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Policy and transparency gaps for oceanic shark and rays in high seas tuna fisheries

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Abstract

The incidental capture by marine fisheries as bycatch poses a global threat to pelagic sharks and rays. In large, industrialized fisheries that often operate in areas beyond national jurisdiction, at least 22 threatened species of pelagic elasmobranchs are caught as bycatch, representing the majority of megafauna bycatch in tuna fisheries. Here, we investigate (1) the efficacy of the current policies of the five tuna-related Regional Fisheries Management Organizations (tRFMOs) in mitigating elasmobranch bycatch, (2) data needed to better assess the amount and impact of elasmobranch bycatch and (3) the research necessary for the adoption of new policies. We found that tRFMOs have adopted 34 active policies that address pelagic elasmobranch bycatch. However, most policies (~76%, $n = 26$) are unlikely to avoid or minimize elasmobranch bycatch. Instead, most policies focus on mitigating post-capture mortality via remediation and requiring or encouraging research and data collection. Despite the emphasis on research mandates, we find that the existence of research was not related to policy adoption, suggesting that lack of research has not historically prohibited policymaking. Overall, we suggest that current research and data transparency, though perhaps not necessary for policy adoption, are not sufficient to adequately evaluate the population-level impacts of bycatch on many elasmobranch species in tRFMO-managed fisheries. Given these results, we recommend a precautionary approach that involves reforms in tRFMO voting processes to facilitate the adoption of binding requirements for elasmobranch catch limits, bycatch avoidance, pre- and post-capture handling and release modifications and protection of areas important to threatened pelagic elasmobranchs.

KEYWORDS
bycatch, elasmobranch, management, mitigation hierarchy, tRFMO

1 | INTRODUCTION

Many oceanic sharks and rays have globally declining populations (Dulvy et al., 2021; Pacoureau et al., 2021). Due to their vulnerable life histories, pelagic sharks, rays and skates (together referred to as pelagic elasmobranchs) are generally at greater extinction risk than other marine vertebrates (Dulvy et al., 2008, 2014). Globally, pelagic elasmobranch populations are estimated to have declined by more than 70% over the past half century (Pacoureau et al., 2021). The impact of these declines is ecologically and socioeconomically significant: many elasmobranch species are apex predators that play important roles in marine food webs, as well as for coastal ecotourism sectors and livelihoods (Baum et al., 2003; Gallagher & Hammerschlag, 2011; Grubbs et al., 2016).

These declines have been attributed mainly to accelerating overexploitation by fisheries (Davidson et al., 2016; Pacoureau et al., 2021). While some elasmobranchs are targeted for their meat or fins, fisheries bycatch (unintentional capture in fishing gear) may make up as much as 50% of the total global elasmobranch catch (Bonfil, 1994). Industrial fishing fleets targeting large epipelagic fish like tuna and swordfish are a primary source of capture of large numbers of pelagic elasmobranchs (Clarke et al., 2014; Gilman et al., 2008, 2014; Molina & Cooke, 2012). Publicly available data for bycatch species in these fisheries are sparse, but some suggest that pelagic shark and rays make up the majority of their megafauna bycatch (Clarke et al., 2014; Hall & Roman, 2013). For example, in the Western and Central Pacific Fisheries Commission (WCPFC), which publishes reported bycatch data from tuna fisheries collected by fisheries observers, elasmobranchs make up 97.6% of reported megafauna bycatch in terms of individuals (Figure 1; WCPFC, 2022). While comparable data are not readily available for other regions, available evidence suggests that elasmobranch catch is similarly high in other tuna fisheries (Clarke et al., 2013; Hall & Roman, 2013; Queiroz et al., 2019). Further, it is likely that pelagic elasmobranch bycatch is even higher than reported data for these fisheries due to poor compliance, low observer coverage and poor enforcement of reporting requirements (Babcock & Pikitch, 2011; Forget et al., 2021; Miyake et al., 2004; Oliver et al., 2015).

