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Global governance guard rails for sharks: Progress towards implementing the United Nations international plan of action

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Abstract

There is growing concern over the conservation status of sharks and relatives exposed to fishing mortality. The Food and Agriculture Organization of the United Nations in 1999 adopted the *International Plan of Action for the Conservation and Management of Sharks* (IPOA), which provides nations with advice on adopting and implementing national plans. An assessment of global national and regional plans of action on sharks (NPOAs) found: most are out of date; limited use of specific, measurable and timebound objectives and activities; no outcome objectives; and few performance assessments. This makes most NPOAs inadequate for planning and assessing efficacy. Over 33% of the annual retained catch of sharks and relatives was from countries without NPOAs and less than 12% was from countries with current NPOAs. NPOAs identified fisheries management framework deficits, ecology knowledge gaps, institutional capacity and coordination shortfalls, and budget constraints as the largest obstacles to implementation and are improvement priorities. We recommend how to amend the IPOA to better support the adoption and effective design and implementation of NPOAs for evidence-i nformed conservation and management.

KEYWORDS
bycatch, chondrichthyan, fisheries management, international plan of action (IPOA-shark), national plan of action (NPOA-shark), outcome objectives

1 | INTRODUCTION

Cartilaginous fishes (class Chondrichthyes – sharks, rays, skates, sawfishes and chimaeras) belong to one of the most diverse marine taxonomic groups and include apex and mesopredators with a broad range of ecological roles across coastal, demersal and pelagic marine ecosystems. This includes large-bodied apex sharks with disproportionately large roles in regulating some marine ecosystems (Estes et al., 2016; Ferretti et al., 2010; Heithaus et al., 2014; Polovina & Woodworth-Jefcoats, 2013; Stevens et al., 2000; Ward & Myers, 2005). Although there is high variability in life-history traits amongst chondrichthyans, many have

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relatively low productivity, late maturity and low natural mortality. Despite chondrichthyans' evolutionary success (Stein et al., 2018), due to their life-history characteristics and behaviour, such as spatially segregating by sex and age class, and aggregating for mating and pupping and at nursery grounds, anthropogenic pressures are causing protracted and irrevocable harm and loss, in some cases with broad, ecosystem-level consequences (Ferretti et al., 2010; Stevens et al., 2000).

Since the early 1990s, there has been growing concern over the sustainability of anthropogenic mortality of sharks and their relatives, including by the Food and Agriculture Organization of the United Nations (FAO) (Garcia & Majkowski, 1990). Concerns include unsustainable increases in mortality rates and reductions in abundance, ecosystem-level cascading effects from declines in abundance in some systems, and fisheries-induced evolution and reduced population fitness caused by selective removals based on heritable traits (Dulvy et al., 2021; Ferretti et al., 2010; Heino et al., 2015; Heithaus et al., 2014; Juan-Jordá et al., 2022). There has also been increasing attention to risks to food, nutrition and livelihood security of coastal fishing communities from declining abundance of sharks (Jaiteh et al., 2017; Seidu et al., 2022) as well as, more broadly, to how fisheries bycatch and discards, including of chondrichthyans, is an obstacle to sustainable seafood production (Roda et al., 2019).

Incidentally captured and targeted in fisheries in exclusive economic zones and on the high seas, products derived from chondrichthyans include shark fins used for soup; gill plates from manta and devil rays used for dried seafood and traditional medicine; meat for human consumption and animal feed; skin for apparel; cartilage and liver oil for medicines and fuel; as well as live primarily small-sized species of sharks and rays as ornamentals for the aquaria trade (Akmal et al., 2020; Dent & Clarke, 2015; Dulvy et al., 2017; Gilman et al., 2008). Depending on a fishery's management framework and markets, some of these species may be discarded, targeted, or retained incidental catch, including retention of shark fins and ray gill plates with discarding of the remaining carcass (Dulvy et al., 2017; Gilman et al., 2008; O'Malley et al., 2016). Habitat degradation and loss and chondrichthyan responses to outcomes of human-induced climate change, including ocean warming, deoxygenation, CO_2 concentration and acidification, are additional anthropogenic stressors (Di Santo, 2019; Dulvy et al., 2021; Jorgensen et al., 2022; Perry et al., 2005; Pucca et al., 2018).

Robust estimates of stock status from model-based assessments are available for a very small proportion of chondrichthyans. While almost all ca. 1250 extant species of sharks and rays are susceptible to fishing mortality, fewer than 100 assessments of stock status have been conducted, and due to data quality constraints, many have inconclusive results (Brouwer & Hamer, 2020; Simpfendorfer & Dulvy, 2017). This makes findings from the less data-intensive and global-scale IUCN assessments extremely valuable for this data-limited group.

While there has been disagreement over whether the IUCN Red List criteria are appropriate across the enormous range of life histories and other ecological attributes of global species (excluding microorganisms), including sharks and their relatives (Connors et al., 2014; Kai, 2021; Mace et al., 2008; Musick, 1999), analyses have found IUCN criteria can be consistent with fisheries reference points when analyzed at the same scale (Dulvy et al., 2017; FAO, 2020; Juan-Jordá et al., 2022). Of 1199 species of sharks and rays assessed against the IUCN Red List criteria, 33% were categorized as threatened (i.e., in one of the 3 IUCN Red List threatened categories of Vulnerable, Endangered or Critically Endangered) due largely to fishing mortality from incidental catch. This is a conservative estimate, as 155 species were categorized as data deficient (Dulvy et al., 2021). Most elasmobranchs categorized under the IUCN Red List as threatened with extinction are coastal species (76%, 296 of 391). The remainder are deepwater (17%) and pelagic (6%) species (Dulvy et al., 2021). Of the 52 species of extant chimaera (subclass Holocephali, also referred to as 'ghost sharks'), 69% are Least Concern, 8% Near Threatened, 8% Vulnerable and 15% Data Deficient (Finucci et al., 2021). Just as the conservation status of a population or stock should not be used to characterize the conservation status of a global species,

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applying global species-level threat status may be unsuitable for regional- and local-level management, such as when a population is at risk of exceeding a biological limit threshold or of extirpation but the global species is not threatened with extinction (IUCN, 2016).

Global reported shark landings reached a peak of 868,000 tons in 2000, tripling the weight of estimated retained catch in 1950, and since, as of 2018, declined by about 22% (FAO, 2020). This was most likely due to reductions in abundance and possibly increased underreporting (Clarke et al., 2006; Davidson et al., 2015; Pacoureau et al., 2021). For example, since 1970, pelagic sharks underwent a 71% decline in global abundance due to an 18-fold increase in relative fishing pressure (Pacoureau et al., 2021).

There has been international recognition and response to these threats to chondrichthyans. In 1999 FAO published the voluntary *International Plan of Action for the Conservation and Management of Sharks* (IPOA, FAO, 1999a) resulting from work by FAO and the Technical Working Group on the Conservation and Management of Sharks (FAO, 1999b, 2002; Garcia & Majkowski, 1990). The impetus for developing the IPOA included deliberations by the Parties to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and subsequent adoption of a measure on the international trade of sharks (CITES, 1994a, 1994b, 1997). Furthermore, 3 of ca. 150 migratory elasmobranch species are listed in the Appendices of the Convention for the Conservation of Migratory Species (CMS, 2020). There are 141 elasmobranchs listed in Appendix II of CITES, which controls international trade in their products, and all sawfishes (*Pristidae* spp.) are listed in Appendix I, which prohibits international trade (CITES, 2023).

