the levels represent only a sample of the possible levels in the system. A classic example of a random factor in a mixed model is the patient or group of patients in medical research (Zuur et al., 2009). By incorporating the patient as a random factor, the treatment effect across patients to be extrapolated to the population level (if reasonable, given the study). In other words, an LMM "borrows strength" from other factor-level data, such as those EEZs without missing values, in order to estimate values with no reference data (Kreft, Kreft, & de Leeuw, 1998).

The assumption that random factors represent a sample of the study population is upheld in this study: the EEZs, species, and gear types were not consistently represented across years. In fact, some EEZs were not represented in the input data at all since they did not have any species-rank catches. An alternative option for clustered data such as these is to build a separate model for each cluster. For example, in this study, separate models could be fitted for each species, EEZ, or a combination of the two. A structure like that would limit the predictive power within existing year-EEZ-gear combinations and some EEZs would need to be omitted from the analysis due to insufficient observations. Thus, the disaggregation would leave many EEZs with taxonomically ambiguous data and many species with underestimated catches which is exactly the problem this disaggregation process is attempting to correct.

3.3.1. Model Selection

The final model of the predictors of species-rank elasmobranch catch in the Mediterranean and Black Seas was determined by first comparing AIC values, then the spread of standardized residuals for each variable (Figure 3.4), and finally the best model's predictive power (Figure 3.5.). The model with the best fit incorporated EEZs, species, and gear types as nested random effects with year as an additional distinct random effect, together accounting for within-group effects on catch amounts (Equation 3.1). The equation of the final model with nested random effects was as follows:

$$\log(\mathrm{SpCATCH}_{\mathrm{sgey}}) = \alpha + \beta_{\mathrm{ELASMO}} \times \log(\mathrm{ELASMO}) + \beta_{\mathrm{OF}} \times \mathrm{OF}_{\mathrm{sgey}} + \alpha_{\mathrm{y}} + \alpha_{\mathrm{e}} + \alpha_{\mathrm{g|e}} + \alpha_{\mathrm{s|g|e}} + \varepsilon_{\mathrm{sgey}}$$

(Equation 3.1)

Where *s* is the species index (1 to 35), *g* is the gear index (1 to 8), *e* is the EEZ index (1 to 25), *y* is the year index (1 to 65), and variables (SpCATCH, ELASMO, and OF) are summarized in Table 3.1. All predictors except OCCUR had a significant effect on the response and thus OCCUR was omitted from the final model. The weak relationship between OCCUR and SpCATCH should not be interpreted as a weak effect *per se* of species occurrence on species catch, but rather is likely attributable to the characteristics of the OCCUR data. This variable does not vary temporally and for many species, occurrence within the Mediterranean and Black Seas likely varies negligibly because of the low spatial granularity of the EEZs. The estimated parameter coefficients indicated that ELASMO was negatively related to SpCATCH, suggesting that EEZs with higher total catch of elasmobranchs (at all taxonomic levels in the database) also have a more species-specific catch. The opposite relationship was found for OF; the greater the proportion of overfished stocks in a country, the less species-rank elasmobranch catch in the data.

The predictive power of the model was assessed by fitting training data (i.e., 75% of the data set) and using the estimated relationships to predict the species-rank catches in the remaining 'test' quarter of data (Figure 3.5). Predictions of the 2000 observations in the test data were clustered uniformly around the 1:1 line. The predicted values that were less precise, and therefore stray from the plotted 1:1 line, represented a random sample of the test data; no single EEZ, gear type, or species was consistently mispredicted.

3.2.3 Taxonomic disaggregation

The LMM parameter coefficients were used to predict the species composition of taxonomically aggregated elasmobranch catches. A disaggregation algorithm was built in R that filtered the species catches predicted by the model to include only those species that may have been caught by the gear types active in a given EEZ in a given year. In alignment with the logic used for the TRI methods of this study (see Section 2.2), if a species' occurrence overlapped with at least 10% of an EEZ, it was considered available to the domestic fisheries operating there; note that only domestic catches are considered in this study. The next filter was gear type, or the means by which a species is caught. A species was considered catchable wherever there was a record of one of its higher-rank taxa caught by a gear type known to catch that species. For example, blackmouth catshark (*Galeus melastomus*), a deep-water catshark commonly caught in the western and central Mediterranean Sea, was only disaggregated from catches attributed to its family, "Scyliorhinidae", and subclass, "Elasmobranchii", that were caught by either bottom trawls or small-scale gear types in one of the 14 EEZs within which it occurs. Through filtering the predictions, no tonnage was falsely attributed to any species in terms of gear types and EEZs that could possibly catch or include it.

The disaggregation proceeded using a stepwise algorithm that iteratively split higher taxa within groups from higher to lower resolution, where applicable; genera were disaggregated first, then families, orders, superorders, and subclass (i.e., Elasmobranchii). The proportions by which higher taxa were split were consistent with the species proportions predicted for the group by the model. This taxonomic disaggregation did not introduce novel species or additional tonnage to the *Sea Around Us* Mediterranean and Black Seas catch database. Rather, predicted catch amounts were appended to the database only after being subtracted from existing higher-rank catch records. Therefore, the species-rank catches could be increased, but constrained by the annual sum of all elasmobranch catches in an EEZ. The result was a catch dataset with the same total catch amount but many more catch records than in the original *Sea Around Us* database.

3.3. Results

3.3.1. Taxonomic proportions of catches

The *Sea Around Us* catch database contains 5.5 million t of elasmobranch catch from the Mediterranean and Black Seas. At the time of writing, nearly 20% (1 million t) of this was species-specific catch (35 species), while the remaining 80% (4.5 million t) was identified to the genus, family, order, superorder, subclass, and class ranks (Figure 3.6A). This represents a higher taxonomic resolution than that of the corresponding FAO catch statistics, of which only 3% (26,115 t) were assigned to species (see Section 2.3.). However, two-thirds of the *Sea Around Us* species-specific catch was attributed to spiny dogfish in the Black Sea, which was excluded from the taxonomic disaggregation in this study. Without Black Sea spiny dogfish, less than 8% (377,862 t) of the catch was identified to species. Excluding Black Sea spiny dogfish catch, the disaggregation in this study increased the species-specific proportion by nearly 2.5 times from 8% to 18% (377,862 to 872,938 t). Thus, the catch that was assigned to higher taxonomic ranks was reduced from 4.5 to 4.0 million t; from 92% to 82% of the catch without Black Sea spiny dogfish, and from 81% to 72% including it. This translates to 0.5 million t of elasmobranch catch newly identified to the species level. The amount of catch disaggregated varied spatially, temporally, and taxonomically, which will now each be addressed in turn.

Spatially, most of the catch was overwhelmingly disaggregated from the EEZs of Turkey, followed by Greece (without Crete) and Italy (mainland) (see Appendix: Table A.2) Turkey's three EEZs (Black Sea, Marmara Sea, and Mediterranean Sea) collectively accounted for 63% (310,095 t) of the total disaggregated catch in the Mediterranean and Black Seas, with the majority from the Black Sea (see Appendix: Table A.2). Remarkably, 85% of Turkey's disaggregated catch originated from the portion of its catch labeled as "Batoidea" (superorder). This portion was allocated to seven species, with the majority assigned to the thornback skate (*Raja clavata*). Six EEZs (South Cyprus, Egypt, Israel, Lebanon, Montenegro, and Tunisia) did not have any species-specific catch previously, but now have between 6-12% of their total elasmobranch catch identified to the species. In contrast, all the catch from Slovenia (286 t) and Bulgaria (2377 t) was identified by species initially and therefore no additional catch was disaggregated. Following the disaggregation, the species-specific proportions for 4 of 34 EEZs in the Mediterranean and Black Seas, including Slovenia and Bulgaria, were 100%, and 12 EEZs exceeded 50%.

The amount of catch that was disaggregated decreased over time (Figure 3.7), corresponding to increases in the original species-level proportion of the *Sea Around Us* data, particularly starting in the 1990s (Figure 3.6). As mentioned previously, Turkey's "Batoidea" catches dominated the disaggregated catch amounts and consequently drove the overall temporal patterns, including a large dip in disaggregated catch in the mid-1970s. Considering sharks and batoids separately revealed that the new species-level shark catches remained fairly constant over the time period. The newly disaggregated shark catch fluctuated between 1500-2600 t for the whole times series, whereas the newly disaggregated batoid catch fluctuated between 1000-11,500 t. At the level of species, temporal trends of the final shark catches were generally preserved from the trends observed for the original *Sea Around Us* catch amounts (see Appendix: Figure A.1), whereas the batoid catch patterns appear quite different for many species (see Appendix: Figure A.2).

The disaggregation increased the catch amounts for 23 of the 35 elasmobranch species with *Sea Around Us* catches in the Mediterranean and Black Seas (Table 3.2). The thornback ray comprised nearly two-thirds (295,584 t) of the catch disaggregated from higher taxa, establishing this species as the second most heavily exploited elasmobranch in the Mediterranean and Black Seas, behind spiny dogfish. The next greatest catch amounts were allocated to starry ray (27,784 t), smooth-hound shark (*Mustelus mustelus*; 25,816 t), and spiny dogfish (25,243 t). In terms of the proportion of each species' initial catch, the white skate (*Rostroraja alba*) and common eagle ray (*Myliobatis aquila*) gained the most catch, increasing by three orders of magnitude each (Table A.2).

