

Why have global shark and ray landings declined: improvement management or overfishing?¹

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1.1. Abstract

Global chondrichthyan (shark, ray, skate, and chimaera) landings, reported to the United Nations Food and Agriculture Organization (FAO), peaked in 2003 and in the decade since have declined by almost 20%. In the FAO's 2012 "State of the World's Fisheries and Aquaculture" report, the authors "hoped" the reductions in landings were partially due to management implementation rather than population decline. Here, we tested their hypothesis. Post-peak chondrichthyan landings trajectories from 126 countries were modelled against seven indirect and direct fishing pressure measures and eleven measures of fisheries management performance, while accounting for ecosystem attributes. We found the recent improvement in international or national fisheries management was not yet strong enough to account for the recent decline in chondrichthyan landings. Instead, the landings declines were more closely related to fishing pressure and ecosystem attribute measures. Countries with the greatest declines had high human coastal population sizes or high shark and ray meat exports such as Pakistan, Sri Lanka, and Thailand. While important progress has been made, country-level fisheries management measures do not yet have the strength or coverage to halt overfishing and avert population declines of chondrichthyans. Increased implementation of legally binding operational fisheries management and species-specific reporting is urgently required to avoid declines and ensure fisheries sustainability and food security.

1.2. Introduction

Sharks, rays, skates, and chimaeras (Chondrichthyans, hereafter "sharks and rays") are one of the most evolutionary distinct fish lineages and play important functional roles in marine environments (Stevens et al. 2000). They are commercially valuable for their fins, meat, liver oil, gill rakers, leather, and are an important source of food security. Shark and rays were once considered the less valued bycatch of more profitable fisheries stocks, such as tuna (Scombridae) and cod (Gadidae) (Stevens et al. 2005). The rising demand for products, coupled with the decline of valuable fisheries, however resulted in rising catches and retention of shark and rays (Clarke, McAllister, et al. 2006; Lack & Sant 2011). Until recently, directed and bycatch shark and ray fisheries were subjected

to little management and were of low management priority (Fischer et al. 2012; United Nations General Assembly 2007).

Concerns for the sustainability of shark and ray fisheries prompted advances in shark and ray fisheries management tools over the past twenty years. For example, in 1999 the United Nations Food and Agriculture Organization (FAO) recommended the development and implementation of National Plans of Actions for sharks (NPOAs hereafter referred to as *Shark-Plans*) by signatory nations to, preferably, be completed before 2001 (UN FAO 2013). These non-binding *Shark-Plans* had ten aims encompassing sustainability, threatened species, stakeholder consultation, waste minimization, ecosystem considerations, and improved monitoring and reporting of catch, landings, and trade. Aside from *Shark-plans*, other global initiatives in chondrichthyan conservation and management over the past 20 years have included, but are not limited to: (i) the introduction of bans on fin removal and carcass disposal at sea (Biery & Pauly 2012; Clarke et al. 2013; Fowler & Séret 2010; Clarke, McAllister, et al. 2006); (ii) application of trade regulations of marine fishes through the Convention on the International Trade in Endangered Species (CITES) (Vincent et al., 2013); (iii) international agreements to prevent Illegal, Unregulated and Unreported fishing (Field et al. 2009; Witbooi 2014), and (iv) management and conservation of migratory sharks and rays through the Convention of Migratory Species Memorandum of Understanding for Sharks (CMS sharks MoU) (Fowler, 2012).

Despite the advances in shark and ray fisheries management, there were concerns that chondrichthyan fisheries were following the predictable pattern shown by unregulated, open-access fisheries: declining catch per unit effort, collapse, and serial depletion (Pitcher & Hart 1982; Lam & Sadovy de Mitcheson 2011). Indeed, shark and ray landings increased 227% from 1950 (the first year of data collection) to the peak year in 2003 and subsequently declined by almost 20% to 2011 (FAO 2013b). The authors of the 2010 State of the World's Fisheries and Aquaculture (SOFIA) expressed that they "hoped" this reduction in shark and ray landings was due to a rise in sustainable fisheries, and hence reduced catch, rather than population declines (FAO, 2010). There was little comment on shark and ray landings declines in the 2012 SOFIA report, however, the most recent SOFIA concluded, "a simple explanation for the recent [landings] trends is not possible" (FAO 2014).

Here, we tested FAO's hypothesis and assessed whether country-by-country variation in shark and ray landings from 2003 to 2011 was best explained by indicators of overfishing or fisheries management performance. We also accounted for ecosystem attributes as they have been shown to constrain fisheries catch (Chassot et al. 2010). If the hope expressed in the SOFIA 2012 report was correct, we expected landings reductions to be in response to management implementation. Conversely, if the interpretation was not correct, we expected landings reductions to be unrelated to management performance

indicators and more closely related to direct and indirect measures of fishing pressure.

1.3. Methods

1.3.1. Analytical approach

The magnitude and trajectories of fisheries landings can be characterized as a function of exposure to fishing pressure which can be modified by fisheries management performance and by the intrinsic sensitivity and resilience of the ecosystem (Fig. 3.1). A series of metrics can be used as indirect drivers of fishing pressure such as human coastal population size and density (Newton et al. 2007) and reliance on fish for income and dietary protein (Allison et al. 2009; Smith et al. 2010). The degree to which these indirect drivers translate into fishing pressure and mortality is modified by the form and strength of fisheries management control that can be characterized with metrics such as scientific capacity, Gross Domestic Product (GDP), and Human Development Index (HDI) (Mora et al. 2009; Pitcher et al. 2009; Allison et al. 2009). International and national protections, or more diffuse measures that are precursors to a good management regimes, may promote reduced catch (Clarke, McAllister, et al. 2006). Metrics that quantify intrinsic sensitivity at the ecosystem level include the size of ecosystem and primary productivity (Chassot et al. 2010; Watson et al. 2013; Myers et al. 2001) and at the species level include species richness, or measures of population growth rate (Dulvy, Pardo, et al. 2014; García et al. 2008).

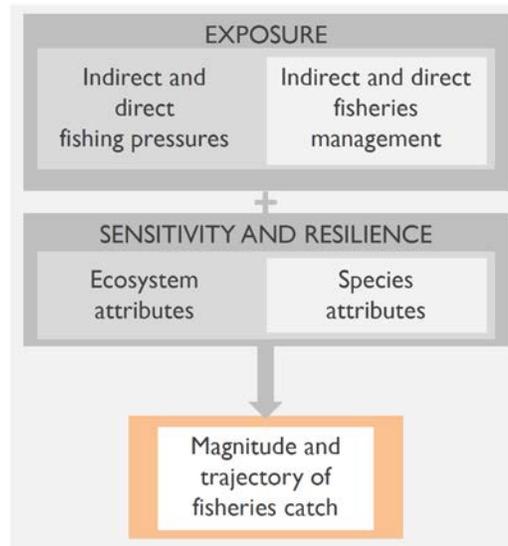


Figure 3.1 Fisheries landings magnitudes and trajectories are a function of exposure to fishing, which is modified by the form and strength of fisheries management, but also the sensitivity and resilience of the ecosystem and species.

First, we describe the collection of the response variable – the trajectory of the landed catch of chondrichthyans followed by the plausible explanatory variables broadly classed as exposure to (i) drivers of fishing pressure, (ii) fisheries management performance, and (iii) sensitivity and resilience of the surrounding ecosystem and species (see Table 3.1 Appendix B for a summary of the measures used in this analysis).

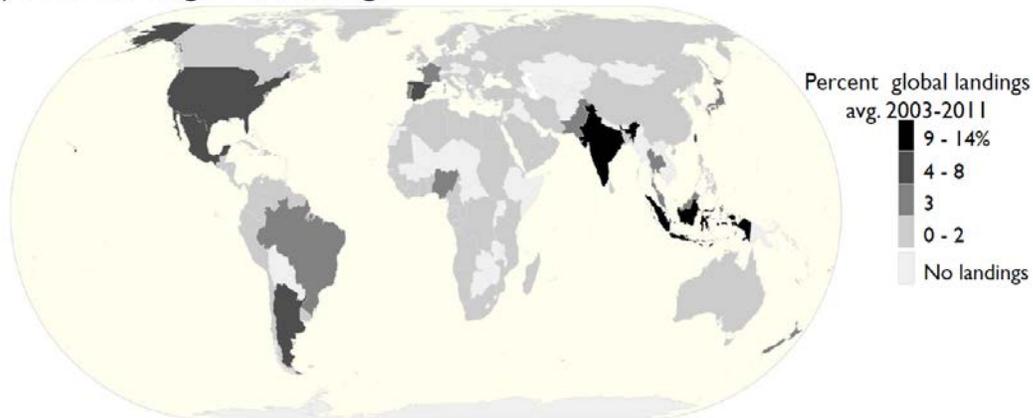
1.3.2. Selection, filtering, and quality control of FAO landings data

We extracted all sharks, ray, skate, and chimaera landings by country from the earliest year of reporting (1950) to, at the time of this analysis, the most recent (2011) from the FAO FishSTAT database (FAO 2013b). Data for 2012 is now available. Chimaeras are included in this analysis; however, they are a small percentage of global landings. We used the “Sharks, rays, chimaeras” category of the “species by ISSCAAP” (International Standard Statistical Classification of Aquatic Animals and Plants) group. Within this broader group were 135 species and 30 aggregate non-species specific “nei” - not elsewhere indicated - reporting categories, which summed to 217,416 tonnes and 548,687 t in 2011, respectively for a total of 766,103 t. Examples of nei categories include “sharks, rays, skates, etc, nei” and “threshers, nei”. The peak of the aggregate global shark and ray landings was 2003 at 895,743 t. In total, 155 countries/overseas territories reported to the FAO, however, countries with no values, or with landings values that remained unchanged, as well as overseas territories, and the “Other nei” category were removed for the analysis.

1.3.3. Response variable – country-by-country chondrichthyan landings trajectories

Landings across reporting categories were summed for each country by year. We calculated both the average and the change in reported landings. Average landings between 2003-2011 were calculated to account for the size of shark and ray fisheries (Fig. 3.2a). Change in reported landings was calculated as the absolute difference between averages of 2001-2003 and 2009-2011 (Fig. 3.2b).