The IPOA defines 'sharks' to encompass all species within the class Chondrichthyes, includes a broad overarching goal of ensuring "the conservation and management of sharks and their long-term sustainable use", and a guiding principle on sustaining stocks that "management and conservation strategies should aim to keep total fishing mortality for each stock within sustainable levels by applying the precautionary approach" (FAO, 1999a). The IPOA does not prescribe the use of a specific threshold above which national plans of action on the conservation and management of sharks (NPOAs) should be developed. Instead, the plan calls on States to determine if there is a need to develop an NPOA based on: (1) regular assessments of the status of shark stocks exposed to fishing, (2) whether the State has directed fisheries for sharks and (3) whether the State has fisheries that "regularly" catch sharks in non-directed fisheries (FAO, 1999a). The IPOA encouraged States to adopt NPOAs by 2001, recommended that NPOAs include descriptions of the management framework, define objectives and strategies, and prescribed regularly conducting performance assessments of NPOAs (FAO, 1999a).

Expanding the scope of previous assessments of FAO members' implementation of the IPOA (Davis & Worm, 2013; FAO, 2022d, 2022e; Fischer et al., 2012), this study assessed global NPOAs to identify:

1. Countries and territories with relatively high chondrichthyan landed catch that have not adopted or prepared a draft NPOA;
2. The proportion of global landed chondrichthyan catch not derived from a country with an adopted NPOA;
3. Whether country-specific weight of landed chondrichthyan catch was a function of the number of years since a country first adopted an NPOA;
4. Significant explanatory predictors of NPOA adoption;
5. The proportion of NPOAs that are old or expired versus recent or in force;
6. Whether NPOA objectives are specific, measurable and timebound in order to support meaningful performance assessments;
7. Whether NPOAs define specific, measurable and timebound activities;
8. Outcomes of performance assessments to identify progress and obstacles to effective NPOA implementation; and
9. The frequency of application of chondrichthyan bycatch management measures.

Findings identify priority opportunities to improve IPOA guidance and its implementation through NPOAs for evidence-informed conservation and management of chondrichthyans.

2 | METHODS

2.1 | Regions, countries and territories with NPOAs

For convenience, we refer collectively to the plans of action on the conservation and management of sharks and their relatives of regions, nations and territories as NPOAs. Global NPOAs and NPOA performance assessment reports were compiled in August 2022. This included adopted and draft plans and performance assessment reports produced by territories, nations and regional entities. NPOAs and performance assessments were accessed from the FAO (2022b) database, which FAO updates twice a year, and by contacting government authorities and other experts.

2.2 | Exploring potential explanatory predictors of NPOA status

Elasmobranch and chimaera catch levels by country and territory were compiled from FAO fisheries statistics for years 2016 to 2020, the most current 5 years for which data were available (FAO, 2022a). The FAO (2022a) database contains reported landed catch in weight by country and territory and does not include discards (FAO, 2022c). We used the 'Sharks, rays, chimaeras' group (code 38), 'Marine fishes' division of the International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP). The FAO Chondrichthyes catch from this five-year period group contained 1543 unique records (flag state/territory and ISSCAAP code 38 categories), which was comprised of 248 unique categories of 206 species and 42 non-species-specific (aggregate or 'not elsewhere indicated') categories (FAO, 2022a). The FAO (2022a) database did not contain chondrichthyan landed catch data for Myanmar. We used 4089 t of landed rays as a rough estimate based on data from the Myanmar Department of Fisheries Dawei Regional Office for the 2013–14 season. However, this estimate is highly uncertain (DOF, BOBLME and FFI, 2015). The countries/territories included in the study sample were those that are included in the FAO database and that had >0 annual chondrichthyan landed catch in at least 1 year between 1950 and 2020 (FAO, 2022a).

Countries and territories with ≥1% of the global estimated total weight of reported landings of elasmobranchs and chimaeras from 2016 to 2020 were categorized as having relatively high chondrichthyan catch. The countries and territories with high catch that have not adopted an NPOA, and that have not prepared a draft NPOA was determined. The proportion of global landed chondrichthyan catch not derived from a country with an adopted NPOA was also determined.

We also assessed whether the country/territory-specific recent weight of landed chondrichthyan catch (FAO, 2022a) was a function of the number of years since a country/territory first adopted an NPOA. Specifically, we used a multilevel distributional regression modelling approach (Kneib et al., 2022; Umlauf & Kneib, 2018) to assess any functional relationship between the chondrichthyan landed catch for each country/territory and the year of first adoption of an NPOA. The model enabled simultaneous assessment of any trend in both the expected landed catch over time and any variance in that temporal trend. The regression model used thin plate regression spline smooth (Wood, 2006) to account for any nonlinear functional form between the landed catch response variable and any temporal trend. We fitted this distributional regression generalized additive mixed model (GAMM) within a Bayesian inference framework (van de Schoot et al., 2021) with robust Student-*t* likelihood (Anderson et al., 2017) and weakly informative regularizing priors (Lemoine, 2019; Röver & Friede, 2020). The random or group-level effects for each distributional parameter (mean, variance) included 16 UN geographic subregions (UN Statistical Division, 2022) as intercept-only effects. The model was estimated using the Stan computation backend (Carpenter et al., 2017) via the brms interface for R (Bürkner, 2017). Modelling both the expected (mean) and variance of a functional distributional form is increasingly used in ecological and fisheries settings to better understand the temporal population or catch dynamics (Bjorndal et al., 2019; Mamouridis et al., 2017).

All 164 countries and territories included in the study sample (those that are included in the FAO (2022a) database that had >0 chondrichthyan landed catch since 1950) were assigned to one of 4 exclusive NPOA implementation states: (1) no draft or adopted NPOA, (2) draft NPOA prepared but no adopted NPOA, (3) NPOA adopted and is dated where either the most current NPOA or performance assessment >4 years old (the IPOA recommends that States conduct performance assessments of NPOAs at least every 4 years, FAO, 1999a) or the NPOA includes a timeline that extends to <2023, and (4) NPOA adopted and is current (either the most current NPOA or performance assessment ≤4 years old or includes a timeline that extends to at least 2023). We then used a machine learning approach based on a model-based recursive partitioning procedure to assess which factors were predictive of the likelihood of a country/territory having adopted an NPOA or having prepared a draft NPOA. Potentially informative country-specific predictors included:

1. Landed chondrichthyan catch;
2. Gross domestic product per capita in 2020 (from UN, 2022, except American Samoa, Channel Is., Faroe Is., Guam and Isle of Man from World Bank, 2022 and Taiwan from IMF, 2022);
3. An economic complexity index (GENEPY, using the most recent available index for 2017, Sciarra et al., 2020);
4. Whether the country/territory is covered by a regional plan of action for sharks (Table S1);
5. Whether the country/territory is a member or participating territory of an intergovernmental body that has adopted a measure calling for the implementation of the FAO IPOA;
6. Whether the country is a member of the Organization for Economic Co-operation and Development; and
7. Three UN geographical region classification schemes with 5, 8 and 21 categories (UN Statistical Division, 2022) (Table S1).

The basis for selecting 17 regional fisheries management organizations and arrangements (RFMO/As) and 4 intergovernmental bodies with remits broader than managing fishery resources for inclusion in this assessment is summarized in Section S2.