3.3.2. Elasmobranch catch composition in the Mediterranean and Black Seas

The final species-specific catches show that, by far, spiny dogfish has indeed been the most exploited elasmobranch species in the Mediterranean and Black Seas (Table 3.2). In the batoid species-specific catch, the thornback ray dominated (82%). With these two species excluded from the time series, patterns of other commonly caught species arose (Figure 3.8). Excluding spiny dogfish, seven species collectively comprised at least 75% of the species-specific shark catch over the 65-year period, in fairly equivalent proportions (Figure 3.8A): porbeagle (*Lamna nasus*; 14%), smooth-hound (13%), blackmouth catshark (12%), angelshark (*Squatina squatina*; 11%), velvet belly lanternshark (*Etmopterus spinax*; 11%), small-spotted catshark (*Scyliorhinus canicula*; 10%), and blue shark (*Prionace glauca*; 10%). Notably, the greatest change in proportion among these species was for the smooth-hound catch which represented only 7% of the shark catch, excluding spiny dogfish, prior to the disaggregation.

The batoid species-specific catches exhibited more disparate species proportions and more volatile temporal trend (Figure 3.8B). Excluding the thornback ray, starry ray dominated batoid catches (36%), followed by the common stingray (*Dasyatis pastinaca*; 17%), common eagle ray (17%), and longnosed skate (*Dipturus oxyrinchus*; 10%). These results also suggest that the giant devil ray (*Mobula mobular*), which originally comprised 43% excluding the thornback ray, may in fact represent a much smaller proportion of the batoid catch, only 6% (Table 3.2).

3.4. Discussion

According to the *Sea Around Us* database of reconstructed catches, the total domestic catch of elasmobranchs in the Mediterranean and Black Seas from 1950-2014 was over five times greater than what was reported by the FAO (5.5 million t and 1 million t, respectively). Before the disaggregation, about 80% (4.5 million t) of the *Sea Around Us* domestic elasmobranch catch in the Mediterranean and Black Seas was catalogued by taxonomic ranks higher than species. The present study newly identified half a million t of shark and ray catch for 23 species distributed across 31 EEZs (27 countries) over 65 years (1950-2014). As a hotspot of elasmobranch threat (Dulvy et al., 2014) and ecosystem deterioration (Piroddi et al., 2015), the Mediterranean and Black Seas in particular would benefit from not only future improvements to fisheries data collection, but also a clarification of historical elasmobranch catch statistics. Stock assessments are only as good as the data they use, and such low taxonomic resolution indicates that more data exist but are hidden within aggregated categories. Stock assessments of this threatened subclass have been hampered by a lack of species-specific data. By increasing the species-specific proportion of catches, it is possible that some elasmobranchs could become eligible for regional stock assessments, giving way to informed conservation policy.

3.4.1 Methods for classifying catch composition

In the literature, there are few retroactive taxonomic disaggregations that use a deductive approach, as this study has done. Those that do, including the *Sea Around Us* catch reconstructions (Doherty et al., 2015; Ulman et al., 2013), use pre-existing species proportions distilled from fisheries statistics or independent surveys to reassign aggregated catches by species (Davies et al., 2009). This approach is challenging for data-limited species such as elasmobranchs: inferring regional catch proportions from the few existing small surveys, or across different taxa, can lead to inaccurate catch estimates (Froese et al., 2013). A more common approach to identifying species composition, albeit not usually in a historical context, is to sample and trace genetic information from marketed species (Ogden, 2008). This technique is particularly useful for illegally traded species, a group within which elasmobranchs are a common example, including threatened terrestrial species such as elephants and tigers (Baker, 2008). Genetic sampling has been used for elasmobranchs to identify the species and geographic origins of the shark fins in the Hong Kong shark fin market (Clarke et al., 2006; Fields et al., 2017).

Between 2003-2016, genetic techniques using mitochondrial DNA revealed that many elasmobranch species that are unrepresented in official catch statistics from Maltese fisheries are indeed caught and landed by Maltese vessels (Vella, Vella, & Schembri, 2017). For example, the genetic survey confirms the result of the present disaggregation that small amounts of common thresher (*Alopias vulpinus*) were caught by Maltese small-scale and industrial longline fisheries throughout the time series under the label "elasmobranch".

3.4.2 What can disaggregated catches reveal about stock status?

To date, few stock assessments have been conducted for Mediterranean and Black Seas elasmobranchs because of their relatively low economic importance and lack of data (Caddy, 2009; Ferretti et al., 2008). Multilateral organizations acting in the region, such as the GFCM and International Commission for the Conservation of Atlantic Tunas (ICCAT), have begun allocating more attention to these species, particularly threatened large-bodied sharks. ICCAT has so far completed three stock assessments and 16 ecological risk assessments for shark species within its purview (i.e., "tuna-like" fishes), with none of the elasmobranch stocks in the Mediterranean considered (ICCAT, 2010, 2012, 2015). The species with ICCAT stock assessments (i.e., porbeagle, blue shark, and shortfin mako (*Isurus oxyrinchus*) are all suspected to have distinct Mediterranean and north Atlantic subpopulations (ICES, 2008; Kohler & Turner, 2008; Walls & Soldo, 2016). Nevertheless, the assessment results are often used to infer the condition of Mediterranean stocks. In absence of stock assessments, limited population exchange, and estimated declines exceeding 80% in three generation times (Ferretti et al., 2008), all three species are listed as Critically Endangered in the Mediterranean by the IUCN (Dulvy et al., 2016). The disaggregated catches presented here provide evidence to support that these species' Mediterranean stocks have been declining since the late 1980s, though the trends are more nuanced than originally thought, at least for domestic catches. The following paragraphs describe species-specific trends in detail.

Porbeagle catch has dropped steadily, with an average catch exceeding 1000 t $year^{-1}$at the peak and dropping to about 200 t $year^{-1}$ in the final decade (2004-2014) (see Appendix: Figure A.1). This pattern was similar before and after the taxonomic disaggregation, possibly suggesting that there was little porbeagle catch within aggregate categories. Catches were predominantly from Italian waters, including a significant proportion from Sicily.

Blue shark catch had a more volatile trend, initially rising steadily from 500 t year^{-1} in the 1950s to over 700 t in 1985 before a precipitous decline, 1992 spike, and eventually building to nearly 700 t again in 2014 (see Appendix: Figure A.1). The majority (70%) of this catch in attributed to Italy and in particular its small-scale fisheries, which account for over 65% of the country's fleet size (AdriaMed, 2005). A possible explanation for the recent catch increases may be the shift in fleet composition attributed to a coastal trawling ban implemented in Italy in 2010 (Pranovi et al., 2015). This European Commission regulation (Council Regulation 1967/2006) prohibits any towed gear from operating within 3 nautical miles or in waters shallower than 50 m. Pranovi *et al.* (2015) reported a trend toward fishers increasingly utilizing small-scale licenses, which are exempt from the ban, in order to continue fishing in the more productive shelf areas. A relevant example of such a fishery is the drifting longline fishery in the southern Adriatic that targets swordfish (*Xiphias gladius*) and albacore (*Thunnus alalunga*), but which catches 10-20% blue shark (AdriaMed, 2005) and is nevertheless considered small-scale.

Shortfin mako catches appears to tell a similar story of diminished stocks with continued exploitation except that the magnitude and timing differ from the blue shark pattern. Prior to the late 1960s, shortfin mako catch fluctuated around 80 t year^{-1} before reaching at 100 t in 1967 and rapidly declining to 50 t in 1976 (see Appendix: Figure A.1). This is consistent with reports claiming this shark was formerly common in the Mediterranean in the late 19th century (Walls & Soldo, 2016) and reported catch declines in the Ligurian Sea, off the northeast coast of Italy, into the 1970s (Boero & Carli, 1979). Since the late 1980s, however, catches have been fairly stable around 100 t year^{-1}, with two notable peaks of 120 t in 2010 and 2013. Most of the catch is attributed to Turkey's waters in the Sea of Marmara, which was also an area with high blue shark and porbeagle catches. A 2017 review of scientific and grey literature found that the highest abundance of large sharks in Turkey may indeed be in the Sea of Marmara, although shortfin mako was most frequently caught in the Levantine Sea, the eastern-most portion of the Mediterranean (Kabasakal, Karman, & Sakinan, 2017).

Generally speaking, the dominant influence of Turkey's catches is unsurprising, as it has three large EEZs and the largest fishing fleet in the Mediterranean and Black Seas (FAO, 2016b). The thornback ray accounted for most of the disaggregated Turkish catch and is known to be a common bycatch species throughout the Black Sea in demersal fisheries such as those targeting turbot (*Scophthalmus maeoticus*) (FAO, 2016b). Discard rates for the thornback ray often exceed 80% (Yıldız & Karakulak, 2017). A recent Black Sea stock assessment using landings data from the EU Commission and national datasets found that its annual fishing mortality (F) may be 64% higher than that at maximum sustainable yield (F_{MSY}) (STECF, 2017). The assessment did not consider any discards or small-scale landings. The present study, which includes these catch components as well as disaggregated catch amounts, suggests that the thornback ray catch was in fact higher for every year of the time series. Nonetheless, the decline and magnitude of the two trends are very similar. Both show catch declines of ~98% from their mid-1980s peak to 2014. The thornback ray was recently assessed as Near Threatened in the Mediterranean by the IUCN Red List (Ellis, Dulvy, & Serena, 2016). This was based on the consideration that while intense fishing pressure may have historically reduced the population by 30% in three generations, subarea surveys suggest potentially stable population sizes (Maravelias et al., 2012). The present research indicates that despite its resilience, this ray in the Black Sea may now show signs of depletion from overfishing.