These fisheries mainly operate on the high seas (i.e., the ocean area beyond national jurisdiction) and have expanded their geographic range and capacity over the past half century (Swartz et al., 2010). Established by international agreement under the United Nations Convention on the Law of the Sea, these fisheries are broadly managed by five tRFMOs (Table S1; Figure S1). tRFMOs are comprised of Contracting Parties and Cooperating Members (CCMs), or nations and territories with an interest in fishing migratory species in an ocean region. These regulatory bodies set policy by formally adopting Resolutions, Recommendations or Conservation and Management Measures (CMMs), which are agreements that detail binding and non-binding responsibilities for members (Table S3). These can be broad policies for all elasmobranchs, as well as more tailored policies specifically for each or a subset of the 22 pelagic species (13 shark species and 9 rays) that are most frequently captured and reported (Table 1; Tolotti et al., 2015). In the context of pelagic elasmobranch conservation, these measures apply to the majority of vessels fishing the high seas (and many in coastal waters as well) and thus exert considerable and critical influence over the sustainability of regional elasmobranch populations (Gilman, 2011).

tRFMOs were originally tasked with the management of a handful of tuna and tuna-like species at the ocean basin scale. However, over the last several decades all but one tRFMO have included non-target or ecologically related species in their convention texts (e.g., convention agreements, Table S1; Juan-Jordá et al., 2017; Pons et al., 2018). All five tRFMOs have passed recent CMMs specifically focused on elasmobranchs. Despite these efforts, tRFMOs have still failed to demonstrate significant bycatch reduction for most taxa in spite of several decades of fishery management (Cullis-Suzuki & Pauly, 2010; Gilman, 2011). This has led to calls for more meaningful action to mitigate their impacts on non-target species (Juan-Jordá et al., 2017; Techera & Klein, 2011).

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There are multiple reasons cited for tRFMOs' failure to reduce bycatch, including low rates of data collection and reporting, lack of biological and fishery knowledge necessary to design effective policies (Gilman & Kingma, 2013; Koehler, 2013), insufficient capacity to develop policy and poor enforcement and compliance of existing measures. The lack of adequate scientific knowledge, often in the form of stock or population assessments, is a particular challenge for pelagic elasmobranchs. Many species are data-poor and lack the basic population-level demographic and life history data necessary to conduct a stock assessment (Clarke et al., 2013). Further, the absence of a stock assessment is often used as argument by tRFMO delegates to prevent the adoption of bycatch reduction policies for pelagic elasmobranchs (e.g., IOTC, 2014; Mandelik et al., 2005; Tolotti et al., 2015).

However, it is unclear whether and what scientific knowledge is required for the successful adoption and implementation of bycatch mitigation policy. It is likewise unclear if regulatory policies currently in place are effective in mitigating bycatch of pelagic elasmobranchs in tuna fisheries. In this study, we examine (1) the efficacy of the current policies of the five tRFMOs in avoiding or reducing elasmobranch bycatch, (2) data needed to better assess the amount and impact of bycatch on impacted elasmobranch species and (3) the research necessary for the adoption of new policies. Answering

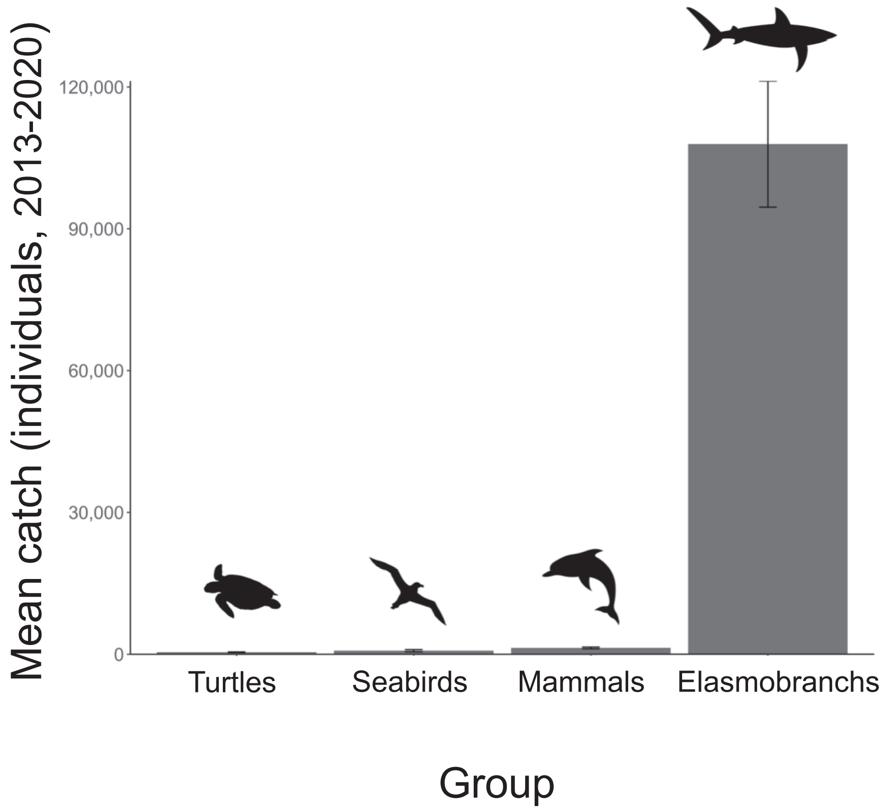

FIGURE 1 Annual mean bycatch ± SE in number of individuals reported in public domain data from WCPFC. Elasmobranchs make up the majority (97.6%) of reported megafauna bycatch from 2013–2020. Data from https://www.wcpfc.int/public-domain-bycatch