Recursive partitioning is a nonparametric technique that produces a classification or regression tree in which cases are assigned to mutually exclusive subsets (or nodes) according to a set of predictor variables. The result is a decision tree where binary nodal splits (if any) are statistically significant based on permutation tests to support a rigorous conditional inference framework given the predictors (Zeileis et al., 2008). Linear and nonlinear predictor functional form and any interactions are all explicitly accounted for, if applicable. We used a recursive partitioning or conditional inference regression tree approach (Strobl et al., 2009) with an ordinal response (Buri & Hothorn, 2020; Tutz, 2022) to explore what predictors might account for the adoption (or not) of an NPOA. The ordinal response variable here comprised 4 ordered categorical levels: (1) no NPOA, (2) a draft NPOA, (3) NPOA adopted but not current; and (4) NPOA adopted and current. The ordinal response conditional inference tree model was fitted using the PARTYKIT package for R (Hothorn & Zeileis, 2015) with a minimum binary split criterion of 0.95 (i.e., a *p*-value <0.05), where predictors were included in the best-fit model only if they met this minimum split criterion.

Adequacy of model fit was assessed by using the C-index metric (concordance metric, Levshina, 2022) and derived using the somers2() function from the HMISC R package (Harrell, 2015) — since the response variable is a 4-level ordinal measure we used the average of pairwise C-indices to derive an ordinal response C-index

(Levshina, 2022). We also derived the ordinal response classification rate or accuracy metric for the best-fit model using the confusionMatrix() function in the caret R package (Kuhn, 2008) as another measure of model adequacy.

As part of the modelling workflow, we also used an ensemble of the conditional inference tree (a forest of conditional trees) to assess relative predictor importance in the final accepted or best-fit binary decision tree (Strobl et al., 2009; Tutz, 2022). The ensemble or conditional random forest was also fitted using the PARTYKIT package for R (Hothorn & Zeileis, 2015). Machine learning-based recursive partitioning procedures are increasing used in ecological and fisheries settings to understand risk factors and screen for potential predictors of subgroup membership (Gonzalez-Pestana et al., 2021; Pfaller et al., 2018; Zentner et al., 2022).

2.3 | Specific, measurable and timebound process, impact and outcome objectives and activities

The IPOA recommends that NPOAs define objectives (FAO, 1999a). Objectives stated in NPOAs were assessed to determine whether they are specific, measurable and timebound and thus support performance assessments (Bjerke & Renger, 2017; Chen, 2015; Davis & Worm, 2013). For example, an objective of maintaining a stock near a specified target reference point over the life of a 5-year workplan, reducing the catch rate or annual magnitude of bycatch by a specified percentage relative to a defined baseline within the next 3 years, or having vessels employ a particular gear design (e.g., no longline wire leaders) or fishing method (e.g., no purse seine sets on live whale sharks) by a specified date would support a performance assessment. Objectives of maintaining healthy shark stocks, improving shark species identification capacity and minimizing waste and discards from captured sharks all lack specificity as they are subject to variable interpretations, are not measurable as they do not define a quantitative outcome, nor are they timebound.

We distinguish between *outcome* objectives that specify a response from interventions on populations, stocks or species of chondrichthyans and *process* and *impact* objectives that specify a process or performance of an activity that is indirectly related to an end result outcome on conservation status (Grant, 2012; Gregory et al., 2012). For example, a specific and measurable chondrichthyan outcome objective could specify that a stock's biomass is maintained above a biological limit reference point, that a depleted stock meets a recovery target such as increasing adult female biomass to above 0.3 times the estimated unfished biomass, or that the global conservation status of a species changes from a threatened to least concern category. An impact objective might specify that a fishery caps its annual catch or retention of a specified species, that all vessels in a fishery adopt a gear design or fishing method that increases selectivity to reduce a shark species' susceptibility to capture or fishing mortality, or that spatially and temporally predictable critical habitat (e.g., nursery habitat, migration corridor) of a threatened shark is closed to fishing. A process objective could be to conduct a stock assessment, convene a meeting to discuss alternative target and limit reference points, develop a training program for port samplers to improve their elasmobranch species identification skills, or conduct research to identify critical habitat of a threatened chondrichthyan population.

Similarly, we determined whether NPOA's include one or more specific and measurable activity and whether a specific and measurable activity is also timebound. The IPOA recommends that NPOAs include strategies or activities for achieving objectives (FAO, 1999a). The study also assessed whether timebound activities, if any, are currently in effect.

2.4 | NPOA performance assessments, progress and challenges

The IPOA recommends that States conduct performance assessments of NPOAs at least every 4 years (FAO, 1999a). For each adopted NPOA, we determined whether a performance assessment was conducted and the date of the assessment. We extracted information from the compiled performance assessments to determine whether they report the achievement of specific, measurable and timebound objectives and information on identified obstacles to implementing planned activities.

2.5 | NPOAs' chondrichthyan bycatch mitigation methods

The IPOA recommends that NPOAs describe the State's management framework (FAO, 1999a). Most chondrichthyan catch is from incidental capture (Dulvy et al., 2021; Simpfendorfer & Dulvy, 2017). We extracted and assessed the subset of conservation and management measures included in NPOAs to mitigate the bycatch of incidentally captured chondrichthyans. We determined the frequency of application of 16 categories of bycatch mitigation approaches. These high-level categories of methods to avoid and minimize bycatch, remediate at-vessel an post-release bycatch mortality and offset residual bycatch of chondrichthyans are defined in the second column of Table 1. In addition, we identify NPOAs that identify their existing fisheries management framework as including a partial or comprehensive harvest strategy for a chondrichthyan stock that is exposed to bycatch fishing mortality.

For each high-level bycatch mitigation method that involves avoiding or minimizing catch risk, Table 1 identifies relevant attributes for susceptibility to capture. These capture susceptibility attributes are as follows: spatial and temporal overlap, vertical overlap ('encounterability' or the probability of encountering the gear based on the vertical habitat distribution of the species relative to the fishing depth of the gear) and selectivity (Hobday et al., 2011; Stobutzki et al., 2002). The last four bycatch mitigation approaches included in Table 1 do not affect capture susceptibility.

TABLE 1 Approaches to avoid, minimize, remediate and offset the catch and fishing mortality of chondrichthyans (Gilman et al., 2023; Gilman, Hall, et al., 2022; Hall et al., 2017; Poisson et al., 2016).

Capture susceptibility attribute	Bycatch mitigation approach
Spatial and temporal overlap	**Static and dynamic area-based management tools**: Permanent static closures; permanent, static spatially explicit restrictions on gear designs and fishing methods; spatially explicit input and output controls; seasonal time/area closures such as at habitat critical for life history stages; quasi-real time dynamic spatial management through habitat suitability and species distribution models, move-on rules and fleet communication; and other area-based measures such as areas zoned for defence.
All	**Input controls**: Limited entry, vessel size limit, limit on amount of gear that can be deployed, limit on number of fishing days or fishing operations, limit on soak duration, ban a gear type
All	**Output controls**: Bycatch thresholds (individual vessel quotas, risk pools, fleetwide caps), retention limits and bans for marketable species, shark finning bans
All	**International trade ban** through CITES (2023)
Vertical overlap	**Depth and time of day of fishing**
Selectivity	Gear designs and materials that **increase escapement**
	Gear designs and materials that **reduce entanglement risk**
	Shielded gear
	Repellents
	Mismatch between morphological characteristics and gear design
	Reduced gear attractiveness
	Reduced gear detection
Not applicable	**Offsets**: Direct, compensatory banking or in lieu fee-based offsets of residual impacts that were not possible to avoid, minimize and remediate
Not applicable	**Changes in fishing methods and gear designs to reduce pre-catch, at-vessel or post-release mortality risk** by reducing stress and injury
Not applicable	**Handling and release best practices to reduce post-release mortality risk**
Not applicable	**Derelict gear mitigation**: Minimize production and ghost fishing efficiency and duration of abandoned, lost and discarded fishing gear

3 | RESULTS

3.1 | NPOA status and chondrichthyan landed catch

There are 55 adopted NPOAs by: (1) 7 regional entities for Central America, European Community, Mediterranean Sea, Pacific Islands, Rio de la Plata Treaty Area, Southeast Pacific and West Africa; (2) 47 nations; and (3) 1 territory (Table S1). Eleven nations have prepared draft NPOAs (Table S1). Of the 164 countries and territories included in the study sample, 68 are covered by an adopted regional plan (Table S1). Of the 116 countries and territories in the study sample with no draft or adopted NPOA, 59% are not covered by a regional plan. The mean and median year of publication of the most recent versions of adopted NPOAs is 2012.