In contrast, some elasmobranch catches show stable or increasing trends in the Mediterranean and Black Seas (see Appendix: Figures A.1 and A.2). Of particular concern are increasing catches of deep-water species such as the longnosed skate and velvet belly lanternshark. For elasmobranchs, depth has been shown to correlate with lower productivity, later age at maturity, and higher longevity (Rigby & Simpfendorfer, 2015), suggesting that a deep-water species may be slow to rebound from a major population decline. Trawling below 1000 m is banned in the Mediterranean and Black Seas (i.e., Recommendation GFCM/29/2005/1) which could provide some refuge from fishing, although the implementation and effectiveness of the ban has been called into question (Cavanagh & Gibson, 2007; Ragonese et al., 2013).

3.4.3 Limitations

This study used a model to parameterize the relationships between the different fishery characteristics of catch records. The accuracy of the model in characterizing the data would improve if an annual abundance index was incorporated, rather than the temporally constant species occurrence variable (OCCUR) that was originally fit here (but omitted due to insignificance, see Section 3.2.). A possible option could be to adjust the *Sea Around Us* species occurrences by year, perhaps by overlaying spatially distributed oceanographic variables such as sea surface temperature and primary productivity. Instead, the model in this study used the percentage of overfished stocks as a proxy for changes in species abundance within each EEZ over time.

The disaggregated catches estimated here were spatially restricted to only those *Sea Around Us* species occurrences exceeding 10% in any given EEZ (see Section 3.2.) This was applied in a reasonable attempt to be conservative when presuming species presence, and thus species catch, given the appropriate gear type and higher taxa from which to disaggregate. Unfortunately, for species with high estimated population declines, 99% for example (Ferretti et al., 2008), species occurrences may still have been overestimated, since occurrences remained constant over time.

The catches presented here have the finest resolution of elasmobranch fisheries catch data so far for the Mediterranean and Blacks Seas. However, these catches should not be considered a complete report of elasmobranch exploitation in the Mediterranean and Black Seas, due to limited species-specific model input data and constraints within the disaggregation algorithm. Only species that were already present in the *Sea Around Us* database and whose distribution ranges overlapped with at least 10% of an EEZ were considered for the disaggregation.

Certainly, more than 35 elasmobranch species are caught, especially incidentally, in the Mediterranean and Black Seas. Species unrepresented by this study may be rare or misidentified and thus are not sufficiently documented for inclusion in *Sea Around Us* reconstructed catches. An example of an increasingly rare species is the smooth hammerhead shark (*Sphyrna zygaena*) which is occasionally bycaught in swordfish fisheries (Megalofonou et al., 2005), but did not have sufficient occurrence data for inclusion in any EEZ disaggregation for this analysis. The same was true for *Chimaera monstrosa*, the only known species of chimaera in the Mediterranean and Black Seas (Dulvy et al., 2016). Additionally, the category "marine fishes NEI" comprises the greatest proportion of catch in the region and undoubtedly contains elasmobranchs. However, the disaggregation procedure used in this study constrains the sum of species-specific catches within the total elasmobranch catch of each group, and since "marine fishes NEI" it is not exclusively comprised of elasmobranch species, it was excluded from this study. If the proportion of "marine fishes NEI" containing elasmobranchs could be estimated by future studies, this taxonomic disaggregation method could be applied to identify an even greater amount of species-specific elasmobranch catch for the Mediterranean and Black Seas.

3.5. Conclusion

A concerning majority of the elasmobranch catch data in the Mediterranean and Black Seas is grouped into taxonomic ranks more ambiguous than species. This limits the study of elasmobranch fisheries and populations, of which many are depleted or on the threshold of depletion. The research presented here has enhanced the specificity and thus the usefulness of catch statistics from 1950-2014, including discards and small-scale catches. Overall, declining trends for the elasmobranchs presented here are comparable to published accounts although it appears that some large-bodied species may have been exploited more intensely and for longer than smaller-scale studies have captured. However, without long-term fishing effort data, it is unwise to conclude that these higher catches are symptomatic of stocks with a larger standing biomass or higher productivity. It is clear, however, that fishing effort has increased over the time period, and it is therefore probable that CPUE has declined. The precautionary approach to elasmobranch fisheries management and conservation is thus recommended, with a particular emphasis on implementation and enforcement of existing legislation.

3.6. Figures

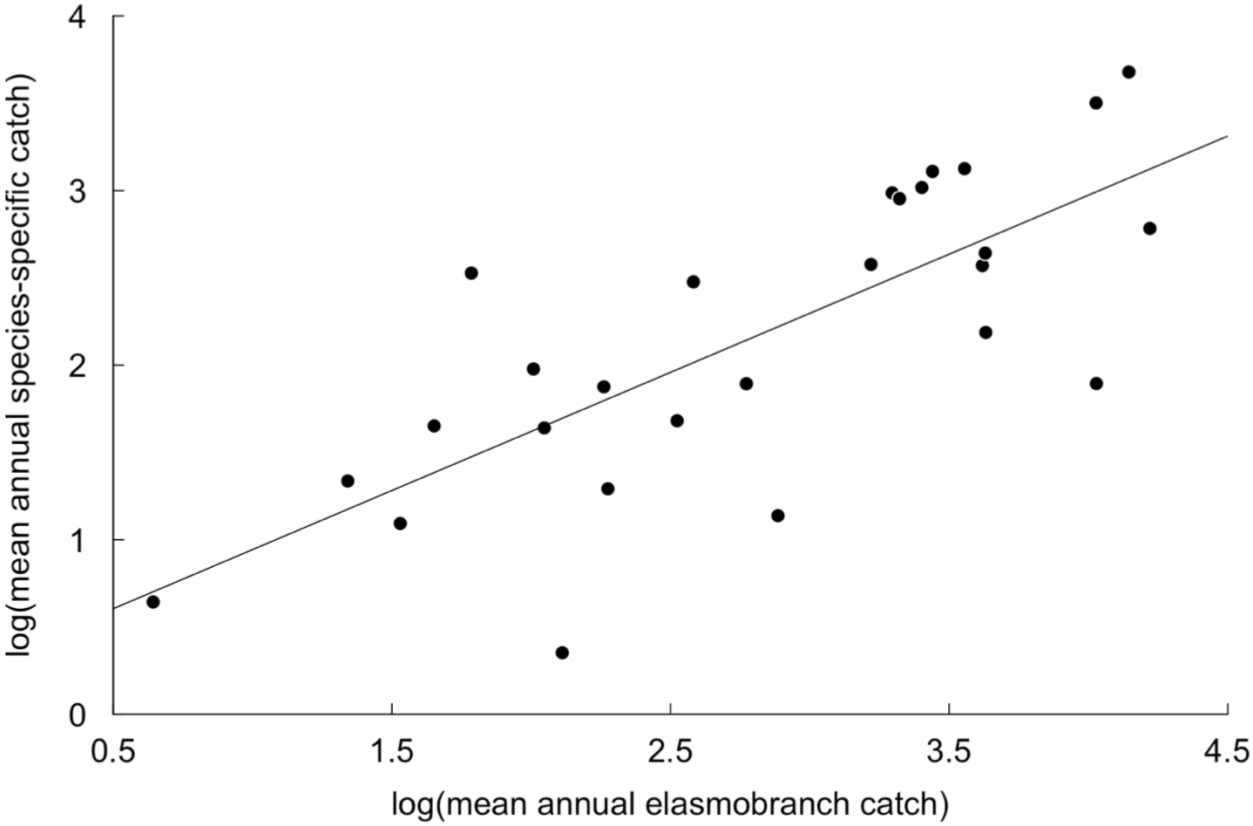

Figure 3.1. Positive relationship between the mean species-specific catch amount per record within each EEZ and the total amount of elasmobranchs caught in that EEZ from 1950-2014 in the Mediterranean and Black Seas. R^2 = 0.57, p = 0.005.

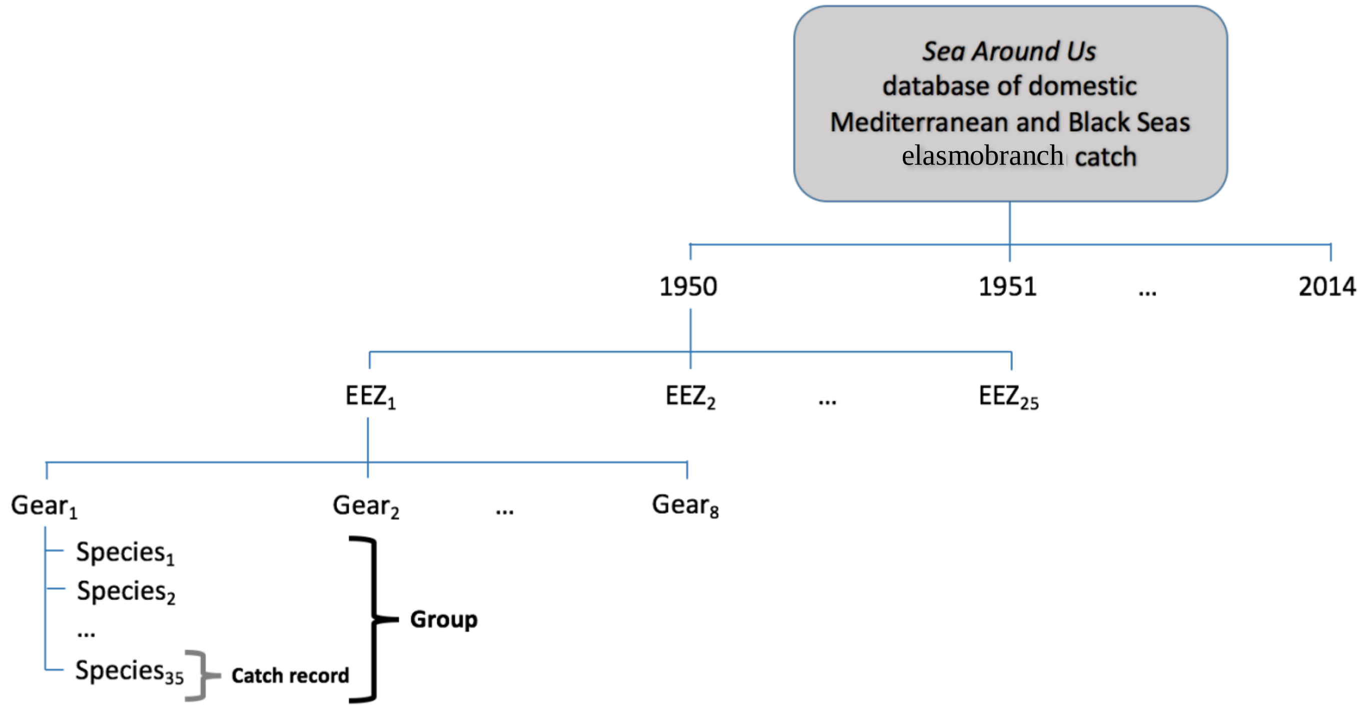

Figure 3.2. Database structure of the *Sea Around Us* catches used to model the predictors of elasmobranch species-specific catch in the Mediterranean and Black Seas. A 'group' contains data clustered by year (n = 65), EEZ (n = 25), and gear type (n = 8). A 'catch record' is the catch of a single species within a group. Groups varied in their number of catch records and some groups did not contain any catches, especially in the beginning of the time series.