(a) Percent of global landings



(b) Change in reported shark and ray landings

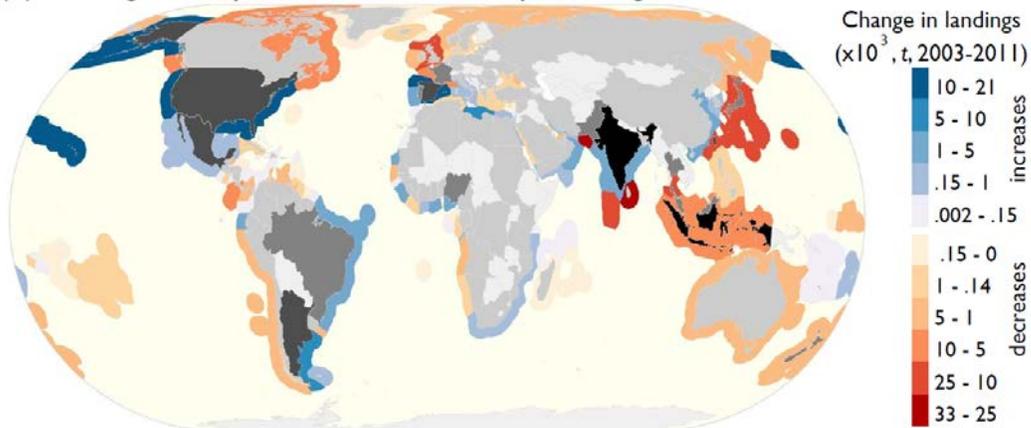


Figure 3.2 Global distribution of (a) country-specific shark and ray landings averaged between 2003-2011 and mapped as a percentage of the total. Landings include fishing from overseas fishing and all categories ('nei' or species-specific), (b) the change in landings between the averages of landings in 2001-2003 and 2009-2011. Mapped to the national waters that extend 200nm from the coast for visual purposes.

1.3.4. Measures of fishing pressure

Indirect fishing pressure

Three indirect measures of fishing pressure were included in the analysis; coastal human population size, marine protein available for consumption, and percentage of threatened species within national waters (Table 3.1 Appendix B).

Coastal human population size and the available marine protein for consumption is related to reduced biomass and unsustainable fishing on coral reefs at island and country scales (Cinner et al. 2009; Newton et al. 2007; Dulvy et al. 2004).

Coastal human population size was captured through nominal coastal settlement data and defined as the number of persons living in rural and urban areas within 100km of the country's coast as of 2011 (NASA Earth Data 2014). National marine protein supply was defined as grams per capita per day of marine fish protein available for consumption and represented reliance on marine resources (Allison et al. 2009; FAO 2013b). The dates of the marine protein supply estimates for each country ranged from 1969-2009; however, only 22 countries had entries earlier than 2009. The state of a country's shark and ray populations was likely to be captured by the percentage of threatened species within national waters. The percentage of shark and ray species classified by the IUCN as having an elevated risk of extinction (Vulnerable, Endangered, or Critically Endangered) within each country's national waters (EEZ - Exclusive Economic Zone that extends 200 nautical miles from the coast) was calculated (Dulvy, Fowler, et al. 2014).

Direct fishing pressure

Ideally, we would have included direct measures of fishing pressure such as fishing intensity, fishing effort, and fishing mortality estimates. The coverage of fisheries by stock assessments and other data intensive measures, however, are limited and only represent 16% of reported teleost fisheries (Ricard et al. 2012). Hence, the fisheries management performance measures included here were not species-specific, mainly because there were few and fewer that were consistent across the global scale. Yet, we feel that the measures we collated were salient because they were global, comparable, and supported by the international community. We included and described four measures of exploitation pressure: overseas landings, the volume of shark and ray meat exports, the volume of fins exported to Hong Kong, and estimated Illegal Unreported Unregulated (IUU) fishing within national waters (Table 3.1 Appendix B).

Overseas shark and ray landings were defined as those taken from beyond each country's EEZ from 2003-2011. Our definition, however, only includes landings from outside the FAO major fishing areas as spatial mismatch between a country's EEZ and a FAO major fishing area exists with the boundaries of the latter extending farther beyond any EEZ. Therefore, our definition of overseas landings is a combination of international and national waters and only removes unambiguous overseas fishing (such as Belize landings from Indian Ocean) and hence will be an underestimate. China, Hong Kong, Norway, and Zanzibar only reported landings from overseas waters.

The volume of shark and ray meat exports was included as a measure of fishing pressure as shark and ray meat is a globally traded commodity. We included the amount of shark and ray meat exports reported to the FAO under 13 commodity codes (FAO 2013b) between 2003-2009 which included fins, liver oil, of mainly sharks, but also to a lesser extent rays, skates, and chimaeras. Spain, Taiwan, Canada, Japan, United Kingdom, and Indonesia reported the largest meat exports at 11 608 t, 4 684 t, 3 813 t, 3 748 t, 3 534 t and 3 497 t respectively. Meat exports between 2003 and 2009, on average, increased 277 t (Table 3.2 Appendix B) with Uruguay and Taiwan reporting the largest increases (16,283 t, and 15,493 respectively). We used the volume of fins that countries exported to Hong Kong based on census trade statistics for 2011 (The Government of the Hong Kong Special Administrative Region of the People's Republic of China 2012). Note, this metric represented 50% of the global trade, included fins from high seas catches, non-adjacent EEZs, and ignored import-reexport of fins, particularly from EU countries, and from those that are large trade entréports such as UAE and Singapore (Clarke 2004a; Hareide et al. 2007; Clarke 2004b). IUU fishing estimates were calculated at the FAO major fishing region scale (MRAG and Fisheries Ecosystems Restoration Research 2008). Each country's value was derived by summing the lower IUU estimates for each FAO major fishing area that corresponded with a country's EEZ.

1.3.5. Measures of fisheries management performance

Indirect measures of fisheries management performance

Ideally, measures of fisheries management would have been country-by-country lists of the shark and ray fisheries management instruments implemented that ensured sustainable fishing. These instruments would have included science-based precautionary catch limits, prohibitions on catch (particularly of threatened species), reduction of bycatch, and habitat and spatial protections in place (Barker & Schluessel 2005). Such data are not readily or consistently available at the global scale for a comparative national analysis. The paucity of data could be due to poorly documented fisheries management but more likely reflects the lack of systematically applied shark and ray fisheries regulations (Fischer et al. 2012; Dulvy, Fowler, et al. 2014). We therefore developed a series of indirect management performance measures by country that described enabling conditions that promoted good management.

Fisheries management implementation and effectiveness are influenced by the economic and development status of a country. We therefore included GDP, Human Development Index (HDI), and percentage of Data Deficient (DD) species in this analysis. Countries with high income, or high development status, have significantly better fisheries management than low income countries (Mora et al. 2009; Gutiérrez et al. 2011; Pitcher et al. 2009). GDP is the nominal value of the sum gross value of a country's economy and is positively correlated with overall management effectiveness (Mora et al. 2009). Countries with high HDI scores, a

composite of health, education, and living standards metrics, are more successful at achieving sustainable fisheries (United Nations Development Programme 2011; Gutiérrez et al. 2011). Shark and ray species categorized as DD, by the IUCN, are those that lack sufficient information to be assigned to a Red List category. Therefore, percentage of species found within a country's EEZ that are listed as DD was included as a measure of scientific capacity.

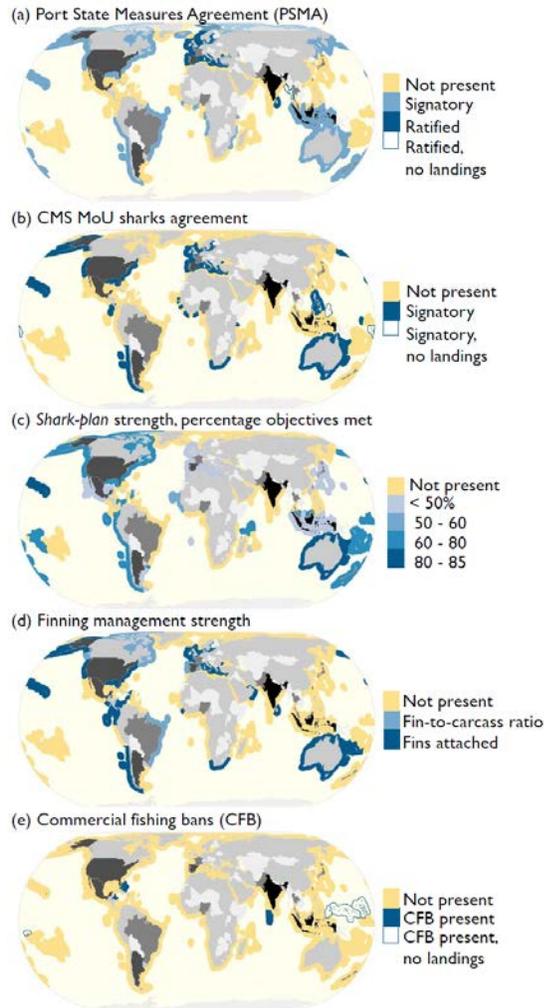


Figure 3.3 Spatial distribution of direct management measures finalized up to the year 2012 to correspond with FAO landings data. (a) Countries that are signatory to, or have ratified the PSMA. EU, Sri Lanka, and Myanmar (which did not report shark and ray landings) ratified the agreement. (b) Countries that were signatory to the CMS sharks MoU. Tuvalu and Palau signed the agreement and had not reported shark or ray landings. (c) The presence and strength of *Shark-Plans*; colours represent how well the document met the ten objectives of sustainable fishing. (d) The presence and strength of finning regulations; fins attached > fin-to-carcass ratio > none. The variability of finning bans are not captured here (such as; South Africa’s 8% fin-to-carcass (dressed weight) ratio for domestic vessels but 14% ratio for foreign vessels; or the variation in Australia’s finning regulations in territorial waters). (e) The location commercial fishing bans (CFB) for sharks.