The total mean annual global landed catch of chondrichthyans from 2016 to 2020 was 690,229 tonnes, of which 66.5% was from 47 nations and 1 territory with an adopted NPOA (Table 2), 6.6% from 11 countries with a draft NPOA and 26.9% from 105 countries and territories without an adopted or draft NPOA (Table S1). Less than 12% of recent annual landed chondrichthyan catch is from countries with current NPOAs (Table 2).

Of the 164 countries and territories included in the study sample, 22 had relatively high chondrichthyan landed catch with ≥1% of the total landed chondrichthyan catch, with 79.7% of the recent weight of global landed chondrichthyans (Table S1). Of these 22 countries, 14 have adopted an NPOA and had combined annual mean recent chondrichthyan landings of 58.0% of the global total, 3 have draft NPOAs (Tanzania, Pakistan and Oman, 3.4% of global chondrichthyan landings) and the remainder (Spain, Nigeria, Portugal, France and Iran, 18.3% of global chondrichthyan landings) have not adopted or prepared a draft.

3.2 | Distributional regression model

The expected trend in landed chondrichthyan catch as a function of the adoption year for the first version of an NPOA for 48 countries/territories is shown in Figure 1a. Countries and territories with higher landed chondrichthyan catch were largely early NPOA

TABLE 2 Summary of findings on the status of global adopted NPOAs. Current NPOAs were adopted, revised or assessed ≤4 years ago or have a timeline that extends through at least 2023.

NPOA status finding	Percent
NPOAs with a specific and measurable outcome objective	0.0
NPOAs that employ harvest strategies for chondrichthyan stocks exposed to bycatch fishing mortality	0.0
Objectives that were specific, measurable and timebound	7.5
NPOAs with timebound and current activities	9.1
Recent annual chondrichthyan landed catch from countries and territories with current NPOAs	11.9
NPOAs that are current	12.7
Latest versions of NPOAs >4 years old and have undergone performance assessments	16.3
NPOAs that identify one or more required measure that increases fishing gear selectivity to minimize chondrichthyan bycatch	21.8
NPOAs that have undergone a performance assessment and reported achieving 1 or more specific, measurable and timebound objective	33.3
NPOAs with 1 or more specific, measurable and timebound activities	50.9
Recent landed chondrichthyan catch from nations and territories with NPOAs	66.5
NPOAs that describe an existing chondrichthyan management measure	69.1

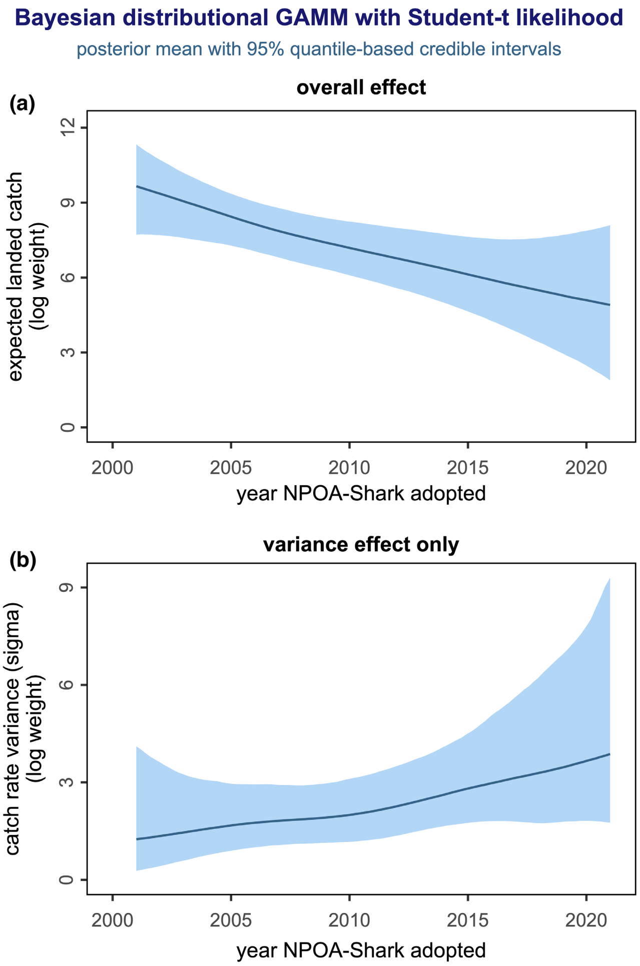

FIGURE 1 Distributional regression model. (a) Expected mean trend in landed chondrichthyan catch while simultaneously accounting for the modelled variance. (b) Modelled variance trend (a component of the mean trend shown in panel a). The response variable is landed catch (weight, mt on log scale). Solid curve = expected conditional temporal trend, polygon = 95% credible interval.

adopters, while those with lower landed catches were generally more recent adopters. The recent landed chondrichthyan catch of 14 countries that first adopted an NPOA during the 6-year period between 2001 and 2006 was 30% of the total global recent catch, while the 34 countries and territories that first adopted an NPOA during the 15-year period between 2007 and 2021 was 37% of the total (including Indonesia in 2015 and India in 2021, which accounts for 14% and 8% of the total recent landed chondrichthyan catch, respectively). The variance in the estimated temporal trend in landed catch increased slightly in more recent years (Figure 1b), suggesting that recent adopters comprised a mixed range of landed chondrichthyan catches compared to the early adopters. Japan and USA were the only countries to have adopted an NPOA by 2001 as prescribed by the IPOA (FAO, 1999a).

3.3 | Recursive partitioning model

Of the 9 explored potentially informative predictors, the conditional inference tree approach identified 2 significant nodes at the minimum split criterion of 0.95: (1) landed chondrichthyan catch ≤300 mt or > 300 mt; and (2) subregions within the higher landed catch subgroup split into regions of (a) Africa and Europe, and (b) the Americas (North, Central, South, Caribbean), Asia and Oceania (Figure 2). The average C-index metric for the best-fit ordinal inference tree model was 81% while the predictive accuracy rate was 0.76 (95% CI: 0.69–0.83), which all indicate that the best-fit ordinal inference tree model (Figure 2) was a good fit to the 164 records for NPOA adoption status (Kuhn, 2008; Levshina, 2022). A conditional forest ensemble comprising the same set of predictors confirmed that the 2 most important predictors of NPOA ordinal status were landed chondrichthyan catch and the 21 UN geographic subregions combined into 2 regional subgroups of Africa/Europe and Americas/Asia/Oceania.