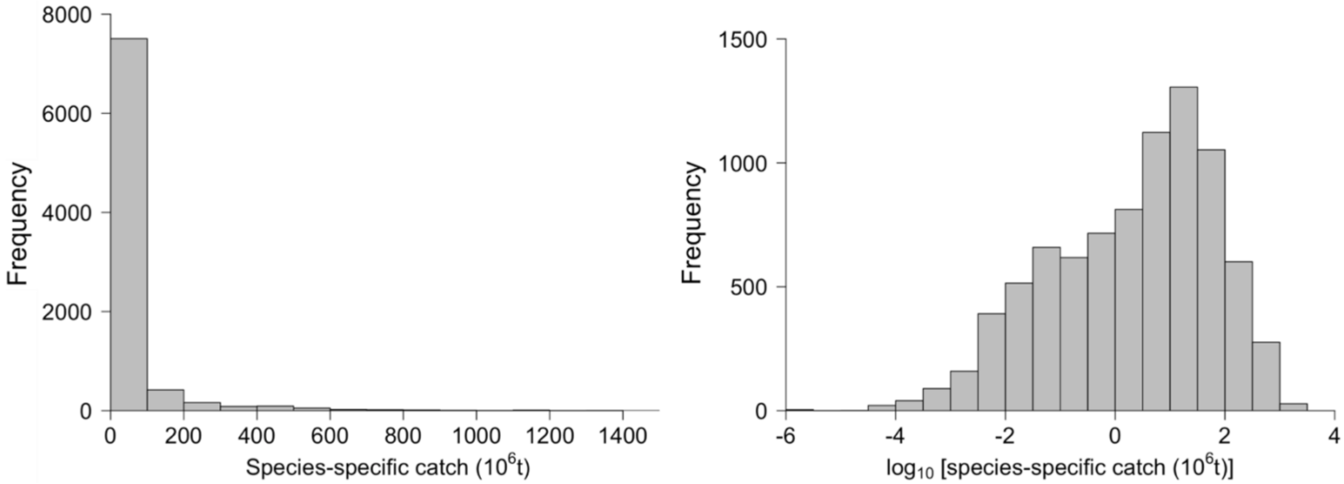

Figure 3.3. Distribution of the raw and log-transformed species-specific elasmobranch catch records in the Mediterranean and Black Seas. The left-handed skew of the log-normal distribution was minimized by the random effects structure in the final model.

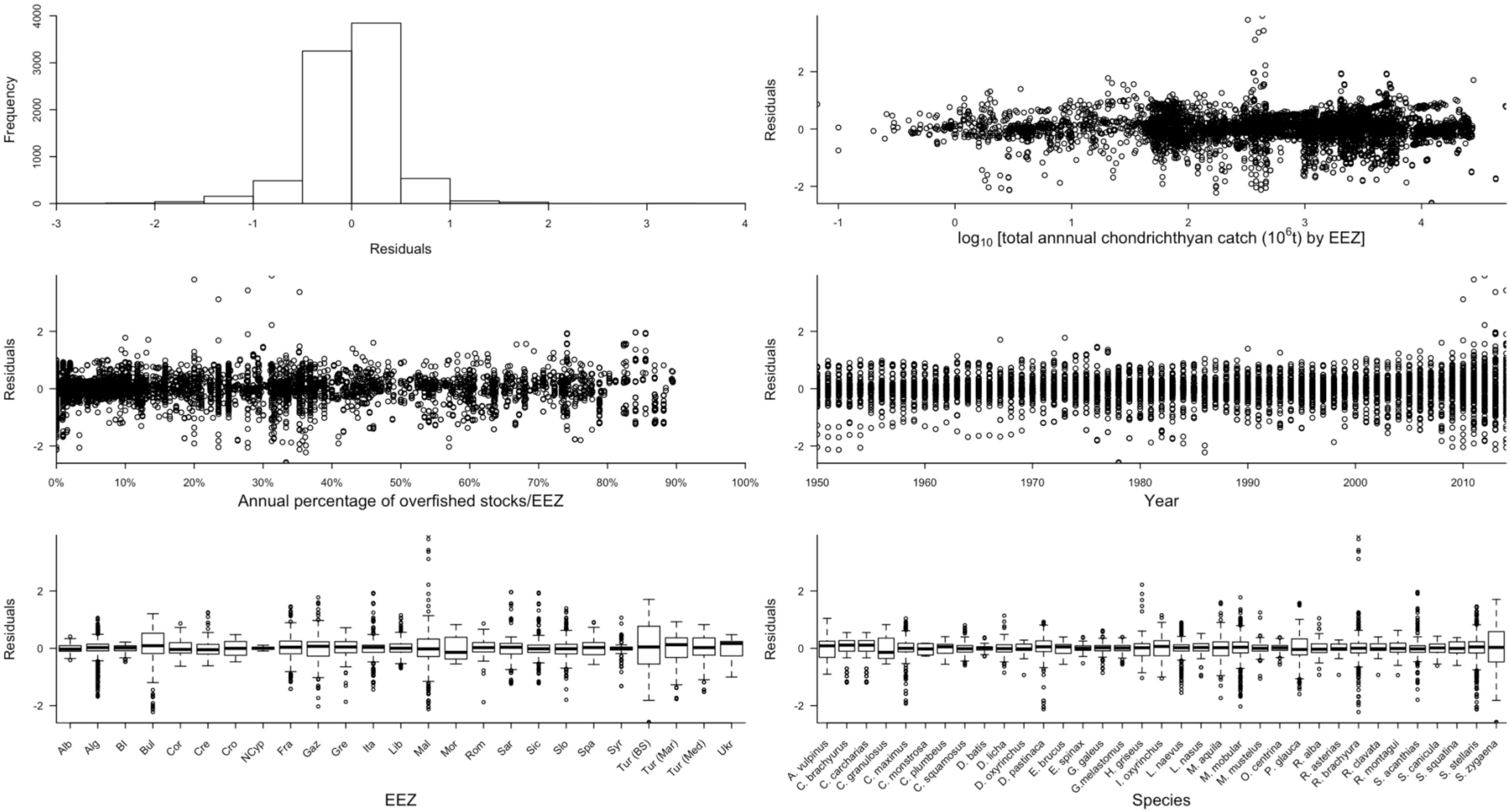

Figure 3.4. Residual plots by variable from the fit of the final linear mixed-effects model of domestic species-specific elasmobranch catch in the Mediterranean and Black Seas (1950-2014). Abbreviated EEZ names are as follows: Alb, Albania; Alg, Algeria; BI, Balearic Islands (Spain); Bul, Bulgaria; Cor, Corsica (France); Cre, Crete (Greece); Cro, Croatia; NCyp, North Cyprus; Fra, France (Mediterranean); Gaz, Gaza Strip; Gre, Greece (without Crete); Ita, Italy (mainland); Lib, Libya; Mal, Malta; Mor, Morocco (Mediterranean); Rom, Romania; Sar, Sardinia (Italy); Sic, Sicily (Italy); Slo, Slovenia; Spa, Spain (mainland, Mediterranean, and Gulf of Cadiz); Syr, Syria; Tur (BS), Turkey (Black Sea); Tur (Mar), Turkey (Marmara Sea); Tur (Med), Turkey (Mediterranean Sea); Ukr, Ukraine.