Direct measures of fisheries management performance

We collated data for nine measures of direct fisheries management that were finalized up to 2012 (Table 3.1 Appendix B). We categorized the uptake and implementation of international policies including the Port State Measures Agreement (PSMA), which is not specific to sharks and rays, and the Convention for Migratory Species Memorandum of Understanding (CMS sharks MoU). Three plus the 22 EU maritime countries had ratified, approved, or accessioned the PSMA (Figure 3.3a). Implementation of the PSMA results in ports with stricter regulations in order to prevent illegally caught fish from being unloaded. For sharks and rays, this means enforcement on fishing that contravened regulations, such as finning or fishing illegally in another country's EEZ. By 2011, 20 countries were signatory to the PSMA, meaning the agreement was not yet ratified (FAO 2013a). Twenty-three countries, plus the 22 EU maritime countries, were signatories to the CMS sharks MoU agreement, which had listed seven migratory shark species under Appendix 1; White (*Carcharodon carcharias*), Basking (*Cetorhinus maximus*), Whale (*Rhincodon typus*), Shortfin Mako (*Isurus oxyrinchus*), Longfin Mako (*Isurus paucus*), Spiny Dogfish (Northern Hemisphere) (*Squalus acanthias*), and Porbeagle (*Lamna nasus*). Species listed on Appendix I are to be the focus of a global or national Conservation Plan that "promotes the conservation of migratory sharks" (CMS, 2013). The objectives of the Conservation Plan include; (1) research and monitoring of populations, (2) ensuring directed and non-directed fisheries are sustainable, (3) promoting protection of critical habitat, (4) increasing public awareness, and (5) enhancing government cooperation. (CMS 2013) (Fig. 3.3b). Support for CITES listings was

not included in this analysis as membership to CITES was not specific to sharks and rays and voting direction of countries for listing species onto appendices was mostly not recorded (a motion generally passed beforehand to ensure voting anonymity).

Twenty-two finalized *Shark-Plans* were scored on a categorical three-point scale according to how comprehensively the ten objectives of sustainable shark fisheries and conservation were addressed (UN FAO 2013). For each country with a *Shark-Plan*, objectives were scored as to whether it was: met comprehensively (=2); mentioned, but not comprehensively addressed (=1); or not addressed (=0). The scores had a maximum score of 20 if all 10 objectives were comprehensively addressed. The *Shark-Plans* performance scores ranged from five (Japan) to the highest 17 (Australia), or 25 – 85% of the objectives met (Fig. 3.3c). We also counted the number of years since *Shark-Plan* completion up to the year of most recent FAO landings data (2011), with values ranging from one to ten years. There was a high positive correlation between completion year and the strength of *Shark-Plans* (Pearson's $r=0.67$) (Fig. 3.1 Appendix B).

Finning is the act of cutting off a shark or rays fins and dumping the carcass overboard (Biery and Pauly 2012; Clarke et al. 2006; Camhi et al. 2008). Finning mostly refer to sharks, but rays can have some of the most valuable fins (Dulvy, Fowler, et al. 2014). Finning bans were scored on an ordinal scale such that (up to 2011); (1) fins-attached, shark and ray fins not removed (n=16 countries plus

18 EU maritime countries) was a preferable management measure to, (2) fin-to-carcass ratio, fins separated from bodies but weight of fins must be a specific ratio of the bodies (n=4 plus 2 EU [Spain and Portugal]), which in turn was better than, (3) no finning ban (n= 86; Fig. 3.3d). Countries with finalized finning ban strategies were expected to initially report increased landings as carcasses, and not just fins, are brought back to port.

Shark “sanctuaries” (hereafter “commercial fishing bans”) are a form spatial protection as branded by environmental non-governmental organization the Pew Charitable Trust. Up to 2012, the following countries had declared commercial fishing bans; Palau, Maldives, Tokelau, Micronesia, Marshall Islands, Honduras, and Bahamas. Commercial fishing bans extend to a country’s EEZ waters and ban commercial fishing for sharks, but not rays (Davidson 2012; PEW charitable trusts 2013) (Fig. 3.3e). They are neither no-take, nor no-entry, and artisanal fishing or landed bycatch is permitted. Commercial fishing bans are included in this analysis, as opposed to all MPAs, to evaluate their stated goal of shark conservation.

Data collection and availability is an essential precursor to fisheries management. Therefore, we calculated the percentage of a country’s landings reported to the species level, relative to the total (Table 3.1 Appendix B; Fig. 3.2 Appendix B). Finally, we included a score that evaluated compliance to UN Code of Conduct for responsible fisheries and was assigned to the 53 countries that reported more

(96%) of the global marine catch (in 1999) (Pitcher et al. 2009). The ranking, however, was not included in the final analysis as the majority of countries we analyzed did not have a score.

1.3.6. Sensitivity and resilience of the species and surrounding ecosystem

Ecosystem and species attributes

We used ecosystem area, species richness, and the number of endemic species, as an index of sensitivity and resilience (Table 3.1 Appendix B). We used EEZ area as a measure of ecosystem size (VLIZ 2012; Chassot et al. 2010). There is a wide range of theoretical and empirical work that relates species richness and diversity to population stability (Anderson et al. 2013; Mellin et al. 2014; Loreau et al. 2001). The species richness of each nation's EEZ was calculated using the IUCN SSG (Shark Specialist Group 2013) Extant of Occurrence (EOO) distribution maps for 1,041 sharks and rays. Endemicity was defined as species with range sizes within the lower quartile of total shark and ray range size (<121,509 km²) (Pompa et al. 2011).

1.3.7. Statistical analysis

To measure the share of global shark and ray landings reported from countries with potentially sustainable fisheries, we calculated average reported landings from countries with direct management measures finalized: signatory to PMSA, signatory to CMS sharks MoU, have finalized a *Shark-Plan*, finning ban, or a commercial fishing ban. We also considered combinations of the presence of

management measures. A country was assigned a value ranging between no management measures present (=0) or all management measures present (=5). All reported landings were included regardless of location or reporting category. Finally, excluding countries that reported an increase in landings, we determined the percentage of the decline reported from countries with any combinations of these management measures.

As a second step in the data analysis, we determined whether particular countries or reporting categories were influential upon the global trend in landings from 2003-2011 using a Jackknife analysis (Juan-Jordá et al. 2011). Countries that reported large increases in landings may mask a steeper global decline, while countries with large declines may drive the global trend. To determine influence, we examined how the global trajectory from 2003-2011 changed in absence of the reported landings from each of the ten countries that reported the largest landings (2003-2011). We repeated this analysis for the top ten reporting landings categories which included a combination of species and aggregate taxonomic categories.

To tackle the overall question of whether management or fishing pressure measures were associated with declining trajectories, we used Random Forest regression. Random Forest is a powerful approach for assessing which explanatory variables account for the most variance in a response, without requiring restrictive assumptions about the nature of relationship between the two

(Liaw and Wiener 2002). Each Random Forest model had 100,001 iterations, with the default value of the number of variables randomly sampled for each decision tree split, and data subsetted more than once (with replacement). Analysis was completed using the randomForest package (Liaw and Wiener 2002) for the statistical software R (R core team, 2012).

To compare and test the sensitivity of the results, we ran Random Forest models on four subsets of the data. First, a model with explanatory variables that included only those countries reporting a decline in catch. Second, the global catch trend is driven mostly by a large aggregate of “sharks, rays, skates, etc, nei”, so we examined drivers of only this subset of the catch. Third, the EU countries have a largely coherent governance framework and we tested whether the global pattern was sensitive to the exclusion of these countries. Fourth, increased landings might arise from better reporting and management, so we considered only those countries reporting an increase in landings separately from those showing declines.

Here, we are interested only in the interpretation of important variables.

Therefore, we ranked explanatory variables according to variable importance measured by the Mean Standard Error (MSE) in descending order. MSE indicates the difference between model performances with actual data compared to a model with the randomly generated variable. High MSE values denote the most important variables, and indicate better model performance with actual

values. Negative MSE values caution that randomly generated explanatory variables are performing better than our hypothesized predictors (Strobl et al. 2008). Partial dependence plots, the visual tool associated with Random Forest, show marginal effects of predictor variables on the response. The y-axis is the average predicted response across trees at the value of x.

1.4. Results

Just more than half (86) of the 147 countries and overseas territories reported reductions in shark and ray landings. The change in landings ranged between a 32,281 t decline (Pakistan) to an increase of 20,065 t (Spain). The average change in landings, across all reporting countries, was an 837 t decline, with a median of a 3 t decline. In total, across all reporting countries, the global landings declined by 129,642 t; with a 244,530 t change for countries reporting declines, and 114,888 t change for those countries reporting increases. Half of the decline in landings, regardless of reporting category or fishing location, occurred in just six countries: Pakistan (32,281 t), Sri Lanka (25,176 t), Thailand (21,051 t), Taiwan Province of China (18,919 t), and Japan (15,471 t; Table 3.1a).

Correspondingly, the broad FAO Fishing Areas regions with the greatest decline in landings occurred in the Western Central Pacific (49,920 t) and the Western Indian Ocean (45,928 t).

The greatest declines, over the same time period, in species-specific categories, were Spiny Dogfish (*Squalus acanthias*, Squalidae), 12,170 t, Whip Stingray (*Dasyatis akajei*, Dasyatidae), 4,557 t, Portuguese Dogfish (*Centroscymnus*

coelolepis, Somniosidae), 3,510 t, Leafscale Gulper Shark (*Centrophorus squamosus*, Centrophoridae), 2,351 t, and Narrownose Smooth-hound (*Mustelus schmitti*, Triakidae) 1,070 t. Three of the five species exhibiting the greatest declines the IUCN classified, globally, as Vulnerable (Spiny Dogfish, Leafscale Gulper Shark) and Endangered (Narrownose Smoothhound). The majority of these populations declined due to intensive fishing pressure. Consequently, Spiny and Portuguese dogfish, and Leafscale gulper shark are currently managed with a zero Total Allowable Catch (TAC) in EU waters. In the US, the Spiny Dogfish fishery re-opened in 2011 under quotas (Table 3.1b).

Table 3.1 Countries and species reporting categories with the greatest changes between 2003-2011 in descending order. Only changes greater than a decline of 500 tonnes or less than an increase of 500t were included in the table for brevity. **(a)** The five countries that reported the greatest declines in landings, the reporting categories for each country, and associated management measures within that country. **(b)** Species-specific reporting categories with the greatest landings reduction, the countries that reported changes in those categories, and the associated management measures for that fishery.