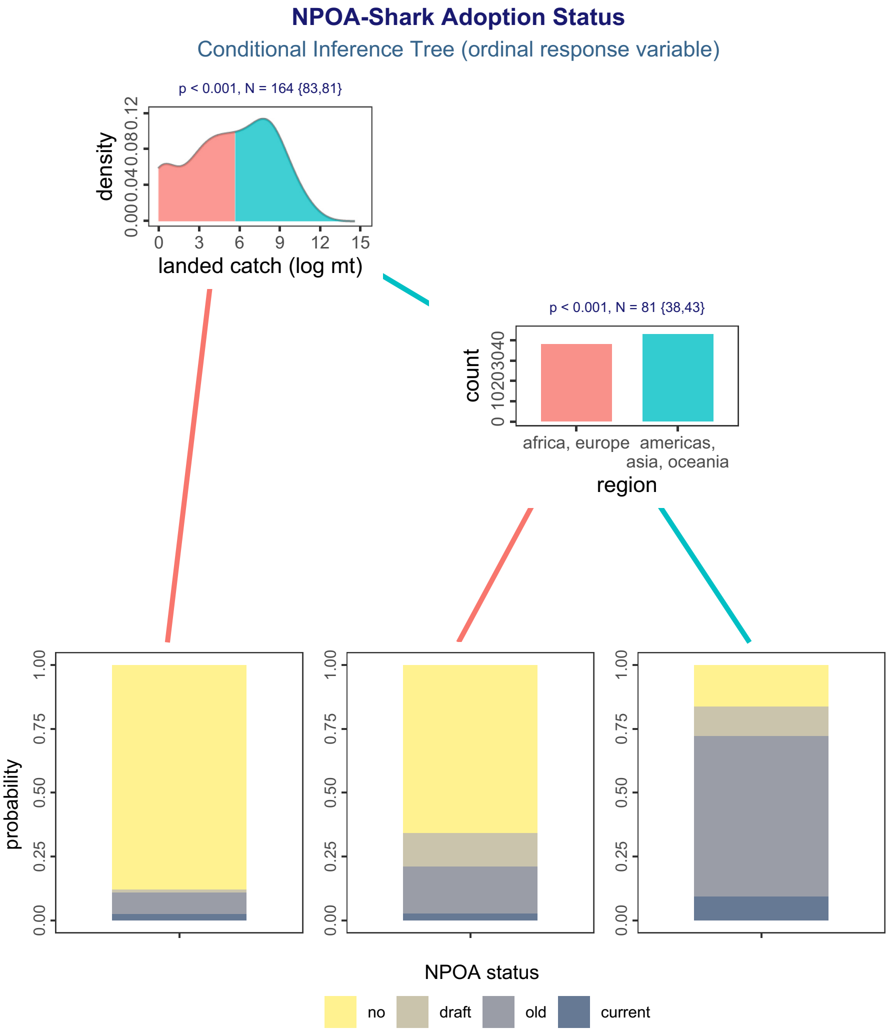

FIGURE 2 Model-based recursive partition tree. Conditional inference tree showing 3 mutually exclusive subgroups of countries and territories with (1) relatively low recent annual landed chondrichthyan catch, (2) relatively high landed chondrichthyan catch and within Africa or Europe, and (3) relatively high landed chondrichthyan catch and within the Americas, Asia or Oceania, defined by model-based recursive partitioning given the 2 informative predictors of landed chondrichthyan catch and region. The stacked bar in each terminal node summarizes the predicted conditional probability for each of the 4 ordinal responses (no NPOA, draft NPOA, adopted and old NPOA, adopted and current NPOA) for that subgroup. An old adopted NPOA = adopted, revised or assessed >4 years ago or includes a timeline that ends prior to 2023. A current adopted NPOA = adopted, revised or assessed ≤4 years ago or has a timeline that extends to at least 2023.

The three terminal nodes of the fitted model are stacked bar summaries of the predicted conditional probability of NPOA status for each of the three subgroups. Figure 2 shows that countries/territories with lower landed chondrichthyan catch (≤300 mt, which is 5.7 mt on a log scale as used on the *y* axis in the top left panel of Figure 2) were most likely to have not adopted an NPOA (bottom left panel: no NPOA adopted probability = 0.88). Countries/territories in the higher landed catch and Africa/Europe regional subgroup were also less likely to have adopted an NPOA (bottom middle panel: no NPOA adopted probability = 0.66). For countries/territories with higher landed catch and in Africa/Eu-rope there was a higher probability of adopted NPOAs not being current (probability = 0.18) than current (probability = 0.03). Coun-tries/territories in the higher landed catch and Americas/Asia/Oceania regional subgroup were most likely to have adopted an NPOA (bottom right panel: the combined probability of NPOA adoption whether dated or current = 0.72; no adoption probability = 0.16). Similar to the higher catch Africa/Europe subgroup, the higher catch Americas/Asia/Oceania subgroup had a relatively high probability of adopted NPOAs being dated (probability = 0.63) than current (probability = 0.09).

Membership in one of four tuna-RFMOs that has adopted a measure calling for implementation of the FAO IPOA (Table S2) helps explain this finding that macro-region significantly explains NPOA status for countries with higher recent landed chondrichthyan catch. Countries in the Americas/Asia/Oceania regional subgroup were 1.6 (95% HDI: 1.1–2.4) times more likely to be a member of one of these four RFMOs than those in the Africa/Europe subgroup. Furthermore, countries in the Americas/Asia/Oceania regional subgroup who are a member of one of the four RFMOs that adopted a measure calling for implementation of the FAO IPOA (Table S2) were 7.3 times (95% CI: 1.6–39.3, $p < 0.004$) more likely to have an old, non-current NPOA than countries in the subgroup who are not members of those RFMOs.

3.4 | Specific, measurable and timebound objectives and activities

Of the 55 adopted NPOAs, 13 contain at least one specific, measurable and timebound objective. The 55 NPOAs define 414 objectives, of which 31 were specific, measurable and timebound. None of the

NPOAs contain specific, measurable and timebound outcome objectives (Table 2).

Of the adopted NPOAs, 52 include activities related to the conservation and management of chondrichthyans, 43 contain at least one activity that is specific and measurable and 28 have at least one specific, measurable and timebound activity. Five of the NPOAs have timebound activities that are current, with schedules that extend to 2023 or beyond (Ecuador, India, Papua New Guinea, South Africa, Thailand) (Table 2).

3.5 | NPOA performance assessments, identified obstacles

Of the 55 NPOAs, 9 have undergone a performance assessment, and 3 of these 9 plans reported having achieved 1 or more specific, measurable and timebound objective. Of the 49 most current versions of NPOAs that are >4 years old, 8 have undergone a performance assessment (Table 2).

Thirty-one NPOAs and six performance assessment reports identified 203 obstacles to NPOA implementation. The most frequently identified deficit was inadequate fisheries monitoring systems and monitoring data (22% of obstacles, 81% of NPOAs). Gaps in knowledge of chondrichthyan biology and ecology, distributions, population structure, stock status and ecosystem effects of fishery removals was the second most frequently identified deficit preventing NPOA implementation (16% of obstacles, 71% of NPOAs). Deficits with control (laws, management measures, regulations, license agreements), surveillance and enforcement systems were the third most frequently identified constraint (14% of obstacles, 58% of NPOAs). Budget constraints (8% of obstacles, 45% of NPOAs), inadequate staff capacity to identify chondrichthyan catch to the species level (5% of obstacles, 35% of NPOAs) and institutional deficits, including poor interagency coordination within nations and poor intergovernmental coordination amongst states (5% of obstacles, 32% of NPOAs), were additional identified obstacles.