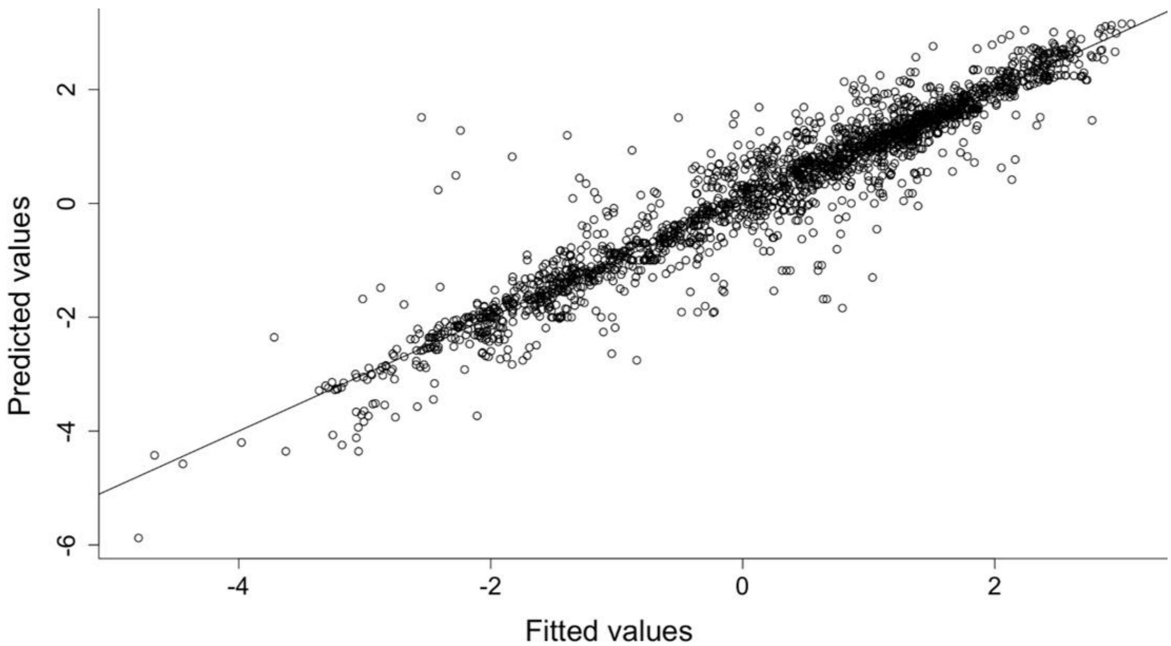

Figure 3.5. The final linear mixed-effects model predicted the test dataset (25% of total species-specific catch dataset) well. $R^2 = 0.9$, $p < 0.001$

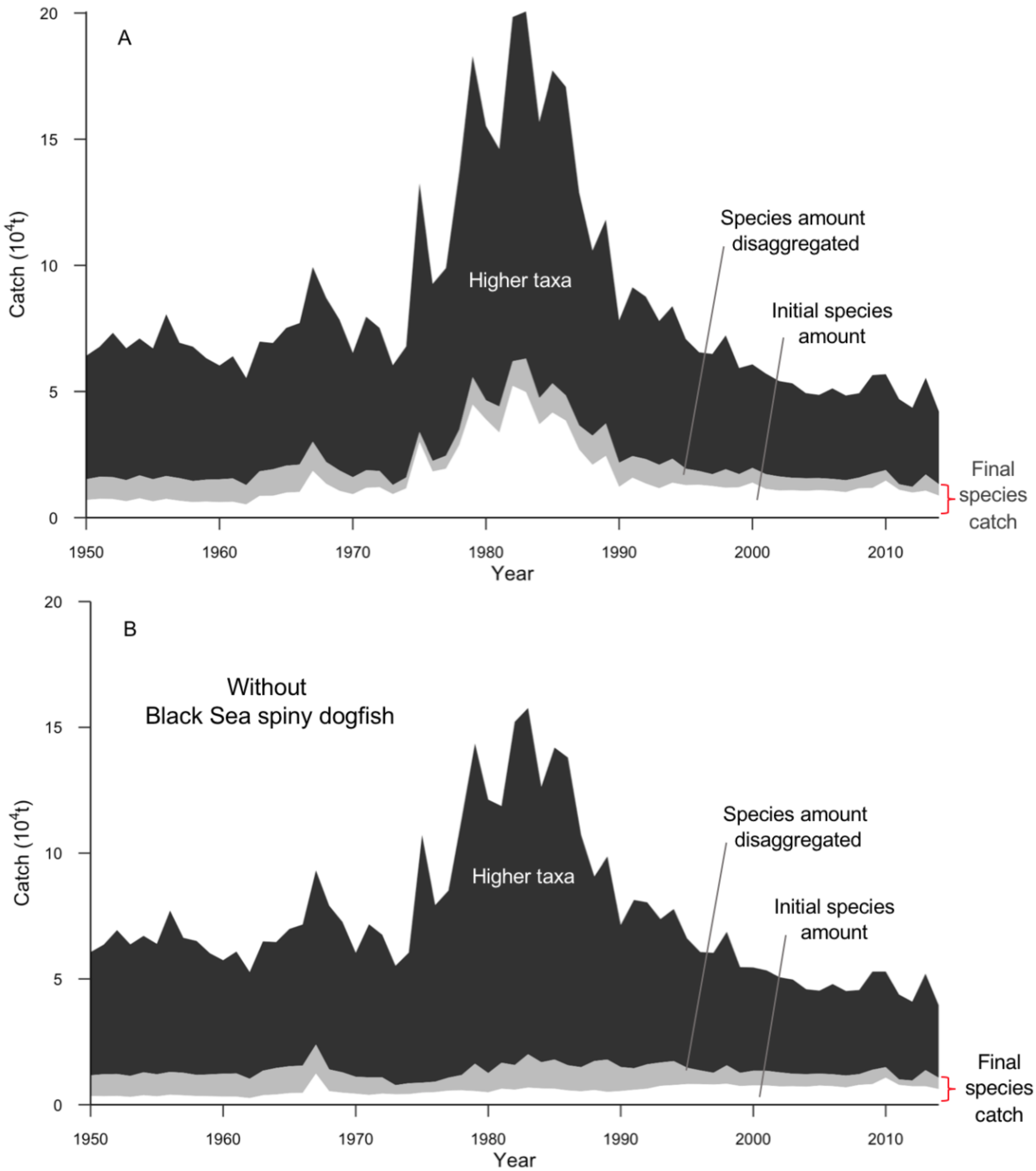

Figure 3.6. Taxonomic resolution of the Mediterranean and Black Sea domestic elasmobranch catches (10^4 t) in the *Sea Around Us* database from 1950-2014 with the initial species-specific portion, the higher taxa (genera to class, inclusive), and the new species-specific catch disaggregated from the higher taxa. *A*: all catch (5.5 x 10^6 t total); *B:* catch without spiny dogfish (*S. acanthias*) from the Black Sea (4.9 x 10^6 t total catch).

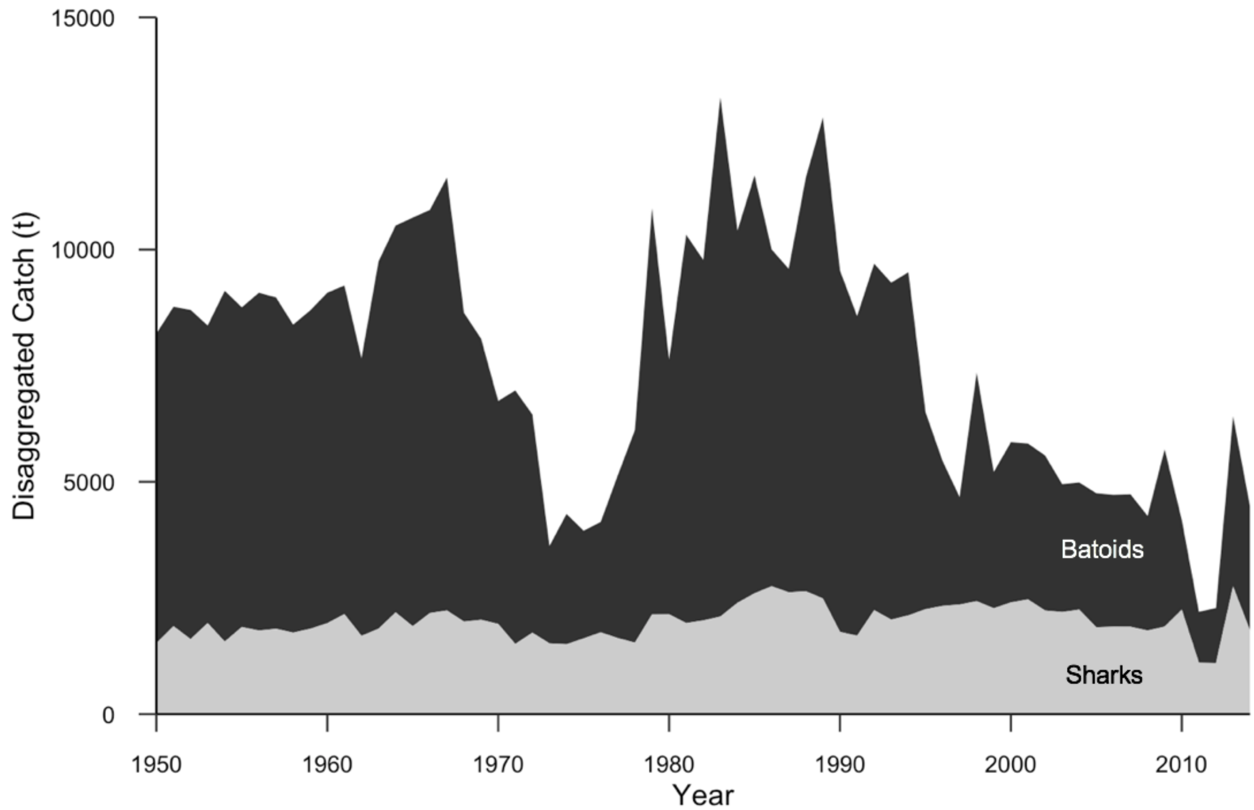

Figure 3.7. The amount of species-specific shark and batoid domestic catch (1.3×10^5 and 3.7×10^5 t, respectively) disaggregated from higher elasmobranch taxa in the *Sea Around Us* Mediterranean and Black Seas data, 1950-2014.