Table 3.1(a)

| Country | Reporting Category | Diff. in landings ('03-'11, t) | Management |
|-----------|--------------------------------|--------------------------------|---|
| Pakistan | Requiem sharks nei | -19,161 | "accessible fishery legislation of Pakistan did not contain any references to sharks" (Fischer et al. 2012) |
| | Rays, stingrays, mantas nei | -11,970 | |
| | Guitarfishes, etc. nei | -1,150 | |
| Sri Lanka | Sharks, rays, skates, etc. nei | -19,019 | "a shark finning ban is the only fisheries management measure explicitly directed at sharks" (Fischer et al. 2012). Sri Lanka prohibited the catch, retention, transshipment, landing, storage, and/or sale of whole bodies or parts of common, bigeye, or pelagic thresher sharks (took effect in 2012) (Shark Advocates International 2012) |
| | Silky shark | -2,798 | |
| | Blue shark | -1,366 | |
| | Oceanic whitetip shark | -889 | |
| Thailand | Thresher sharks nei | -698 | "lack of data and trained staff, the absence of systematic monitoring and control of shark resources...and the absence of a baseline assessment on the status of shark populations" (Fischer <i>et al</i> 2012) |
| | Sharks, rays, skates, etc. nei | -10,665 | |
| | Rays, stingrays, mantas nei | -10,387 | |
| | Sharks, rays, skates, etc. nei | -24,536 | NPOA - two stock assessments to be completed and a TAC (Total Allowable Catch) management |

| | | | |
|---------------------------------|-----------------------------------|---------|---|
| Taiwan, Province of China | Rays, stingrays, mantas nei | -1,319 | scheme will be implemented if the shark resources declined significantly; finning management was introduced (2012) (Fishery Agency 2004). Since 2003 commercial fishing vessels were required to report Blue, Mako, and Silky shark catches separately (Fischer <i>et al.</i> 2012) |
| | Silky shark | 1,058 | |
| | Shortfin mako | 1,855 | |
| | Blue shark | 3,562 | |
| Japan | Sharks, rays, skates, etc. nei | -10,915 | NPOA does not have specific measures for reduction of shark catches (Fisheries Agency 2009) |
| | Whip stingray | -4,557 | |

Table 3.1(b)

| Reporting category | Country | Diff. in landings ('03-'11, t) | Management |
|--------------------|--------------------------|--------------------------------|--|
| Spiny dogfish | United Kingdom | -6,227 | Spiny Dogfish were classified as Critically Endangered in the Northeast Atlantic. Their population was estimated to have fallen by 95% over 100 years. In the EU, in 2011, the TAC was set to zero to allow the population to recover (Fordham 2004). Canada has a quota on the Pacific and Atlantic coasts, however, the Atlantic quota was not based on scientific advice and there were no restrictions on bycatch or discards (DFO 2007). In the United States, the Spiny Dogfish fishery re-opened on May 1, 2011 under a quota (NOAA 2011) |
| | Canada | -5,382 | |
| | New Zealand | -974 | |
| | France | -881 | |
| | Ireland | -865 | |
| | Norway | -781 | |
| | United States of America | 3,907 | |
| Whip stingray | Japan | -4,557 | No information on management. IUCN classified as Near Threatened (Huveneers & Ishihara 2006) |
| Portuguese dogfish | United Kingdom | -1,672 | IUCN classified the European populations of both the Portuguese and Leafscale Gulpher shark as Endangered (Stevens & Correia 2003; White 2003). In 2010, both populations were subject to a zero TAC in EU waters (OSPAR Commission 2010; Shark Trust n.d.) |
| | Portugal | -1,108 | |
| Leafscale gulper | Portugal | -1,538 | |

| | | | |
|--------------------------------|---------|------|--|
| Narrownose smooth- hound | Uruguay | -726 | Classified as Endangered - no information on management (Massa et al. 2006) |
|--------------------------------|---------|------|--|

Countries with the greatest increases in landings over the same period were Spain (20,065 t) then the United States (10,698 t), followed by Argentina (8,748 t), Libya (7,574 t), India (4,998 t) and Nigeria (4,944 t) (Table 3.3 Appendix B). United States had the greatest increase when excluding our previously defined overseas landings. Spain reported the greatest landings increases mainly of Blue Shark and to a lesser extent the Cuckoo Ray (*Leucoraja naevus*, Rajidae) and Shortfin Mako, (*Isurus oxyrinchus*, Lamnidae). In terms of management, the Blue Shark and the Shortfin Mako fisheries currently have no catch limits in the EU; the Cuckoo Ray is subject to a combined Total Allowable Catch (TAC) for all species of skate and ray in EU waters. The greatest landings increase by FAO Fishing Area was recorded in the Eastern Central Atlantic (26,674 t) and Southwest Atlantic (20,083 t).

From a global perspective, the largest increase in categories was Blue Shark (62,907 t), “Stingrays, butterfly rays nei” (40,444 t), and to a lesser extent “Thresher sharks nei” (15,880 t), “Smooth-hounds nei” (6,113 t), “Dogfish sharks nei” (4,705 t) and Little Skate (*Leucoraja erinacea*, Rajidae; 4,520 t). Indonesia switched reporting, however, in 2005 from “sharks, ray, skates, etc, nei” and “rays, skingrays, mantas, nei” into 11 finer resolution reporting categories. Consequently, an increase in a reporting category may be a result of better reporting from Indonesia. Therefore, excluding Indonesia, the categories with the greatest increase are Blue Shark (49,549 t), Little Skate (4,225), Shortfin mako (3,052), Thornback ray (3,042), “Smooth-hounds nei” (2,986), and “Dogfish sharks nei” (2,705).

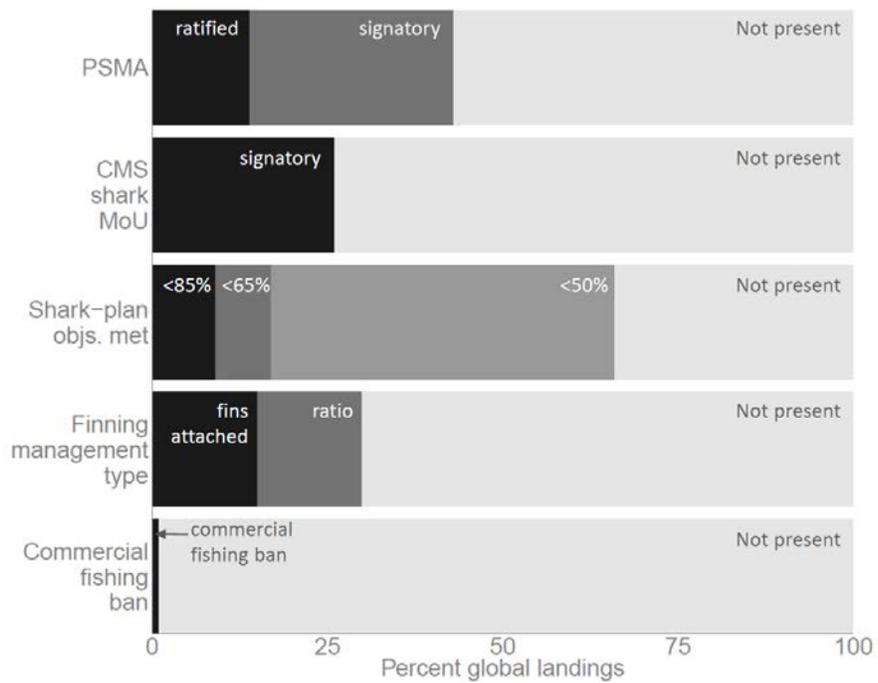


Figure 3.4 The percentage of global shark and ray landings reported from countries with the management measures we considered: PSMA, CMS sharks MoU, *Shark-Plans*, finning management, or commercial fishing ban. The strongest management is represented by the black bar. The light grey bar represents the percentage of landings from countries that do not have/or are not party to the management measure.

1.4.1. What percentage of global reported landings were reported from countries with management measures?

We found that a large share of the global shark and ray landings reported between 2003-2011 appear to be subject to one or more of the management measures we considered (Fig. 3.4). Over a quarter (29%) of the landings was from countries signatory to the agreement but have yet to implement. Fourteen percent of the landings reported were from countries that ratified the PMSA. A quarter (26%) of the landings were from signatories of CMS sharks MoU. Both PMSA and CMS sharks MoU have an implementation bias skewed towards Northern hemisphere countries (Fig. 3.3a,b). Two-thirds (64%) of landings were reported from countries with finalised *Shark-Plans*, but only 9% came from countries with relatively comprehensive *Shark-Plans*, those that met 65-85% of the objectives of sustainable fishing (Fig. 3.4). Ten percent of landings were reported from countries with the strongest finning bans -- a fins-attached policy. Countries with commercial fishing bans had contributed little to the global reported landings. Five out of the six countries with commercial fishing bans did not report any landings, the remainder accounted for less than one percent (0.56%) of the global landings prior to implementation. A quarter (27%) of the global shark and ray landings were from countries that did not report in any species-specific categories, while the majority of landings (75%) are from countries reporting less than a quarter of their landings to species-specific categories. The bulk of the decline in global chondrichthyan catch (80%) occurred in countries with two or fewer of the considered management measures.

Countries with relatively stronger management measures, that we considered, in place showed modest declines in landings. Australia, United States and to a lesser extent Chile, Uruguay – had *Shark-Plans* (addressing between 65-85% of the objectives) but three reported modest declines (<2,000 t) and the United States reported an increase in landings. The strongest finning policy, fins-attached, did show moderate signs of being associated with countries reporting a large share of the reductions: 30% of the decline is reported from countries with a fins-attached policy. This pattern was strongly influenced by Sri Lanka, which adopted fins-attached in 2001. Finally, 18 and 29% of the global decline was reported from countries signatory to CMS sharks MoU or PSMA, respectively.

1.4.2. Was the global trend sensitive to influential countries or reporting categories?

Ten countries accounted for two-thirds (62%) of global shark and ray landings from 2003-2011 (Fig. 3.5a). Removing Taiwan the global trend was less steep (5% higher) (Fig. 3.5b). Indonesia reported the greatest landings but they remained stable over time and therefore had negligible effect on the global landings trend (Fig. 3.5a,b). Spain reported the greatest landings increase and therefore, without their increased landings, the global trend would have been steeper (5% steeper) (Fig. 3.4b).