3.6 | NPOA chondrichthyan bycatch management measures

Of the 55 NPOAs, 69% described 1 or more existing chondrichthyan management measure, and these same 38 plans also described 1 or more chondrichthyan bycatch management measure. The 140 bycatch measures included in these NPOAs included 8 of the categories of bycatch management measure included in Table 1:

- Output controls: 86 measures, including 31 finning bans and 31 retention bans.
- CITES restrictions on international trade: 17 measures
- Input controls: 14 measures, including for example bans on purse seine sets on whale sharks, bans on certain gear types and limited entry.
- Area-based management tools: 9 measures.
- Increased escapement: 7 measures, bans on using wire leaders by pelagic longline fisheries.
- Managing fishing depth: 2 measures, bans on the use of shark lines by tuna pelagic longline fisheries (attaching branchlines to floats or floatlines in order to fish shallow to target epipelagic sharks).
- Handling and release methods: 2 measures.
- Mismatch between morphological characteristic and gear design: 2 measures, minimum mesh size.

The other 9 bycatch mitigation categories in Table 1 (derelict gear mitigation, managing the time of day of fishing, gear designs and materials that reduce entanglement risk, shielded gear, repellants, reduced gear attractiveness, reduced gear detection, offsets and modifications to fishing methods and gear to reduce pre-catch and at-vessel mortality) were not described as being employed in the NPOAs. None of the NPOAs describe employing harvest strategies for a chondrichthyan stock that is exposed to bycatch fishing mortality.

4 | DISCUSSION AND CONCLUSIONS

Combined, the old age of most NPOAs, and very limited employment of performance assessments, which is hindered by little use of specific, measurable and timebound objectives and activities, indicates that NPOAs are largely inadequate for effective planning and assessing the efficacy of activities for the conservation and management of chondrichthyans. This is consistent with findings from an assessment of NPOAs from a decade earlier (Lack & Sant, 2011). With only 9 of 55 NPOAs having undergone a performance assessment and only 3 reporting that they had achieved specific, measurable and timebound objectives, the study findings were inconclusive on the effects of implementation of the IPOA on the conservation and management of chondrichthyans, which are now largely depleted globally (Dulvy et al., 2021; Pacoureau et al., 2021). Instead, countries might be using NPOAs as an *end* per se to meet their ‘soft law’, non-binding, voluntary obligation, and not as a *means* for planning their chondrichthyan management activities. An often-cited benefit of soft laws, including non-binding international obligations is that they are dynamic, allowing for changes over time (Abbott & Snidal, 2000), and we propose ways to amend the IPOA to improve the likelihood of achieving its overarching goal of ensuring the conservation and management of chondrichthyans and their long-term sustainable use.

In combination with improvements to the IPOA and NPOAs proposed below, it is a priority to have remaining nations with high chondrichthyan fishing mortality adopt NPOAs and to regularly assess and update NPOAs. Over two decades since the adoption of the IPOA, nations with NPOAs now represent two thirds of the estimated global recent chondrichthyan landed catch. However, this leaves a third that is not from fisheries of nations with an NPOA. Furthermore, less than 12% of recent annual chondrichthyan retained catch is derived from fisheries of countries with a current (recently adopted, revised or assessed, or current timeline) NPOA. Being a member of an RFMO that has called upon members to implement the IPOA has not resulted in maintaining current NPOAs, as indicated by member countries with relatively high chondrichthyan catch from the Americas, Asia and Oceania who have a disproportionately high likelihood of having non-current NPOAs. It is a priority for nations to regularly assess and revise NPOAs when necessary. The 11 nations with draft NPOAs only represent 6.6% of annual landed chondrichthyan catch, and thus moving draft plans to adoption would provide only a small contribution to filling this gap, although the cumulative benefits of small improvements are important, and fisheries with relatively small chondrichthyan catch be a hazard to individual threatened populations. Identifying why the 8 countries with relatively high chondrichthyan landed catch without an NPOA have not adopted one is a priority, which is information that is not available in member reports to the Committee on Fisheries of the FAO Council (FAO, 2022d, 2022e). Budget constraints, identified by about half of NPOAs reporting obstacles to implementation, may also be an obstacle to NPOA preparation and adoption for some countries.

The IPOA calls for States to adopt an NPOA when: “their vessels conduct directed fisheries for sharks or if their vessels regularly catch sharks in non-directed fisheries,” (FAO, 1999a). The IPOA does not define what constitutes shark-t argeting fisheries nor regular shark incidental catch. None of the 55 NPOAs specify a quantitative threshold for chondrichthyan bycatch that was the basis for deciding whether to adopt an NPOA. The IPOA should be amended to include explicit guidance on chondrichthyan bycatch that warrants nations adopting an NPOA. An assessment of the implementation of the IPOA-seabirds similarly identified a lack of explicit criteria to determine whether a national plan is needed (Good et al., 2020). This proposed more specific guidance could include thresholds for the proportion of global chondrichthyan landed catch, proportion of total catch of an individual stock, proportion of fisheries catch, and whether stocks and species of conservation concern are exposed to a nation's fisheries. Additional precautionary criteria could be included that are suitable for data-limited fisheries and stocks, such as identifying gear types that are understood to pose the largest global hazard to chondrichthyans due to bycatch of pelagic longline, demersal longline, benthic trawl, drift and fixed gillnet and tuna purse seine (Croll et al., 2015; Dulvy et al., 2016; Finucci et al., 2021; Gray & Kennelly, 2018; Oliver et al., 2015).

We used recent chondrichthyan landed catch as an indicator for countries with the highest total chondrichthyan fishing mortality. However, the FAO global landings database has limitations. These include reporting chondrichthyan landed species in aggregated categories such as “marine fishes not identified” that cause underestimates for chondrichthyans (Fischer et al., 2012; Friedman et al., 2018), and not accounting for underreported and unreported landed catch (Garibaldi, 2012; Zeller et al., 2018), including for chondrichthyan species included on CITES appendices (Okes & Sant, 2022). More importantly, identifying priority countries by relying on landed chondrichthyan catch did not account for other components of total fishing mortality, which unfortunately are largely not available for most fisheries. Other components of total fishing mortality that were not accounted for are pre-catch losses, dead discards, ghost fishing mortality, post-release mortality and collateral (unaccounted or cryptic) mortality (Gilman et al., 2013; ICES, 2005; Uhlmann & Broadhurst, 2015). For example, observer coverage rates remain at very low levels in most fisheries, where, for instance, 47 of 68 fisheries that catch marine resources managed by RFMOs have no observer coverage (Gilman et al., 2014), creating very limited availability of fisheries discards data. Discard rates are unavailable for over two thirds of global fisheries (Roda et al., 2019).

The IPOA should be amended to clarify that specific, measurable and timebound objectives and activities are needed in NPOAs for meaningful performance assessments. As stated in New Zealand's NPOA performance assessment, when objectives are vague, a “lack of performance measures to assess progress meant that assessments by Advisory Group members were somewhat subjective, and members did not always agree” (New Zealand Ministry for Primary Industries, 2021). Similarly, and consistent with the current study findings, Davis and Worm (2013) highlighted the lack of timebound activities as a critical deficit with Canada's NPOA. Good et al. (2020) also recommended the employment of specific and measurable objectives for seabird national plans to implement the IPOA-seabirds. Of the half of FAO member nations (98) that participated in FAO's most recent survey of implementation of the IPOA, 29 nations with adopted NPOAs reported that their degree of NPOA implementation with regard to policy was 79%, 83% on legislation, 84% on institutional frameworks and 81% on operations and procedures (FAO, 2022d, 2022e). Here we found that very few NPOAs include specific, measurable and timebound objectives (over 76% of NPOAs lack any specific, measurable and timebound objectives, and over 92% of the objectives in adopted NPOAs are not specific, measurable and timebound) with only 5 of 55 NPOAs containing activities that state timelines that extend until at least 2023. Furthermore, only 9 NPOAs have undergone a performance assessment, and only 3 reported achieving a specific, measurable and timebound objective. Several NPOAs adopted the 10 aims stated in the IPOA as the NPOA objectives. However, none of the IPOA aims are specific or measurable. The IPOA could be improved by clarifying how the IPOA's overarching, general aims could be translated into specific, measurable and timebound objectives, and in turn, activities to achieve each objective. This in turn would present a theory of change by providing clearer guidance on how the IPOA intends for NPOAs to improve shark conservation and management.