these questions can help understand the efficacy of current tRFMO elasmobranch bycatch mitigation policy and identify the research necessary to develop and adopt effective elasmobranch bycatch reduction policy in the future.

One way to assess the effectiveness of regulatory policies for conservation goals is by using a mitigation hierarchy, a risk-based biodiversity conservation approach initially developed to mitigate terrestrial biodiversity loss (Mandelik et al., 2005). This approach has been adapted for marine megafauna (Arlidge et al., 2020; Milner-Gulland et al., 2018) and recently applied to elasmobranch bycatch (Booth et al., 2019). The mitigation hierarchy includes five measures important in identifying and mitigating the impacts of bycatch: *Avoid* the likelihood of capture, *Minimize* the likelihood of capture, *Remediate* capture by reducing the likelihood of post-capture mortality, *Compensate* to pay monetarily for damage done to the population and *Research* the impact of bycatch (Figure 2; Milner-Gulland et al., 2018). This framework is structured as a hierarchy of management options according to the relative likelihood of reducing bycatch mortality, with *Avoid* approaches having the greatest likelihood and *Research* having the lowest likelihood to reduce immediate bycatch mortality (Booth et al., 2019).

Despite its broad utility, the bycatch mitigation hierarchy has not been applied to pelagic elasmobranch bycatch in tRFMOs. We use it here to classify current tRFMO pelagic elasmobranch bycatch policies and their efficacy in reducing or mitigating bycatch. Specifically, we identify the tRFMO policies that are currently in place for addressing pelagic elasmobranch bycatch, classify those policies according to the mitigation framework approaches to understand their likely relative efficacies and ascertain whether the availability of scientific information is a necessary precursor to policy adoption. Finally, we use a scoring rubric to identify major gaps in data collection and availability, that, if addressed, would enable more informed and effective management and conservation for pelagic elasmobranchs. Overall, we aim to understand whether tRFMO pelagic elasmobranch bycatch mitigation policies are adequate to meet the stated aims of elasmobranch conservation.

2 | METHODS

2.1 | Pelagic elasmobranch species

We focus on a subset of 22 threatened pelagic elasmobranchs (Table 1) that have been the centre of recent conservation concern. All are listed under the Convention on International Trade in Endangered Species (CITES) Appendix II and the Convention for Migratory Species Appendix II (Cardeñosa et al., 2018; Vincent et al., 2014), with the exception of blue shark (*Prionace glauca*, Carcharhinidae), which is listed on CMS but not CITES. In addition, all these species are the focus of data collection and policy efforts in tRFMOs. We omitted elasmobranch species that have been listed on CITES, but which are not currently the focus of data collection or policy in any tRFMO because their catch is low or largely undocumented.

TABLE 1 Pelagic elasmobranch species included in this study. All species except *Prionace glauca* were recently listed on CITES appendix II, and all species are reported in tRFMO capture records