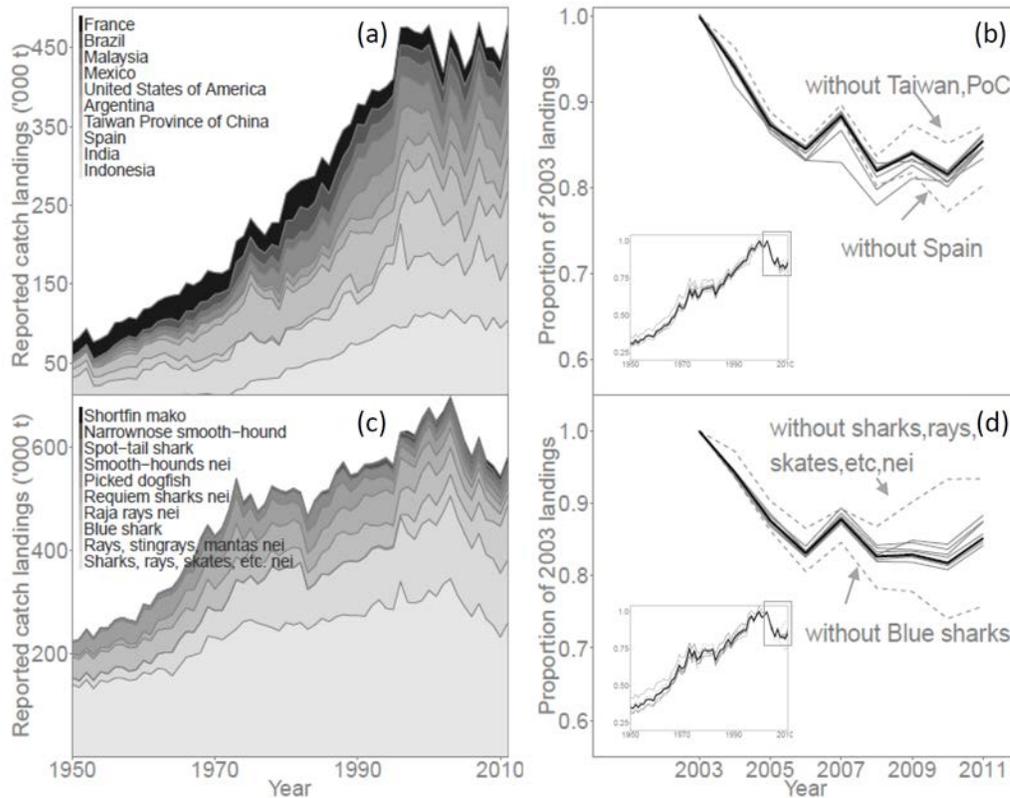


Figure 3.5 Jackknife analysis to test the sensitivity of the global landings trend to influential countries or reporting categories: (a) ten countries that reported the greatest landings between 2003-2011, (b) the influence of these ten country's landings on the global trajectory as determined by recalculating the global trend in absence of their landings, (c) ten reporting categories with the greatest landings between 2003-2011, (d) the influence of these ten reporting categories on the global trajectory as determined by recalculating the trend in absence of their landings. "Sharks, rays, skates, etc, nei" reported the greatest decline and therefore without this category the global trend would be less steep. Without the dramatic increase in Blue shark landings, the global trend would be steeper.

Ten reporting categories accounted for four-fifths (83%) of global landings reported from 2003-2011 (Fig. 3.4c). The taxonomically undifferentiated category of “sharks, skates, rays, etc, nei” declined the most, and therefore this category drove the overall global trajectory (Fig. 3.5c). Excluding “sharks, rays, skates, etc, nei” revealed that the remaining landings would have been less steep (decline of 7%) (Fig. 3.5d).

Contrastingly, the decline in global landings would have been greater had it not been ameliorated by the dramatic increase in Blue Shark landings. Without Blue Shark landings, the global decline would have been 25% (10% steeper than the global trend) (Fig. 3.5d). For this analysis, Indonesia’s landings were not included to get a more accurate picture changes in landings, rather than changes due to reporting category shifts. When Indonesia is included, Blue Shark and “shark, ray, skate, etc, nei” still have the greatest influence (data not shown). Finally, the decline of reported landings in the “sharks, rays, skates, etc, nei” category cannot be accounted for in the increased reporting in the “Blue Sharks” category. Countries that reported declines in “sharks, rays, skates, etc, nei” are not those that reported increased Blue shark landings.

1.4.3. What measures were most important in describing landings trajectories?

Overfishing, rather than improved management was the key driver of declines in shark and ray landings. The most important variables that explained landings trajectories were two measures of indirect fishing pressure – (1) human coastal population size and (2) shark and ray meat exports (Fig. 3.6, Fig. 3.3 Appendix B). The nature of the relationship suggested that countries with higher fishing pressure, and trade, experienced greater declines in landings (Fig. 3.6, Fig. 3.3 Appendix B). While the effect

was weaker, countries that reported greater fin exports, or higher estimated IUU fishing in their waters, reported marginally bigger declines in landings. As expected, all three ecosystem and species attributes explained substantial variability in the majority of models. Specifically, small tropical countries exhibited steeper declines, i.e. those small EEZ's, high endemism, high species richness. Average shark and ray landings reported between 2003-2011 was the most important across all model subsets, and had a positive relationship, however, this variable was only to account for size of fishery and therefore not included in the discussion.

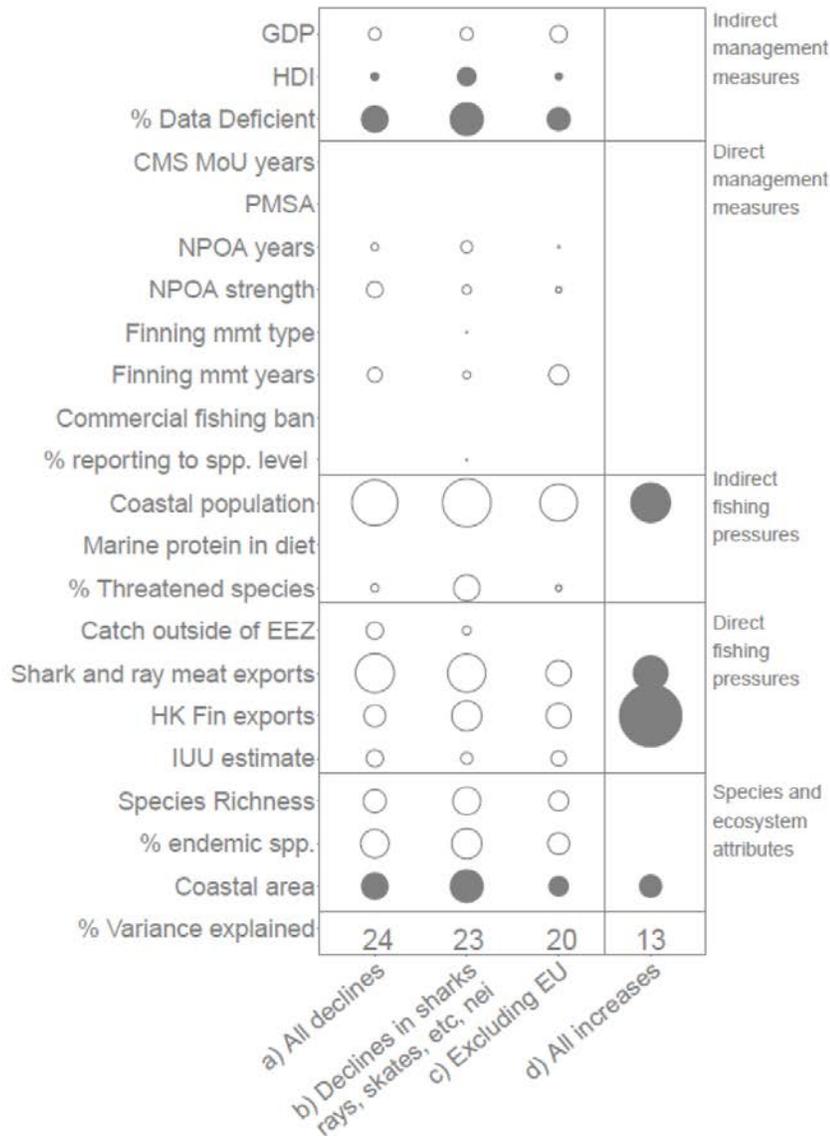


Figure 3.6 Variable importance dot plot for all model subsets. Size of dot represents the Mean Standard Error associated with that variable from a Random Forest analysis. The larger the dot, the more important the variable is in describing the response. Hollow dots represent a negative relationship (see Appendix B Fig. 3.3). Model output for: (a) all countries reporting a decline, (b) country-specific declines only within the “sharks, rays, skate, etc, nei” reporting category, (c) countries that reported a decline, with EU countries excluded, (d) countries that reported an increase in landings.

By comparison, the influence of the indirect and direct management measures was marginal as shown in the partial dependence plots (Fig. 3.3 Appendix B). The most important management-related variable was a measure of the shortfall in scientific capacity: the percentage of Data Deficient species in the EEZ follow by *Shark-plan* year and strength, finning ban years, GDP, and HDI respectively. Countries with low percentage of DD species, finning management in place for longer, larger GDPs, or low HDI report marginally bigger declines (Fig. 3.3 Appendix B). Five of the six unimportant variables were direct management measures and only one fishing pressure measure was unimportant; marine protein in diet.

1.5. Discussion

While the foundations for improved management have been laid, our analyses showed that the implementation was insufficient to account for the global reduction in shark and ray landings. Instead, it is more likely that the decline in shark and ray landings was due to reductions in fisheries catches, likely a result of population declines. The decline in shark and ray landings was strongly related to indirect and direct fishing pressure measures and only weakly related to measures related to fisheries management. Our findings lead to six questions: (1) is there additional evidence for shark and ray population declines?; (2) did aggregate reporting influence our interpretation; (3) what are global priorities to promote shark and ray fisheries sustainability; (4) why did shark and ray landings decline; (5) why were shark and ray management efforts not reflected in landings trajectories; and (6) what effective fisheries management progress has been made?

1.5.1. Is there additional evidence for shark and ray population declines?

There are two independent lines of evidence for widespread shark and ray population declines. First, a recent global analysis of the sustainability of the reported global catch (i.e. not accounting for discards or IUU fishing) suggests coastal species and large predators such as sharks were already heavily depleted by 1975 (Costello et al. 2012). By classifying FAO landings categories into 112 shark and ray fisheries, they found the average biomass of these shark fisheries was 37% of that which would provide Maximum Sustainable Yield (B_{MSY}) (Costello *et al.*, 2012). If B_{MSY} occurs at 30-50% of unexploited biomass, then by 2009 the populations had on average declined by between 81% and 89% from the virgin population baseline (Dulvy, Fowler, et al. 2014; Costello et al. 2012). Second, the IUCN SSG estimates that 25% of all sharks and rays are threatened with elevated extinction risk (Vulnerable, Endangered, or Critically Endangered) primarily as a result of steep declines due to overfishing (Dulvy, Fowler, et al. 2014).