The IPOA should be expanded to recommend that NPOAs include explicit, measurable and timebound objectives and activities to address deficits across all components of robust management frameworks to address fishing mortality and other priority threats to chondrichthyans. This includes, for example, monitoring, control, surveillance, enforcement and outcomes of enforcement actions (Cochrane, 2002), as well as raising social values for chondrichthyans (Fischer, 2021; Manfredo et al., 2021), and harmonizing and integrating national management frameworks within broader regional frameworks, such as RFMO harvest strategies for stocks of highly migratory chondrichthyans. The IPOA could also include in the suggested contents for NPOAs the role of market-based mechanisms in achieving improvements in fisheries governance and fishing practices that are related to the effects of fisheries on chondrichthyans (Cannon et al., 2018; Martin et al., 2012; Roheim et al., 2018).

The assessment of NPOA objectives did not evaluate whether objectives are achievable nor relevant, which are two additional components of 'SMART' (specific, measurable, achievable or assignable, relevant and timebound) objectives (Bjerke & Renger, 2017; Doran, 1981), as this may depend on the fishery-specific enabling environment, which may not be possible to ascertain based only on evaluating the information contained in NPOAs. For instance, a data-limited fishery with minimal or no onboard observer and electronic monitoring coverage might initially be restricted to adopting primarily process objectives, such as having all vessels in a fishery use a gear design to increase shark selectivity or reduce fishing mortality by a specified date, and not outcome-based objectives, such as achieving a threshold catch rate or fleetwide catch level (Gilman, Hall, et al., 2022). Furthermore, in some cases, it may be desirable to intentionally establish challenging objectives, as advocated by goal-setting theory (Locke & Latham, 2013), such as when addressing a dire and acute problem, such as the imminent extirpation of a chondrichthyan population.

Whether a country/territory is covered by a regional plan of action for sharks was not an informative predictor of NPOA adoption. However, regional plans might have influenced decisions to develop NPOAs within the assessed UN regions, such as for the European Union, where all 23 countries covered by the European Union's regional plan and that are part of the study sample lack a draft and adopted NPOA (Table S1a). The 7 regional plans do not state that they eliminate the need for national plans and, in some cases, explicitly clarify this point. For example, the Pacific Islands regional plan states that, "The development of an RPOA [regional plan of action]… does not remove the necessity for the PICTs [Pacific island countries and territories] to undertake national assessments of their…fisheries as a basis for deciding whether…an NPOA should be developed," (Lack & Meere, 2009). Similarly, the Mediterranean Sea regional plan states that its purpose is to identify priorities and actions to be implemented at national and regional levels while encouraging individual States to adopt national plans (UNEP, 2003). The IPOA does not discuss the role of nor prescribe developing regional plans of action (FAO, 1999a) and could be amended to describe their role in complementing but not replacing national-level plans, to plan, coordinate and harmonize regional-level chondrichthyan conservation and management activities. This is consistent with a recommendation made by Davis and Worm (2013) who proposed developing a regional plan for the Canadian Atlantic and Arctic region in order to provide a mechanism for coordinated implementation of species-specific management plans. The IPOA could highlight the benefit of regional plans in defining regional-level output objectives, such as harvest strategies for highly migratory straddling stocks.

Largely consistent with an assessment of NPOAs from a decade earlier (Fischer et al., 2012), inadequate fisheries monitoring and fisheries data; gaps in knowledge of chondrichthyan biology and ecology; deficits with control, surveillance and enforcement systems; and budget constraints were the four most frequently identified obstacles to NPOA implementation (as well as obstacles to performance assessments and plan revisions). These are global improvement priorities. For territories, countries and regions with deficits in one or more fisheries management component of monitoring, control, surveillance and enforcement, FAO (2009) recommended incrementally implementing the IPOA, which could be conducted while simultaneously improving and augmenting the robustness of their management framework.

The lack of outcome objectives in NPOAs, and no reference to the employment of harvest strategies to manage chondrichthyan stocks, is concerning. The IPOA could be expanded to describe the benefits of outcome objectives and harvest strategies for the conservation and management of chondrichthyans. Harvest strategies include choices about data collected, assessment methodologies and predefined harvest control or decision rules, which are management responses, such as the measures summarized in Table 1, that are implemented to reduce the exploitation rate when a stock is at risk of exceeding a biological limit threshold or to keep the stock fluctuating around a target threshold, where the latter can be selected based on achieving an agreed balance of biological and socioeconomic objectives (Rayns, 2007; Skirtun et al., 2019). By engaging in a Management Strategy Evaluation (MSE) process (Punt et al., 2016; Sainsbury et al., 2000), alternative harvest strategies could be tested to demonstrate that these outcome objectives could be achieved by a given strategy. MSE simulates the likely performance and tradeoffs of alternative harvest control rules against the management objectives and accounts for the effects of uncertainty (MSC, 2022; Punt et al., 2016). The MSE process also helps to clarify management objectives in that objectives become clearer as stakeholders and managers explore tradeoffs revealed through the simulation analysis. For NPOAs to have maximum operational effectiveness, having specific objectives and a harvest strategy demonstrated to be able to achieve these objectives is essential. With neither specific objectives nor strategies, the plans have limited operational utility.

There are several potential reasons why NPOAs do not describe harvest strategies as part of their current or planned chondrichthyan management framework. A large proportion of chondrichthyan fishing mortality is from incidental catch in multispecies fisheries targeting more valuable species (Dulvy et al., 2021; Juan-Jordá et al., 2022), where management authorities tend to develop robust, comprehensive harvest strategies only for principal market species. Furthermore, a very small proportion of chondrichthyan stocks have undergone robust stock assessments with conclusive findings (Simpfendorfer & Dulvy, 2017). While the incidental catch and the lack of reliable stock assessment might be perceived to preclude applying harvest strategies, there are tools to address these issues. Tools are in development to evaluate multispecies tradeoffs, including from incidental catch (Huynh et al., 2022; Kaplan et al., 2021). As to the potential unreliability of assessments for bycatch species, one purpose of MSE is to test harvest strategies when the assessment model is considerably in error (Butterworth, 2007) and to consider harvest strategies that need not necessarily employ assessment models at all (Carruthers & Hordyk, 2018). The development and implementation of national fisheries harvest strategies might be challenging in countries with capacity limitations. However, because many stocks occur in multiple EEZs and the high seas (particularly for highly migratory pelagic species), harvest strategies and stock assessments tend to be more appropriate for regional and not national fishery bodies (Juan-Jordá et al., 2022). Yet the regional plans also lacked outcome objectives, and national-level plans could include objectives to improve regional management of straddling chondrichthyan stocks.