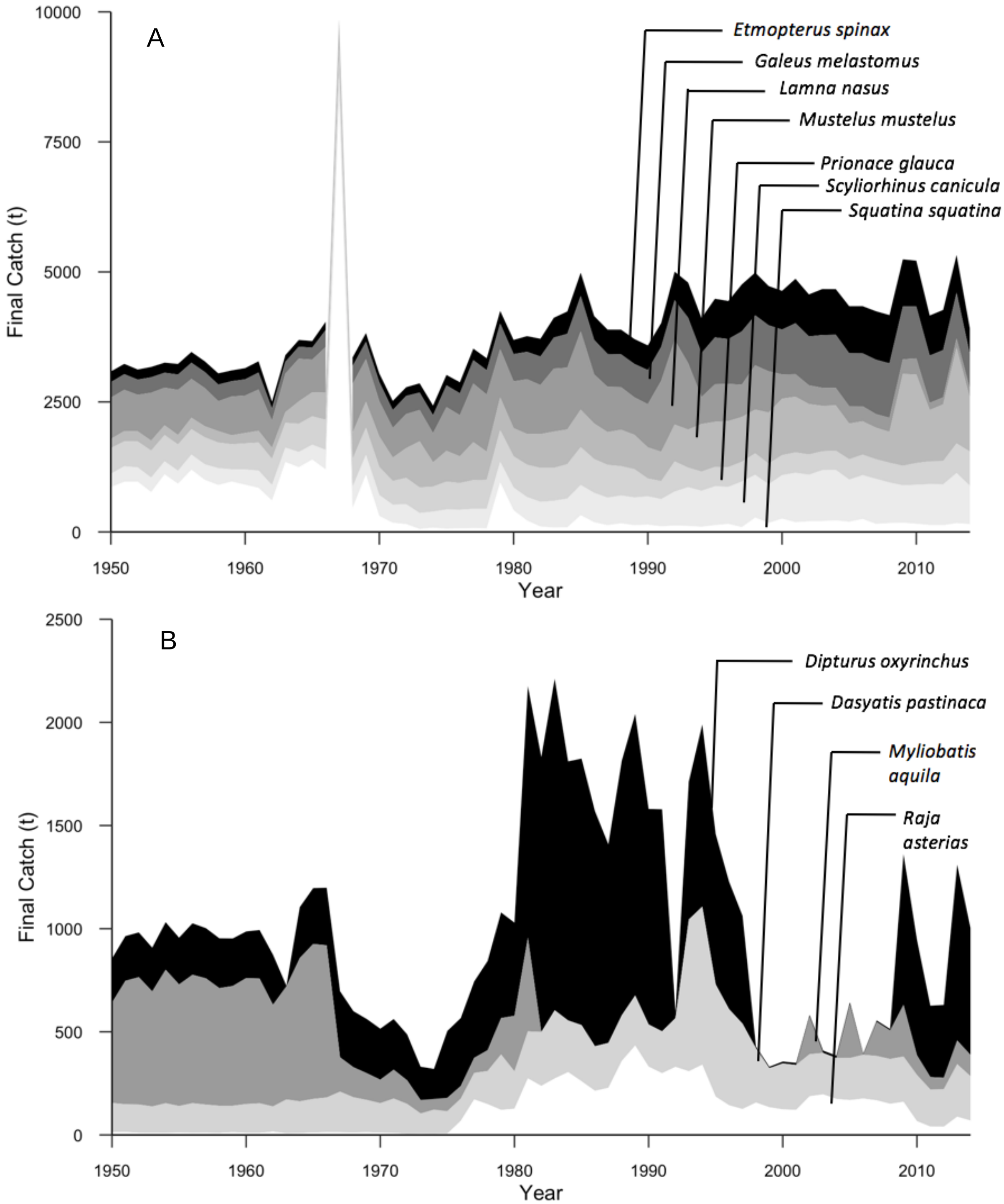

Figure 3.8. Final catch time series of the species collectively comprising at least 75% of the total catch of sharks (*A*) and batoids (*B*) in the *Sea Around Us* data for the Mediterranean and Black Seas from 1950-2014. Note: the peak in angelshark (*Squatina squatina*) catch in 1967 is attributed to a data error from official Turkish catch statistics.

3.7. Tables

Table 3.1 Summary of the response (SpCATCH) and predictor variables initially tested during the model selection process for modelling predictors of species-specific domestic elasmobranch catch in the Mediterranean and Black Seas. Note that OCCUR was the only variable that did not have a significant effect on SpCATCH and was thus omitted from the final model.

Variable Name	Description	Mean (range)	Type
SpCATCH	Annual domestic catch (t) of each species per country	44.4 t (1.33 x 10^{-6} t – 1626 t)	Continuous log-normal response
Predictive variables			
YEAR	Year caught	N/A	Nominal factor (65 levels)
EEZ	EEZ	N/A	Nominal factor (25 levels)
SPP	Species	N/A	Nominal factor (35 levels)
OCCUR	Total EEZ occurrence of species, summed across ½ degree latitude-longitude cells	0.01 (5.12 x 10^{-6} – 0.08)	Continuous
GEAR	Annual gear type used	N/A	Nominal
OF	Annual percentage of the number of each EEZ's stocks that are overfished (overexploited or collapsed)	20.7% (0% – 89.5%)	Continuous
ELASMO	Annual total domestic elasmobranch catch (t)	2808 t (0.07 – 53120 t)	Continuous

Table 3.2. Changes in total catches (t) of elasmobranch species (1950-2014) in the *Sea Around Us* database following a taxonomic disaggregation of higher taxa (genus to subclass) in the Mediterranean and Black Seas.

Species	Initial Catch (t)	Disaggregated Catch (t)	After	Percentage change (%)
Selachimorpha (sharks)				
Alopias vulpinus	14,808.4	5503.8	20,312.1	37
Carcharhinus brachyurus	6.4	0.0	6.4	0
Carcharhinus plumbeus	5.1	0.0	5.1	0
Carcharodon carcharias	135.0	0.0	135.0	0
Centrophorus granulosus	3664.2	5153.2	8817.5	141
Centrophorus squamosus	4.1	0.0	4.1	0
Cetorhinus maximus	5728.4	5315.9	11,044.3	93
Dalatias licha	3761.8	0.0	3761.8	0
Echinorhinus brucus	114.7	0.0	114.7	0
Etmopterus spinax	27,876.6	977.1	28,853.7	4
Galeorhinus galeus	12,614.4	5159.8	17,774.2	41
Galeus melastomus	35,497.3	3302.0	38,799.3	9
Hexanchus griseus	691.7	4120.0	4811.8	596
Isurus oxyrinchus	907.7	4583.5	5491.2	505
Lamna nasus	32,425.9	14,664.5	47,090.3	45
Mustelus mustelus	16,204.2	25,815.9	42,020.1	159
Oxynotus centrina	1724.4	0.0	1724.4	0
Prionace glauca	16,447.4	15,671.1	32,118.6	95
Scyliorhinus canicula	24,097.0	10,514.6	34,611.6	44
Scyliorhinus stellaris	3.2	0.0	3.2	0
Sphyrna zygaena	2.6	0.0	2.6	0
Squalus acanthias	697,689.8	25,243.5	722,933.3	4
Squatina squatina	31,278.8	3834.5	35,113.2	12
Batoidea (rays)				
Dasyatis pastinaca	3573.1	10,429.0	14,002.1	292
Dipturus batis	9.2	0.0	9.2	0
Dipturus oxyrinchus	624.5	7150.7	7775.3	1145
Leucoraja naevus	135.7	1700.7	1836.4	1254
Mobula mobular	4651.8	0.0	4651.8	0
Myliobatis aquila	126.5	13,698.2	13,824.6	10,831
Raja asterias	881.1	27,784.1	28,665.2	3153
Raja brachyura	243.5	205.6	449.0	84
Raja clavata	73,195.9	295,583.9	368,779.8	404
Raja montagui	546.8	1698.4	2245.2	311
Rostroraja alba	60.3	6965.5	7025.8	11,558
Total	**1,009,737.2**	**495,075.5**	**1,504,812.7**	**48**

Chapter 4: Conclusions

This thesis evaluated and improved the quality, in terms of taxonomic resolution, of elasmobranch catch statistics in the Mediterranean and Black Sea from 1950-2014. This research was motivated by the data deficiency problem that recurrently limits the creation and implementation of management policies for elasmobranchs in this region of the world. The findings here could be used to inform more focused (e.g., species-specific) policies and prioritize the implementation of existing regulations, particularly species retention bans. The Taxonomic Resolution Index and the taxonomic disaggregation methods could be applied to different regions and taxonomic groups to better understand the species composition of low resolution catch data.

As a whole, the taxonomic resolution of elasmobranch catches in the Mediterranean and Black Seas has improved very little. While most countries showed some improvement, the leaders of the 1950s have increasingly lagged behind other countries over time and in the final year of reported catch data (2014) only two countries (Spain and Malta) reported at least half of the commercial taxa in their waters. Predictably, countries with consistently low taxonomic resolution were relatively poor countries with weak fisheries governance, located primarily in the Levantine Basin of the Eastern Mediterranean Sea. Unfortunately, these are the same countries within which elasmobranch landings have been increasing rapidly since the early 2000s (Colloca et al., 2017). Sustainable solutions to overexploitation are especially urgent for these countries, as they are catching a greater diversity and amount of elasmobranch species than they report. Many of these countries are characterized by a lower Human Development Index, a greater dependency on domestic fisheries, and a faster-growing human population than the countries that report more accurately (Blanchard et al., 2017). Additionally, the small-scale fishing sectors in these countries represent a large proportion of fisheries (FAO, 2016b), which likely contributes to the lower coverage of reporting in the Eastern Mediterranean Sea (i.e., more vessels, smaller vessels, low traceability), and also indicates the degree of local reliance on fisheries.