1.5.2. Did aggregate reporting influence our interpretation?

We caution that those countries with stable or increasing shark and ray landings may not have sustainable shark and ray fisheries. There were 62 countries (and overseas territories) reporting stable trajectories (± 150 t) and another 32 with increased landings. Stable or increased landings of aggregate species complexes has been shown to mask declines or disappearance of the most sensitive or more valuable species (Dulvy et al., 2000; Branch et al., 2013). For example, catches of skate species (Rajidae) reported as 'skates and rays' within British waters exhibited a stable trajectory. Yet, species-specific,

fisheries-independent population trends revealed the disappearance of three of the largest skate species, and steep declines in the two largest remaining species. The declines had been masked by compensatory rises in the abundance of the smaller species (Dulvy *et al.*, 2000). Furthermore, the poor taxonomic resolution of fisheries landings data masked the near extinction of the Angel Shark (*Squatina squatina*) from European waters. This species was recorded and sold under the product name “Monkfish”. The decline of the Angel Shark went almost entirely unnoticed because their dwindling catch was substituted with catches of anglerfish (*Lophius* spp.) sold under the same name (Dulvy and Forrest, 2010). Hence, accurate species-specific data on landed catch, and ideally discarded catch, are essential precursors to sustainable fisheries management.

The FAO strongly recommend that all landings be reported to a species-specific level (Fischer *et al.* 2012). Species-specific reporting has to be a condition of entry into fisheries or of fisheries licensing. Refining catches into species-specific categories will allow for better understanding of landings trends, lead to the improvement of management, and inform the true status of individual stocks (Stevens *et al.* 2000). Similarly, fins-attached regulation can improve statistical reporting as carcasses brought back to port can be more readily identified (Fowler & Séret 2010). Transitioning to species-specific reporting will require considerable investment in training, which may require foreign assistance from richer countries with well-developed fisheries management, or cost recover from the industry (Trebilco *et al.*, 2010). We hope such

activities are mainstreamed into the fisheries improvement activities of Development agencies and NGOs (Dulvy & Allison 2009).

1.5.3. What are global priorities to promote shark and ray fisheries sustainability?

Our study highlights the necessity to focus on the sustainability of Blue Shark and “stingrays, butterfly rays nei” fisheries that have together increased by almost 100,000 tonnes over 2003-2011. First, ensuring the sustainability of Blue Shark catches is of high importance given evidence for increased retention and the substantial contribution to global catches in the past decade. In Chile, the retention of Blue Sharks increased almost sixty-fold between 1999-2009 (Bustamante & Bennett 2013). Globally, Blue Sharks fins are estimated to comprise 17% of the overall fin market weight in Hong Kong (Clarke, Magnussen, et al. 2006). Blue Sharks have comparatively higher rates of productivity than other sharks and hence have great potential to be fished sustainably (Kleiber et al. 2009). According to assessments by scientists associated with Regional Fisheries Management Organizations (RFMO's), Blue Shark catches are thought to be sustainable in the Atlantic and Pacific, although no country in this region has adopted quotas or fishing limits for Blue Sharks (Kleiber et al. 2009). There are concerns, however, that stock assessments are not reflecting the recent catch rate declines for Blue Sharks, by 5% per year since 1996-2009, in the North Pacific (Clarke et al. 2013). Unfortunately, these stock assessments are driven by the longest, rather than the most pertinent time series, the latter of which suggests steep declines in catch rate.

Second, the rise of landings in “stingrays, butterfly rays, nei” is mainly as a result of improved reporting by Indonesia. The rise in catches of rays (and skates) is concerning, however, because they are often overlooked by management and are generally more threatened than sharks (Dulvy, Fowler, et al. 2014). Skates and rays (Batoids) are commercially exploited mainly for meat and the fins of the shark-like rays (Devil and Manta Rays (genus *Mobula*) are exploited for their gill plates). Steep declines have been noted for many skates and rays, including: Sawfishes (*Pristidae spp.*, *Pristidae*) (Dulvy, Fowler, et al. 2014), and the largest skates such as the Common Skate (*Dipturus 'batis' complex*, *Rajidae*) (Brander 1981). Despite high risk and high exploitation rates, skates and rays were often overlooked in *Sharks-Plans*, and finning bans (UN FAO 2013).

1.5.4. Why did shark and ray landings declining?

We find that international demands for shark and ray meat products and human coastal population are explaining shark and ray declining trajectories. Therefore, the most plausible explanation for the shark and ray declining landings we observe is that local and international demands are driving fishing pressure and overexploitation.

Coastal human population size has repeatedly been shown to relate to indirect and direct measures of fishing pressure at a range of spatial scales from local to global. Catch rates, direct and indirect effects of fishing are related to the number of islanders on coral reef islands (Jennings & Polunin 1996) and coastal human population density also relates to fisheries footprints and reef health at a regional (Mora 2008; Dulvy et al. 2004) and global scale (Newton et al. 2007). We also found that countries with high

shark and ray meat exports reported larger declines, which indicates an important role of international meat trade in driving overfishing of sharks and rays (Clarke 2014).

1.5.5. Why were shark and ray management efforts not reflected in landings trajectories?

We showed that there has undoubtedly been an increase in national and international commitments and policies specific to chondrichthyan fisheries in the past two decades. Our analyses show, however, that important international commitments have yet to be realised in the form of concrete fishing limits or restrictions on fishing for sharks and rays. This result is probably because the measures we considered, with the exception of CITES, were not yet legally binding, far from comprehensive, lacked clear implementation guidelines, operated with vague wording, and lacked compliance monitoring (Fischer et al. 2012; Lack & Sant 2011). Here, we highlight some of the shortfalls and limitations of the PMSA, CMS sharks MoU, *Shark-plans*, finning bans, and commercial fishing bans that resulted in little or no effect on landings trajectories and provide suggestions for improvements.

Some of the international agreements and initiatives included in our analysis do not have widespread implementation. For example, the Port State Measures Agreement (PMSA) to combat IUU fishing is a new initiative (2009). To date, 26 countries plus the EU countries have signed, only five have ratified. Until ratified, the full potential of this agreement for improving fisheries sustainability cannot be realised. Addressing IUU fishing would have far reaching consequences for the sustainability of shark and ray fisheries (Doulman 2000). The global extent of IUU fishing for sharks and rays is

unknown however, the massive, uncontrolled catches of shark and rays in species-rich countries, in addition to the IUU fishing, is a major problem for the persistence of shark and ray populations. IUU fishing has been noted to be a major problem in Indonesia and for vulnerable endemic sharks (FAO 2014; Fischer et al. 2012). Without controls on IUU fishing, it is estimated that fisheries management decisions are flawed subsequently leading to management goals not being met, and potentially, the overfishing of populations (Doulman 2000; FAO 2013a).

Similarly, CMS sharks MoU potentially had not affected fisheries trajectories as the agreement included a few highly migratory, pelagic species. As of 2012, the eight species listed in the CMS sharks Appendices represent less than 15% of threatened, migratory sharks and rays and no Endangered or Critically Endangered migratory shark or ray has been listed by CMS sharks (Fowler 2012). Also, the CMS needs a mechanism for compliance.

The national and regional *Shark-Plans* reviewed here are non-binding and have been found to emphasize early stages of fisheries management such as communication, finning management, and forming partnerships rather than more direct catch and effort controls (Camhi et al. 2008). *Shark-plans* that were more comprehensive (i.e. Australia, United States, Canada) represented relatively sound management already in place (Fordham, personal communication).

We found commercial fishing bans have been gazetted in countries with very small, or non-existent, commercial shark fisheries (as found in the past 60 years of the FAO landings records). Spatial protections that are strict and no-entry have been shown to increase predator biomass (Robbins et al. 2006). Commercial fishing bans, however, are not no-entry and countries often do not have the enforcement capacity to monitor large marine areas after implementation. For example, Palau has one enforcement boat to monitor the entire EEZ (Vianna, Gabriel, personal communication). Additionally, commercial fishing bans may have limited future conservation benefits as a result of having no protections or management plans in place for shark bycatch mortality (Campana et al. 2011) and mortality from artisanal fishing (Hawkins & Roberts 2004), which can be significant. Therefore, we suggest that commercial fishing ban designation be expanded and extent protection to rays and skates, to bycatch, and to not forestall national and international fisheries management initiatives that promote sustainable resource utilization.

Derogations or loopholes exist that undermine the implementation and effectiveness of finning regulations. First, the relative weight of a shark's fins averages 3% but varies among species from 1.1 to 10.9% of the total weight of the animal (Biery & Pauly 2012). Second, the setting of a fin landing ratio is also complicated by the choice of denominator – whole carcass, gutted carcass or dressed carcass (head removed) (Biery & Pauly 2012). Hence, the use of a blanket 5% fin-to-carcass ratio (Fowler & Séret 2010) can allow for more sharks to be killed and disposed of further complicating mortality estimates (Biery et al., 2012). In addition, some countries have ratios higher

than the recommended 5% and whether the percentage ratio refers to dressed carcasses or whole bodies is unclear (Fowler & Séret 2010). Third, countries may allow for exceptions. Such as, the EU which on November 2012, EU closed a loophole on a fins attached rule that had been in effect since 2003. From 2003 to 2013, five EU countries were allowed to apply for Special Fishing Permits (SFP) exempting them from the fins attached policy. This exception became the rule for Portuguese and Spanish fishing fleets which held 220 (91%) SFPs issued in 2005/6 (Fowler & Séret 2010). Fins naturally attached policy is the most reliable, is the easiest finning ban strategy to enforce (Fowler & Séret 2010), and would permit better data collection.

1.5.6. What effective fisheries management progress has been made?

There have been considerable improvements in the management of shark and ray fisheries. First, Indonesia reports the largest landings of shark and rays to FAO and has made considerable progress in taxonomic resolution of their landings in the past decade. Prior to 2004, Indonesia reported 100,000 t of landings in two aggregate categories: “sharks, rays, skates, etc, nei” and “rays, stingrays, mantas nei” and in 2005 switched reporting into 11 family categories (Fischer et al. 2012). Currently, the majority countries report in an aggregate ‘nei’ category which therefore presents vast opportunity for each country to improve this necessary step towards effective management.