Common name	Species	Family	IUCN Red List Designation	Distribution	CITES appendix
Pelagic thresher	*Alopias pelagicus*	Alopiidae	EN	Indian, Pacific	II
Bigeye thresher	*Alopias superciliosus*	Alopiidae	VU	Global	II
Common thresher	*Alopias vulpinus*	Alopiidae	VU	Global	II
Silky shark	*Carcharhinus falciformis*	Carcharhinidae	VU	Global	II
Oceanic whitetip shark	*Carcharhinus longimanus*	Carcharhinidae	CR	Global	II
Shortfin mako shark	*Isurus oxyrinchus*	Lamnidae	EN	Global	II
Longfin mako shark	*Isurus paucus*	Lamnidae	EN	Global	II
Porbeagle	*Lamna nasus*	Lamnidae	VU	Global	II
Reef manta ray	*Mobula alfredi*	Mobulidae	VU	Indian, W. Pacific	II
Oceanic manta ray	*Mobula birostris*	Mobulidae	EN	Global	II
Longhorned pygmy devil ray	*Mobula eregoodootenkee*	Mobulidae	EN	Indian, W. Pacific	II
West Atlantic pygmy devil ray	*Mobula hypostoma*	Mobulidae	EN	Atlantic	II
Shorthorned pygmy devil ray	*Mobula kuhlii*	Mobulidae	EN	Indian, W. Pacific	II
Spinetail devil ray	*Mobula mobular*	Mobulidae	EN	Global	II
Munk's devil ray	*Mobula munkiana*	Mobulidae	VU	E. Pacific	II
Sicklefin devil ray	*Mobula tarapacana*	Mobulidae	EN	Global	II
Bentfin devil ray	*Mobula thurstoni*	Mobulidae	EN	Global	II
Blue shark	*Prionace glauca*	Carcharhinidae	NT	Global	—
Whale shark	*Rhincodon typus*	Rhincodontidae	EN	Global	II
Scalloped hammerhead	*Sphyrna lewini*	Sphyrnidae	CR	Global	II
Great hammerhead	*Sphyrna mokarran*	Sphyrnidae	CR	Global	II
Smooth hammerhead	*Sphyrna zygaena*	Sphyrnidae	VU	Global	II

2.2 | Policy analysis

We compiled a comprehensive database of all bycatch policies adopted by four tRFMOs that apply to threatened pelagic elasmobranchs and bycatch. This included policies (Conservation and Management Measures, Resolutions, Recommendations, and Amendments) dating from 1976–2021 that were formally proposed, agreed upon, and adopted and contained the keywords "bycatch," "by-catch" or "incidental catch," and also contained the words "elasmobranch," "shark," or "ray" within the.

body text. We gathered policies from public tRFMO websites (IATTC: https://www.iattc.org/ResolutionsActiveENG.htm, IOTC: https://iotc.org/cmms, WCPFC: https://www.wcpfc.int/system/files/booklets/31/CMM%20and%20Resolutions.pdf, ICCAT: https://www.iccat.int/en/RecRes.asp). Because CCSBT is a special commission that follows the bycatch policies established by other tRFMOs when fishing in their convention areas (per *Resolution to Align CCSBT's Ecologically Related Species measures with those of other tuna RFMOs*, adopted 2018), we excluded it from all policy analyses to avoid double-counting duplicate policies. We also screened out six policies that were no longer active because they were replaced by newer amendments, but also noted the first year that the policy was adopted in its earliest version.

This screening yielded 34 active policies applicable to pelagic elasmobranch bycatch (Data S1). We coded each of these policies based on (1) species or genus (if mentioned), (2) gear type, (3) date of adoption and (4) whether the policy was binding. We determined whether each policy was considered "binding" or "not binding" (this determination is dependent on the legal language used by each tRFMO; for example, ICCAT considers "Recommendations" binding, and "Resolutions" non-binding, while the opposite is true for IOTC, Table S2).

2.3 | Mitigation hierarchy

We used the bycatch mitigation hierarchy to categorize policy contents along a spectrum of mitigation approaches. A single policy document may contain multiple approaches within the bycatch mitigation hierarchy; therefore, within each policy, we coded for the presence or absence of each of the five approaches (Figure 1): Avoid, Minimize, Remediate, Compensate, and Research. Presence of an approach was defined as a clearly stated and specific requirement to be carried out by state or non-state parties regarding bycatch using that approach (Table 2). Within each of the five approaches, we also