Due to the high level of threat for over half of the elasmobranch species in the Mediterranean and Black Seas, exploitation needs to be monitored using species-specific data. It is important to note that the IUCN Red List status information alone cannot be used to inform bans on fishing for threatened elasmobranchs; sustainable fishing practices could potentially improve the risk status of some threatened species (IUCN, 2009). The GFCM/36/2012/3 regulation protects 24 species of threatened elasmobranchs (those listed in Annex II of the Barcelona Convention) by advising that they be released at sea unharmed when possible, and may not be sold (GFCM, 2017). Since reported landings for these species did not change, with the exception of the basking shark, there is no evidence that these prohibitions are being implemented or enforced. 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 program in 2013 through which it aimed to help design and fund plans to address five thematic areas (GFCM, 2012):

1) Support of institutional and technical cooperation in the Southern Mediterranean and in the Black Sea;
2) Strengthening national capacity in the field of data collection and support of the establishment of regional databases;
3) Enhancing the development of artisanal fisheries in the Mediterranean and Black Seas;
4) Promotion of aquaculture for food security and economic growth;
5) Improvement of governance in the region through an integrated maritime approach.

The outcome of the five year program will hopefully become clear as it approaches completion at the end of 2018. For now, it is promising to see that the plan emphasizes the importance of artisanal fisheries, socio-economically and environmentally, as well pragmatism toward the logistics of comprehensive fisheries data collection.

The Mediterranean and Black Seas once contained healthy marine ecosystems with an abundance of predators such as elasmobranchs (Zogaris & De Maddalena, 2014). Dense coastal human populations and fisheries intensification have led to the depletion of nearly all the fish stocks and the near-extirpation of over half of its elasmobranch species. To focus initiatives aimed at recovery, historical data are essential. Retroactive data improvements could provide insight into which species have been depleted and which areas may still be important for the persistence of these fishes. Ambiguous historical catch data are not to be disregarded: they represent a large untapped resource that may help to inform the path toward restoring damaged populations and ecosystems.

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Appendices

Appendix A: Reported and omitted elasmobranch taxa

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)	Taxonomic rank	# years reported
Sharks, rays, skates, etc. nei.	Elasmobranchii	Subclass	**65**
	Batoidea (skates and rays)		
Blonde ray	*Raja brachyura*	Species	2
Common eagle ray	*Myliobatis aquila*	Species	9
Common guitarfish	*Rhinobatos rhinobatos*	Species	6
Common stingray	*Dasyatis pastinaca*	Species	10
Cuckoo ray	*Leucoraja naevus*	Species	6
Eagle rays nei	Myliobatidae	Family	11
Guitarfishes, etc. nei	Rhinobatidae	Family	**33**
Longnosed skate	*Dipturus oxyrinchus*	Species	2
Mediterranean starry ray	*Raja asterias*	Species	6
Rays, stingrays, mantas nei	Batoidea	Superorder	**65**
Spotted ray	*Raja montagui*	Species	5
Stingrays, butterfly rays nei	Myliobatiformes	Order	11
Thornback ray	*Raja clavata*	Species	19
White skate	*Rostroraja alba*	Species	5
	Selachimorpha (sharks)		
Angelshark	*Squatina squatina*	Species	24
Angelsharks, sand devils nei	Squatinidae	Family	**61**
Basking shark	*Cetorhinus maximus*	Species	11
Bigeye thresher	*Alopias superciliosus*	Species	3
Blackmouth catshark	*Galeus melastomus*	Species	13
Blue shark	*Prionace glauca*	Species	18
Bluntnose sixgill shark	*Hexanchus griseus*	Species	30
Catsharks, etc. nei	Scyliorhinidae	Family	25
Catsharks, nursehounds nei	Scyliorhinidae	Family	30
Dogfish sharks nei	Squalidae	Family	**65**
Gulper shark	*Centrophorus granulosus*	Species	**61**
Longnose spurdog	*Squalus blainville*	Species	**60**
Picked dogfish	*Squalus acanthias*	Species	**48**
Porbeagle	*Lamna nasus*	Species	**44**
Sharpnose sevengill shark	*Heptranchias perlo*	Species	6
Shortfin mako	*Isurus oxyrinchus*	Species	18
Small-spotted catshark	*Scyliorhinus canicula*	Species	21
Smooth-hound	*Mustelus mustelus*	Species	4
Smooth-hounds nei	*Mustelus*	Genus	**65**
Thresher	*Alopias vulpinus*	Species	18
Tope shark	*Galeorhinus galeus*	Species	11
Velvet belly	*Etmopterus spinax*	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 the references citing them 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	1
Squatina squatina	1980-2014	Italy	1, 2
Squatina squatina	2000-2014	Bulgaria, Georgia, Romania, Russia, Ukraine	3, 4
Rhinobatos rhinobatos	1950-2014	Croatia, France, Italy, Spain,	5

[1] Maynou et al., 2011; [2] Ragonese, Vitale, Dimech, & Mazzola, 2013 ; [3] Ulman et al., 2013; [4] FAO, 2016
[5] Bradai & Soldo, 2016

Appendix B: Original and aggregate gear types

Table A.1. Original industrial fisheries gear type categories from the *Sea Around Us* Mediterranean and Black Seas elasmobranch data and associated aggregated categories used for all analyses in this study.

Original gear type	Aggregate gear type
Bottom trawl	Bottom trawl
Shrimp trawl	Bottom trawl
Otter trawl	Bottom trawl
Dredge	Dredge
Gillnet	Gillnet
Longline	Longline
Pelagic trawl	Pelagic trawl
Purse seine	Purse seine
Mixed gear	Unknown
Unknown	Unknown
Blank	Unknown

Appendix C: Disaggregated species-specific elasmobranch catches

Table A.2. Synoptic table of Mediterranean and Black Seas elasmobranch species-specific catches, 1950-2014 (sum rounded to the nearest t for values > 1 t) by EEZ and gear type. The 'final' values are catch amounts after the taxonomic disaggregation and 'initial' are the original catches from the *Sea Around Us* database. Dashes (-) indicate that there were no records of elasmobranch catch with a given gear type in a given EEZ.

	Catch (t) by gear type – final (initial)							
EEZ	**Bottom trawl**	**Gillnet**	**Longline**	**Pelagic trawl**	**Purse seine**	**Small-scale**	**Unknown**	**EEZ total**
Albania	53 (3)	-	-	0 (0)	0.8 (0)	-	31 (6)	**85 (9)**
Algeria	49,150 (48,386)	-	-	-	-	13,310 (9821)	6257 (4782)	**68,717 (62,988)**
Balearic Is.	16,678 (13,435)	-	-	-	-	5221 (4140)	1919 (1919)	**23,818 (19,495)**
Bulgaria	583 (583)	-	-	413 (413)	-	1381 (1381)	-	**2377 (2377)**
Corsica (France)	532 (40)	-	-	-	-	267 (34)	-	**799 (74)**
Crete (Greece)	260 (57)	-	-	-	26 (12)	1566 (851)	-	**1852 (920)**
Croatia	3233 (111)	-	-	-	11(10)	0 (0)	504 (71)	**3748 (192)**
Cyprus (North)	2106 (1683)	-	-	-	-	1849 (0)	0.1 (0)	**3955 (1683)**
Cyprus (South)	225 (0)	-	80 (0)	-	-	500 (0)	34 (0)	**838 (0)**
Egypt	-	-	-	-	-	7361 (0)	-	**7361 (0)**
France (Med)*	10,525 (2360)	4312 (3096)	-	-	515 (0)	16,647 (3259)	-	**33,310 (9236)**
Gaza Strip	1861 (1861)	-	-	-	-	4533 (4319)	-	**6394 (6180)**
Georgia	65,635 (65,480)	-	-	190 (172)	514 (514)	17,770 (17,507)	-	**84,109 (83,673)**
Greece (without Crete)	51,643 (24,147)	-	-	-	1218 (675)	68,847 (37,937)	-	**121,707 (62,759)**
Israel	1061 (0)	-	-	-	-	776 (0)	-	**1837 (0)**

* France was the only country that domestically caught elasmobranchs with the gear type 'dredge': 1311.3 t (521.3 t). Dredges were omitted from the table, although the catch is included in totaled catch amounts.