Second, a number of species have recovered under strict management regulations. For example, Great White Shark populations increased in California after a prohibition on catches was implemented in 1994 (Burgess et al. 2014) . Spiny Dogfish also recovered under strict catch quotas in the United States and the fishery re-opened in 2011 (COSEWIC 2011). Third, another encouraging sign of progress includes seven West

African countries that developed a regional plan of action for shark and ray fisheries management. While non-binding and lacking fishing quotas, this coalition has led to improved knowledge of the major shark fisheries, increased landings surveys, improved public awareness, improved understanding of sawfish status, and improved engagement with international conservation efforts such as the 2006 IUCN Red List assessment (Dulvy, Fowler, et al. 2014). Similarly, South American countries (Chile, Columbia, Ecuador, and Peru) have worked together to develop a regional plan of action for the protection and management of chondrichthyans in this region (Gomez 2008).

1.6. Conclusion

We show that the management measures we considered have had little influence on shark and ray fisheries landing trajectories. We interpret these findings, however, as a way to encourage the continued pressure on countries to sustainably manage their shark and ray fisheries. Our analysis determined a number of countries and fisheries that deserve prioritization for conservation and management action. First, fisheries management development is necessary in the countries that report the greatest declines, such as Pakistan and Sri Lanka, and have little to no management in place. Second, countries reporting large increases, or a substantial portion of the world's landings can become the focus of conservation and management efforts to forestall potential impeding population declines (such as Indonesia, Philippines, India, and Spain). Third, countries with relatively stronger management should improve further by sustainably managing fisheries that are of conservation concern and report landings to species-specific categories. These countries also should also work together and support

developing countries with chondrichthyan management as sharks and rays are generally not confined to one national jurisdiction. Fourth, those fisheries with dramatic increases in landings need to be the focus of stock assessments and scientific management. Finally, we strongly suggest that countries implement the current scientific advice that includes, and is not limited to, catch limits, bycatch limits, finning bans, stock assessments, and species-specific data collection.

1.7. Appendix B

Appendix B Table 3.1. Summary table of all predictor variables and definitions. Variables are organized according to their broad category class (Fig. 3.1).

| Variable | Definition |
|---|--|
| <i>Indirect fishing pressure measures</i> | |
| Human coastal population size | Nominal value of persons living 100km from the coast |
| Marine protein in diet | Country specific index of grams/captia/day of marine fish protein available for consumption |
| Percentage of threatened species | Percentage of shark and ray species classified as Vulnerable, Endangered, or Critically Endangered in EEZ |
| <i>Direct fishing pressure</i> | |
| Catch outside of EEZ (tonnes) | Reported landings from FAO major fishing areas that do not overlap with a country's EEZ waters |
| Shark and ray meat exports | Avg. reported export of shark and ray meat from FAO between ('92-'03) in tonnes (see Appendix B Table 3.3). |
| Hong Kong fin exports | Country specific fin exports to Hong Kong in 2011 |
| IUU fishing | Lower estimate of IUU fishing in EEZ waters |
| <i>Indirect fisheries management</i> | |
| Gross Domestic Product (GDP) | Value of a country's economy; standardized to US dollar |
| Human Development Index (HDI) | Composite index that captures a country's development status |
| Percentage of Data Deficient (DD) species | Percentage of shark and ray species classified as Data Deficient (DD) in EEZ |
| <i>Direct fisheries management</i> | |
| Port State Measures Agreement (PSMA) | Countries that have signed and ratified the PSMA to combat IUU fishing. PMSA was initiated in year 2009. |
| Convention of Migratory Species Memorandum of Understanding | Countries that have signed the CMS sharks MoU; an international agreement that lists 8 shark species. |
| <i>Shark-plans</i> (National Plans of Action for sharks) | Duration: years the country had a finalized <i>Shark-plan</i> . Strength: how well the FAO's 10 objectives of sustainable fishing were met (Appendix B Table 3.1). |
| Finning ban | Duration: years finning regulation has been in place. Strength: the type of management plan (Appendix B Table 3.2). |
| Ban on commercial fishing | Ban on commercial fishing for sharks in EEZ. |
| Species specific reporting | Percentage of landings reported (avg. '03-'11) in species specific categories (see Appendix B Figure 3.2). |
| <i>Sensitivity and Resilience: Ecosystem productivity and resilience</i> | |
| EEZ area | Area (km ²) of a country's EEZ |

Species productivity and resilience

| | |
|------------------|--|
| Species richness | Shark and ray species within a country's EEZ |
| Endemic richness | Shark and ray species, within a country's EEZ, with a range size less than the lower quartile of all species |

Appendix B Table 3.2. Summary of commodity codes for shark and ray meat exports and total reported tonnes for 2003 and 2009 (the most recent data).

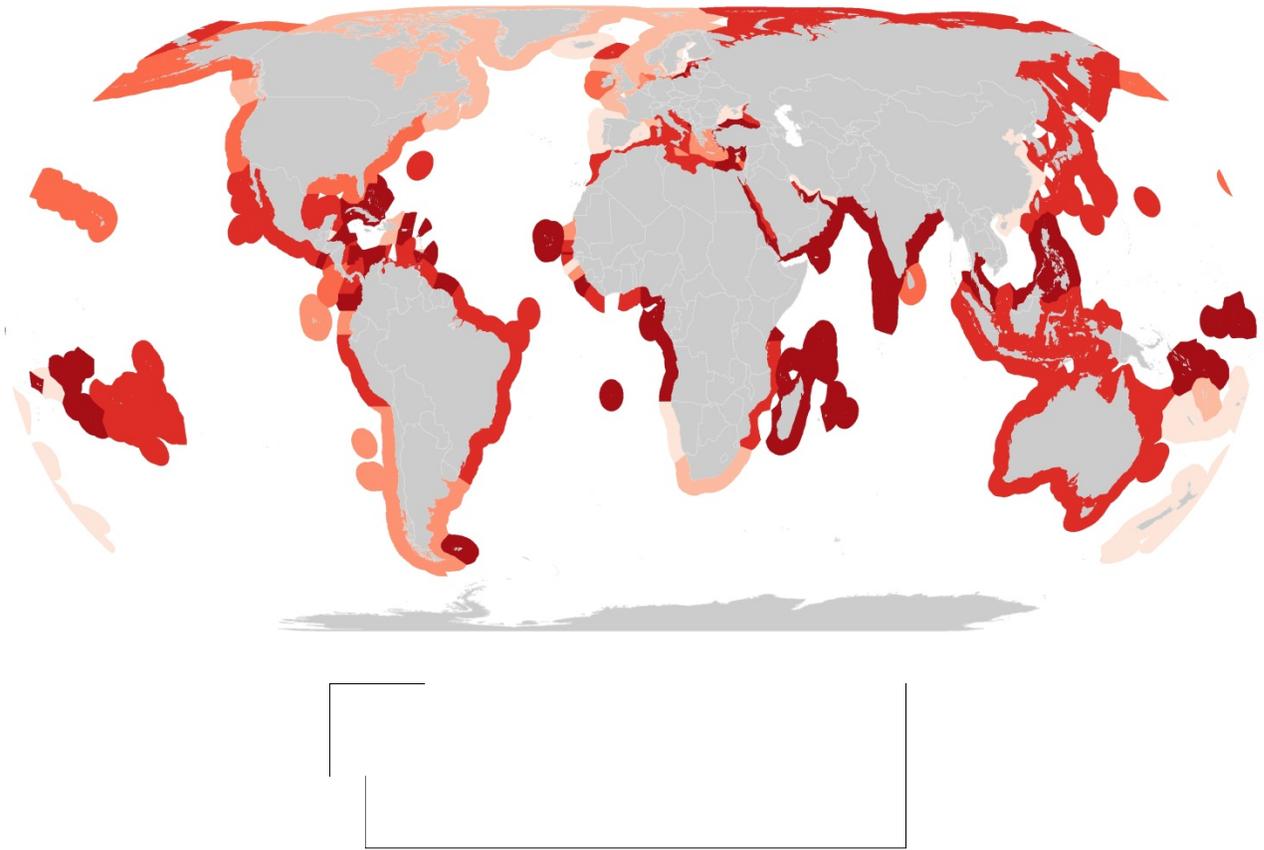
| FAO FishSTAT commodity code | 2003 | 2009 |
|---|--------|---------|
| Shark fillets, fresh or chilled | 15 | 12 |
| Shark fillets, frozen | 3,566 | 4,958 |
| Shark fins, dried, salted, etc. | 0 | 0 |
| Shark fins, dried, unsalted | 0 | 0 |
| Shark fins, frozen | 0 | 0 |
| Shark fins, prepared or preserved | 0 | 0 |
| Shark fins, salted and in brine but not dried or smoked | 0 | 0 |
| Shark liver oil | 51 | 40 |
| Shark oil | 42 | 40 |
| Sharks nei, fresh or chilled | 8,299 | 5,162 |
| Sharks nei, frozen | 40,098 | 81,339 |
| Sharks, dried, salted or in brine | 483 | 347 |
| Sharks, rays, chimaeras nei, frozen | 5,380 | 1,840 |
| Sharks, rays, etc., dried, salted or in brine | 0 | 0 |
| Sharks, rays, skates, fresh or chilled, nei | 89 | 747 |
| Sharks,rays,chimaeras, nei fillets fresh or chilled | 1 | 0 |
| Sharks,rays,chimaeras, skates, nei fillets frozen | 3,523 | 4,472 |
| Skates, fresh or chilled | 818 | 366 |
| Skates, frozen | 208 | 2,652 |
| SUM | 62,573 | 101,975 |

Appendix B Table 3.3. Countries reporting the greatest increase in landings between 2003-2011 in descending order. Only changes of greater than 100 tonnes (per reporting category) were included for brevity.