While over two-thirds of NPOAs include summaries of existing chondrichthyan management frameworks, as prescribed by the IPOA (FAO, 1999a), most plans are outdated, with more than half being over a decade old. NPOAs therefore very likely do not provide a contemporary characterization of chondrichthyan management measures. Furthermore, many of the plans provide examples of a sample of management measures and not comprehensive summaries.

While recognizing these limitations, the gaps in the use of several high-level categories of bycatch mitigation approaches suggest that there is a need to improve national fisheries management authorities' awareness of the full suite of approaches to manage chondrichthyan bycatch. The IPOA should be expanded to provide this information. The gaps in bycatch mitigation approaches included mitigating (i) the production and ghost fishing by abandoned, lost and discarded fishing gear (Gilman et al., 2021; Macfadyen et al., 2009); (ii) pre-catch, at-vessel and post-release mortality risk (Ellis et al., 2017; Gallagher et al., 2014; Gilman, Chaloupka, et al., 2022; Musyl & Gilman, 2019); (iii) several methods to increase fishing gear selectivity such as reducing the attractiveness of the gear by using certain bait species and artificial bait and not using light attractors (Gilman et al., 2020; Poisson et al., 2016); and (iv) bycatch offsets (Booth et al., 2020; Gilman et al., 2023). These NPOA gaps are potentially substantial opportunities to improve global chondrichthyan conservation and management measures.

The IPOA should be expanded to describe which approaches to mitigating chondrichthyan bycatch are appropriate based on fishery-specific retention practices and other management measures, and for non-retained species, their at-vessel and post-release mortality rates. For example, the IPOA states that NPOAs should aim to minimize shark discards (FAO, 1999a). While discard bans may incentivize fishers to implement more selective fishing gear designs and methods to reduce catch rates of unwanted species and sizes of catch subject to the ban, this might substantially exacerbate fishing mortality of chondrichthyan species with low at-vessel and post-release mortality rates (Ellis et al., 2017; Gilman, Chaloupka, et al., 2022). Therefore, this recommendation in the IPOA should be revised to improve clarity on under what conditions discard bans are likely to be effective in supporting conservation objectives. For chondrichthyan species with low at-vessel as well as post-release mortality rates, in addition to reducing catchability, prescribed handling-and-release practices and policy interventions that, under certain enabling environments, reduce retention, including retention bans in shark sanctuaries, and shark finning and trade bans, can effectively reduce fishing mortality (Friedman et al., 2018; Gilman, Chaloupka, et al., 2022). The most promising approach to reduce the fishing mortality of species with either high retention rates or that have high at-vessel or post-release mortality rates is to employ methods that reduce catch risk. For these species, retention bans, shark finning restrictions and other output controls might be ineffective unless they indirectly lead to the use of methods that reduce their catch rates. Bans on retention and international trade might cause fishers to change targeting practices, discontinue retention and prevent species subject to the retention and trade bans from becoming targets (Tolotti et al., 2015). Similarly, shark finning bans might reduce retention of species with little or no market value other than for the fins, and might result in fishers discontinuing the use of fishing methods and gear designs to target sharks. However, for species retained for their meat and other products (due to existing market demand or demand created by increasing supply of shark meat caused by finning bans), and where black markets for fins exist, finning bans are unlikely to reduce mortality rates (Clarke et al., 2013; Worm et al., 2013). Retention bans and, consistent with findings of a previous review of NPOAs by Fischer et al. (2012), finning bans, were the two most frequently employed chondrichthyan management measures identified in the NPOAs.

In selecting chondrichthyan management measures, the IPOA should also be expanded to recommend that States account for key criteria when developing and updating NPOAs. Criteria for assessing alternative chondrichthyan bycatch management strategies include the tier in a sequential mitigation hierarchy (Booth et al., 2020; Gilman et al., 2023); costs to economic viability, practicality and fisher safety; size of the effect on bycatch fishing mortality; and the relative strength of evidence of efficacy (Gilman & Chaloupka, 2023). The IPOA could describe a criterion for assessing multispecies conflicts, where some management measures can benefit one threatened bycatch species but exacerbate the catch or mortality risk of others (Gilman, Chaloupka, et al., 2019). And the IPOA could include a criterion on the likelihood of compliance, which is determined by whether crew behaviour affects efficacy, whether fishers are predicted to voluntarily implement the method, and whether the fisheries management framework is sufficiently robust to deter non-compliance (Gilman, Hall, et al., 2022).

In summary, the following are proposed supplements to the IPOA to support NPOAs achieving robust chondrichthyan conservation and management:

- Provide specific guidance on criteria that warrant NPOA adoption, suitable for both data-rich and -limited conditions.
- Explain the benefits of defining specific, measurable and time-bound objectives and activities in enabling effective NPOA implementation and meaningful performance assessments.
- Provide guidance on how NPOAs could comprehensively address deficits of fisheries management frameworks, including monitoring, control, surveillance, enforcement, outcomes of enforcement actions and social values.
- Describe how regional plans can complement but do not replace national plans, and provide guidance on the role and benefits of regional plans.
- Describe the benefits of outcome objectives over process and impact objectives.
- Describe approaches for chondrichthyan bycatch management and
- Highlight the importance of accounting for the following criteria when considering alternative bycatch management strategies:
    - fishery-specific enabling environment,
    - tier in a sequential mitigation hierarchy,
    - costs to commercial viability,
    - likelihood of compliance and
    - conflicts with other threatened species.

This study conducted the first comprehensive assessment of the implementation of the IPOA. The old age of most NPOAs, limited performance assessments, and limited use of specific, measurable and timebound objectives and activities suggest that NPOAs are largely not being used by nations to plan nor assess the efficacy of chondrichthyan conservation and management activities. To improve implementation, the IPOA should be amended to clarify that specific, measurable and timebound objectives and activities are needed for meaningful performance assessments, that these objectives and activities should address deficits across all components of a robust fisheries management framework and that outcome objectives and harvest strategies are critical for the conservation and management of chondrichthyans. Countries with higher landed chondrichthyan catch were early NPOA adopters. However, two decades since adoption of the IPOA, over 36% of countries with relatively high chondrichthyan landed catch have not adopted an NPOA. Less than 12% of recent annual chondrichthyan retained catch is derived from fisheries of countries with a current NPOA. It is a priority to have remaining nations with high chondrichthyan fishing mortality to adopt NPOAs, and for nations to regularly assess and update NPOAs. Amending the IPOA to define specific criteria, including quantitative thresholds, to determine whether nations should adopt an NPOA might contribute to achieving current NPOAs by all countries with high chondrichthyan catch and fishing mortality. This is especially the case for countries in Africa and Europe, which had a relatively low probability of having adopted an NPOA, however, countries in all regions had a low probability of having a current (recently adopted, revised or assessed) NPOA. The IPOA could be expanded to describe how regional plans can be designed to complement but not replace national-level plans. The IPOA should also be expanded to identify the full suite of approaches for managing bycatch, clarify under what conditions alternative bycatch mitigation approaches are effective at reducing chondrichthyan fishing mortality and define criteria for bycatch management strategies. Inadequate fisheries monitoring, gaps in knowledge of chondrichthyan biology and ecology, and deficits with control, surveillance and enforcement systems were the most frequently identified obstacles to NPOA implementation, highlighting global improvement priorities. Findings identify priority opportunities to improve the guidance provided by the IPOA and its implementation through NPOAs for local to global evidence-informed conservation and management of chondrichthyans.

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CONFLICT OF INTEREST STATEMENT

The authors declare no competing interests.

DATA AVAILABILITY STATEMENT

This paper analyzed existing, publicly available data. Any additional information required to reanalyze the data reported in this article is available from the lead contact upon request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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