Table A.2. continued

EEZ	Catch (t) by gear type – final (initial) Bottom trawl	Gillnet	Longline	Pelagic trawl	Purse seine	Small-scale	Unknown	EEZ total
Italy (mainland)	311 (82)	-	136 (62)	0.9 (0.5)	-	65,346 (39,257)	183 (34)	**65,976 (39,435)**
Lebanon	-	-		-	-	1069 (0)	-	**1069 (0)**
Libya	55,014 (49,958)	-		-	-	14,187 (8430)	-	**69,202 (58,387)**
Malta	700 (700)	-	189 (184)	-	-	2482 (1957)	-	**3371 (2841)**
Montenegro	30 (0)	-	-	-	-	22 (0)	-	**53 (0)**
Morocco	773 (313)	1474 (0)	-	-	-	2308 (0)	-	**4555 (313)**
Romania	-	-	-	322 (322)	-	9067 (893)	-	**1229 (1215)**
Russia (Black S.)	239,026 (238,421)	73 (0)	-	32,018 (31 993)	13,950 (13,950)	6928 (4829)	22,013 (21,275)	**314,009 (310,467)**
Sardinia (Italy)	72 (21)	-	37 (16)		-	1968 (846)	36 (9)	**2113 (892)**
Sicily (Italy)	103 (18)	-	38 (13)	0.3 (0.1)	-	10,722 (5061)	65 (7)	**10,930 (5100)**
Slovenia	31 (31)	-	-	0.8 (0.8)	0.3 (0.3)	254 (254)	-	**286 (286)**
Spain (mainland)	5166 (0)	-	-	-	-	26,478 (24 183)	0 (0)	**31,643 (24,183)**
Syria	2163 (975)	-	-	-	-	4306 (3158)	-	**6468 (4134)**
Tunisia	-	-	144 (0)	-	-	3082 (0)	419 (0)	**3644 (0)**
Turkey (Black S.)	356,169 (187,569)	-	-	-	-	39,298 (18,858)	-	**395,467 (206,428)**
Turkey (Marmara)	55,118 (24,976)	-	-	-	-	42,500 (3083)	-	**97,618 (28,059)**
Turkey (Med.)	63,599 (21,912)	-	-	-	-	12,434 (2623)	-	**76,032 (24,535)**
Ukraine	-	-	-	-	-	48,392 (47,264)	25,625 (20,386)	**74,016 (67,651)**
Gear type total final (initial)	**981,818 (683,121)**	**5858 (3096)**	**624 (275)**	**32,946 (32,901)**	**16,235 (15,162)**	**422,707 (239,945)**	**57,086 (48,489)**	**1,518,586 (1,023,510)**

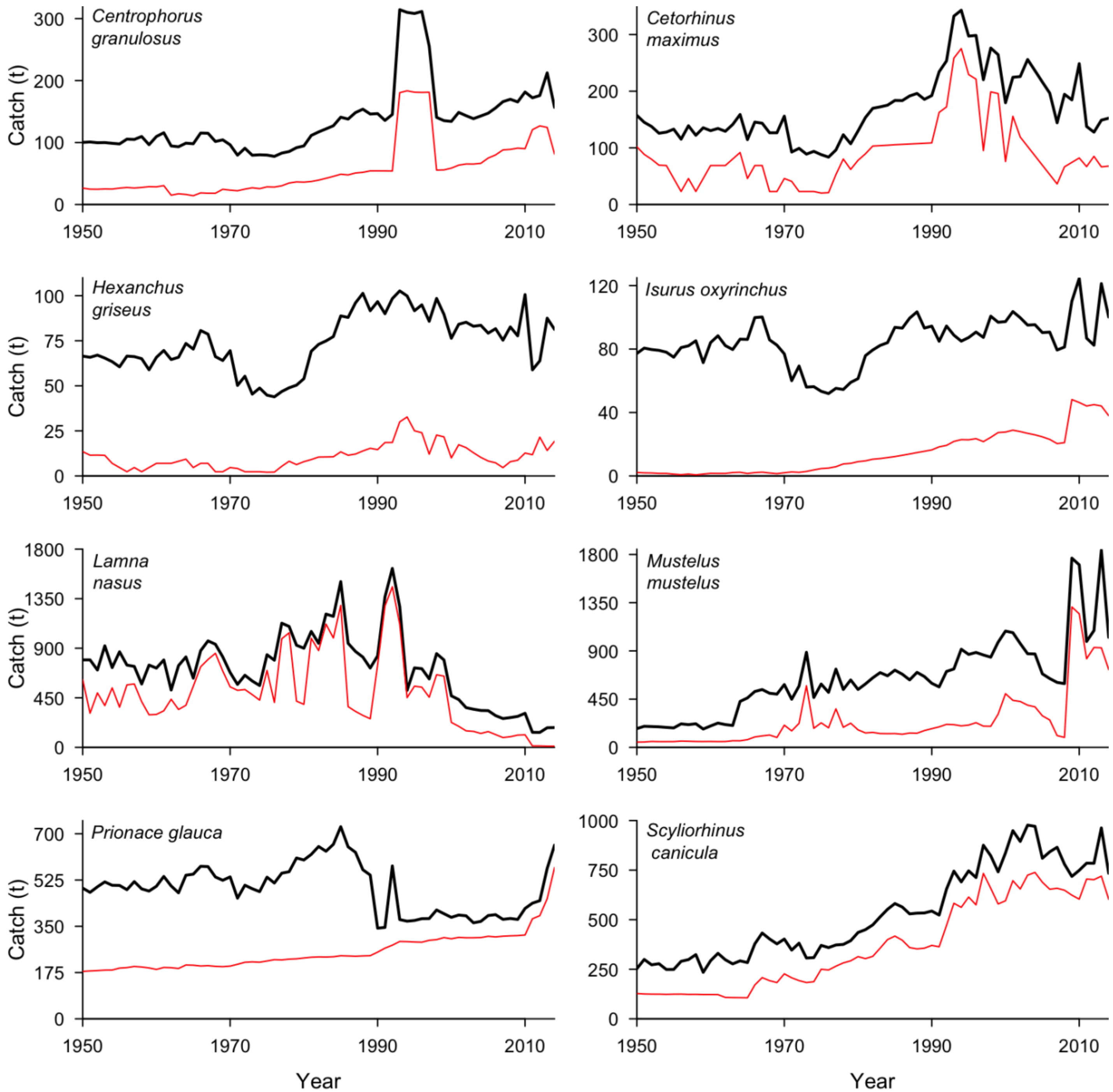

Figure A.1. Catch trends (1950-2014) for most shark species in the Mediterranean and Black Seas were similar before (red curve) and after (black curve) the taxonomic disaggregation of higher elasmobranch taxa in the *Sea Around Us* catch database. This figure shows the 8 species (of 23) with the most disaggregated catch (from top-left): gulper shark (*Centrophorus granulosus*), basking shark (*Cetorhinus maximus*), bluntnose sixgill shark (*Hexanchus griseus*), shortfin mako (*Isurus oxyrinchus*), porbeagle (*Lamna nasus*), smooth-hound (*Mustelus mustelus*), blue shark (*Prionace glauca*), and small-spotted catshark (*Scyliorhinus canicula*).

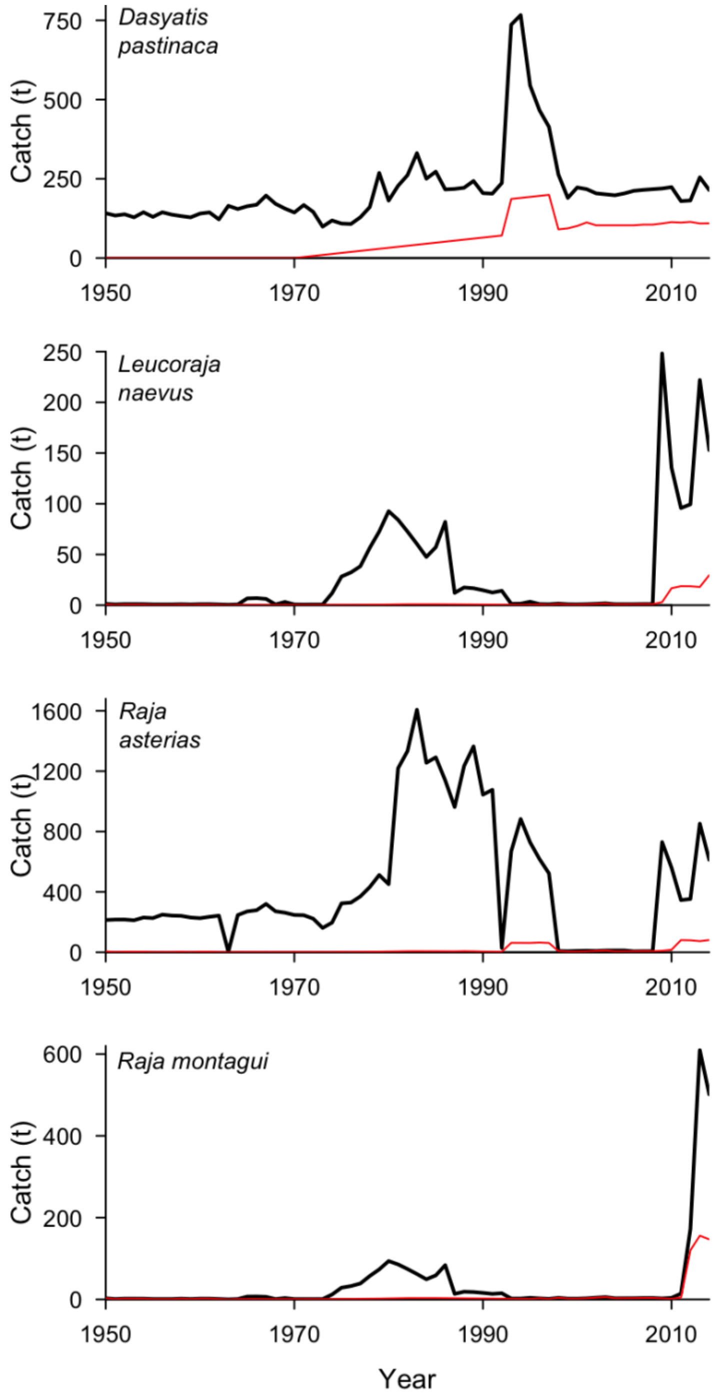

Figure A.2. Catch trends (1950-2014) for most batoid species in the Mediterranean and Black Seas differed before (red curve) and after (black curve) the taxonomic disaggregation of higher elasmobranch taxa in the *Sea Around Us* catch database. This figure shows the 8 species (of 11) with the most disaggregated catch (from top-left): common stingray (*Dasyatis pastinaca*), longnosed skate (*Dipturus oxyrinchus*), Cuckoo skate (*Leucoraja naevus*), common eagle ray (*Myliobatis aquila*), starry ray (*Raja asterias*), thornback ray (*Raja clavata*), spotted ray (*Raja montagui*), and white skate (*Rostroraja alba*). Note: some catches were too low before the disaggregation to be visible here.