| Country | Reporting category | Change in landings ('03-'11, t) | Management |
|--------------------------|--------------------------------|---------------------------------|--|
| Spain | Blue shark | 31,077 | no catch limits in EU (Shark Trust, 2014) |
| | Rays, stingrays, mantas nei | 2,450 | NA |
| | Cuckoo ray | 1,187 | Combined TAC in place for all species of skate and ray in EU waters |
| | Shortfin mako | 694 | no catch limits in EU |
| | Thornback ray | 578 | minimum landing sizes have been implemented in some areas of the UK by Sea Fisheries Committees (Ellis, 2005); 2009 subject to TACs in EU waters (Shark Trust, 2014) |
| | Catsharks, etc. nei | 434 | no catch limits in EU |
| United States of America | Tope shark | 401 | no catch limits in EU |
| | Little skate | 4,225 | Currently, no specific management plan in place for Little Skate (NEFMC 2003) |
| | Picked dogfish | 3,907 | NOAA catch limits |
| | Rays, stingrays, mantas nei | 3,610 | NA |
| | Dogfish sharks nei | 1,241 | NA |
| | Rays, stingrays, mantas nei | 3,822 | NA |
| Argentina | Argentine angelshark | 1,539 | IUCN classified as Endangered; operating under Maximum Permitted Catch |
| | Plownose chimaera | 1,502 | unknown |
| | Yellownose skate | 1,168 | There are Total Allowable Catches (TACs), minimum sizes and overall annual quotas for skates, but they are not enforced (Kyne <i>et al.</i> 2007) |
| Libya | Dogfish sharks nei | 6,432 | NA |
| | Smooth-hounds nei | 1,013 | NA |
| India | Sharks, rays, skates, etc. nei | 4,989 | NA |
| Nigeria | Sharks, rays, skates, etc. nei | 4,124 | NA |
| | Rays, stingrays, mantas nei | 820 | NA |

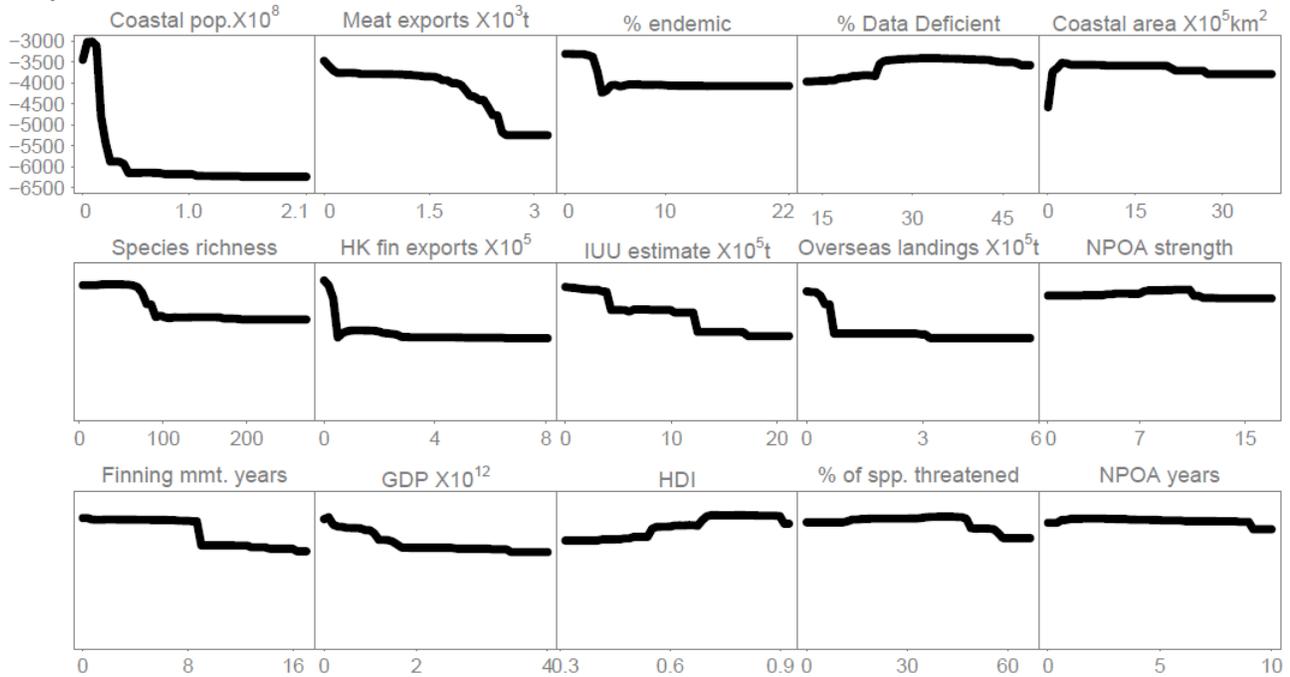
| | Coastal pop. | Marine Diet | GDP | HDI | % spp. reporting | % DD | Finning mmt years | NPOA years | NPOA strength | PSM years | CMS MoU years | FAO Code score | Landings (EEZ) | Outside EEZ | Meat exports | Fin exports | % THR | IUU est. | EEZ area | SR | % Endemic | |
|--------------------------------|--------------|-------------|-------|-------|------------------|-------|-------------------|------------|---------------|-----------|---------------|----------------|----------------|-------------|--------------|-------------|-------|----------|----------|------|-----------|--|
| Coastal pop. | 1 | | | | | | | | | | | | | | | | | | | | | |
| Marine Diet | -0.01 | 1 | | | | | | | | | | | | | | | | | | | | |
| GDP | 0.39 | 0.12 | 1 | | | | | | | | | | | | | | | | | | | |
| HDI | -0.10 | 0.32 | 0.45 | 1 | | | | | | | | | | | | | | | | | | |
| % spp. reporting | -0.29 | 0.27 | 0.08 | 0.50 | 1 | | | | | | | | | | | | | | | | | |
| % DD | 0.12 | -0.08 | 0.06 | -0.14 | -0.19 | 1 | | | | | | | | | | | | | | | | |
| Finning mmt years | -0.31 | -0.21 | 0.11 | 0.57 | 0.53 | -0.31 | 1 | | | | | | | | | | | | | | | |
| <i>Shark-plan</i> years | 0.13 | 0.15 | 0.61 | 0.32 | -0.11 | 0.29 | 0.08 | 1 | | | | | | | | | | | | | | |
| <i>Shark-plan</i> strength | -0.06 | -0.06 | 0.11 | 0.47 | 0.06 | 0.24 | 0.38 | 0.62 | 1 | | | | | | | | | | | | | |
| PSMA years | -0.03 | -0.03 | -0.04 | 0.45 | 0.43 | -0.19 | 0.35 | -0.03 | 0.40 | 1 | | | | | | | | | | | | |
| CMS MoU years | -0.13 | -0.37 | 0.14 | 0.30 | 0.01 | -0.05 | 0.15 | 0.31 | 0.42 | 0.27 | 1 | | | | | | | | | | | |
| FAO Code score | -0.18 | 0.42 | 0.34 | 0.77 | 0.65 | 0.02 | 0.48 | 0.39 | 0.44 | 0.26 | 0.14 | 1 | | | | | | | | | | |
| Avg landings catch outside EEZ | 0.80 | -0.04 | 0.01 | -0.22 | -0.19 | -0.05 | -0.18 | -0.10 | 0.08 | 0.09 | -0.26 | -0.25 | 1 | | | | | | | | | |
| Meat exports | 0.56 | 0.05 | 0.62 | 0.36 | 0.31 | -0.03 | 0.32 | 0.41 | 0.26 | 0.38 | -0.14 | 0.33 | 0.41 | 0.49 | 1 | | | | | | | |
| Fin exports | 0.83 | -0.05 | 0.06 | -0.18 | -0.16 | 0.19 | -0.18 | -0.03 | 0.09 | 0.12 | -0.34 | -0.15 | 0.92 | 0.12 | 0.48 | 1 | | | | | | |
| % THR | 0.12 | -0.10 | -0.13 | -0.44 | -0.55 | 0.07 | -0.61 | -0.14 | -0.08 | -0.23 | -0.02 | -0.32 | 0.19 | -0.07 | -0.32 | 0.12 | 1 | | | | | |
| IUU est. | 0.55 | 0.23 | 0.40 | 0.10 | -0.55 | 0.42 | -0.50 | 0.42 | 0.13 | -0.28 | -0.11 | -0.05 | 0.29 | 0.56 | 0.13 | 0.36 | 0.28 | 1 | | | | |
| EEZ area | 0.15 | -0.13 | 0.15 | 0.26 | 0.13 | -0.24 | 0.49 | 0.19 | 0.37 | 0.29 | -0.15 | 0.34 | 0.22 | -0.05 | 0.54 | 0.23 | -0.02 | -0.02 | 1 | | | |
| SR | 0.47 | -0.03 | 0.27 | 0.02 | -0.46 | 0.53 | -0.21 | 0.47 | 0.31 | -0.29 | 0.00 | 0.08 | 0.27 | 0.36 | 0.08 | 0.38 | 0.10 | 0.77 | 0.18 | 1 | | |
| % Endemic | 0.25 | 0.17 | 0.16 | 0.30 | 0.13 | 0.32 | 0.16 | 0.31 | 0.28 | -0.02 | -0.13 | 0.50 | 0.20 | 0.22 | 0.21 | 0.36 | -0.35 | 0.41 | 0.20 | 0.69 | 1 | |

Appendix B Figure 3.1 Pearson's correlation table. Values highlighted blue represent positive correlations, red boxes are negative correlations. FAO Code of Compliance score was dropped from the analysis due to extensive NAs.

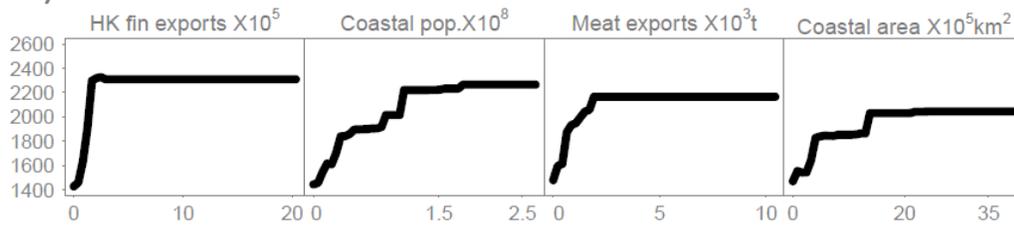


Appendix B Figure 3.2 Distribution of the reporting resolution. Darker colours represent countries that report none of their shark and ray landings to the species level (India reports all landings in “sharks, rays, skates, etc, nei”). Lighter colours are those countries with better taxonomic resolution (greater than 75% of landings to species level). Countries that do not report shark and ray landings have no EEZ mapped.

a) All declines



b) All increases



Appendix B Figure 3.3 Random Forest partial dependence plots of important variables from (a) the model that explained the most variance – all countries reporting a decline. Variables are order from left to right, top to bottom in terms of importance (see Figure 3.8, column one). (b) countries reporting an increase in landings.