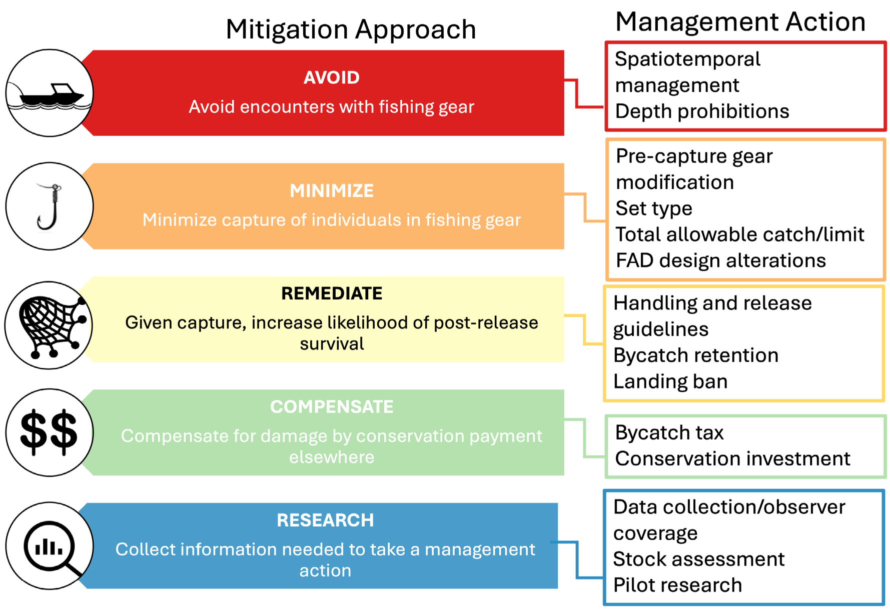

FIGURE 2 Conceptual figure of bycatch mitigation approaches in fisheries, adapted from Milner-Gulland et al. (2018)

noted the specific requirement directed by the policy (e.g., landing ban, bycatch limit, Table 2).

2.4 | Gaps and research requirements for single-species policy

Finally, we examined a subset of single-species/genus policies to understand the impact of scientific information on policy decisions for species considered of conservation concern. Commonly, tRFMO policy focuses narrowly on a single species (e.g., landing and retention ban for silky shark (*Carcharhinus falciformis*, Carcharhinidae) or genus) (e.g., handling modifications for mobulid rays [*Mobula spp*., Mobulidae]); for simplicity, we refer to these as "single-species" policies though they may pertain to a genus. For each the species within each tRFMO, we recorded whether that species was the subject of one or more single-species policy. For those with single-species policy, we noted which of the following non-research policy instruments applied in each tRFMO, each of which represents one of the mitigation approaches: (1) landing, retention and transshipment ban (*Remediate*), (2) bycatch/catch limit (*Minimize*) and (3) spatial management (*Avoid*). These instruments were chosen as they were the most frequently appearing requirements within single-species policies based on a preliminary reading of the policies. With the exception of some mobulid rays and the pelagic thresher shark (*Alopias pelagicus*, Alopiidae), all species in this study are globally distributed; thus for each tRFMO, we considered all species included in Table 1 that have overlapping distributions with the Convention Area as potentially eligible for a single-species policy for each tRFMO (Table S3). In a case where a "single-species" policy was established for a genus, we considered that policy to apply to each member of the genus that is distributed in that tRFMO's Convention Area.

To understand the effect of research knowledge on the likelihood of policy adoption, we matched our single-species policy data with published stock assessments from the RAM Legacy Stock Assessment database (http://ramlegacy.org/) and tRFMO websites and documents for the species included in this study (Data S2). In the context of elasmobranchs and tRFMOs, stock assessments are quantitative studies that may be conducted either internally or externally and are based on catch time series, demographic data, and life history parameters. These assessments fit statistical population dynamics models to produce time series estimates of biomass, fishing mortality and uncertainty, and compare these to biological reference points for one or more species (Begg et al., 1999; Hilborn & Walters, 1992). Normally, a stock assessment will result in one or more of the following stock status designations: (1) overfishing is occurring (fishing mortality exceeds a certain threshold, for example, mortality rate that is some fraction of F_{MSY}), (2) the population is in an overfished state (stock biomass falls below a certain threshold, for example, below spawning stock biomass threshold), (3) the population is not overfished, (4) the population is not currently being overfished, (5) some combination of the above (e.g., the population is not overfished but is currently being overfished), or (6) that the uncertainty is too high to make a determination (Ricard et al., 2012). As above, for each tRFMO we considered only species that have overlapping distributions with the Convention Area as eligible for assessment (Table S3). In cases where a stock is considered two or more populations in one Convention Area based on genetic structure, we included both stock status determinations for that eligible stock in that region (e.g., "overfished/overfishing occurring"). If an assessment was conducted for a stock's distribution across more than one commission's Convention Area, we considered this assessment as applicable to that population in all tRFMOs within the scope of the study. If the assessment did not result in a clear stock status determination, we characterized the result as "undetermined." We considered stocks designated "overfished," "overfishing occurring" or both of these designations to be under the larger category of "overexploited."

TABLE 2 tRFMO policy requirements grouped within approaches of the hierarchy for mitigating bycatch mortality

Mitigation approach	Example requirement	Description/notes
Avoid Does the policy direct fishers avoid capture of a non-target species or group?	• Spatial management • Close nursery or pupping area	Spatial or temporal management areas must be clearly defined, for instance a responsibility to avoid shark nursery areas for the purpose of conservation
	• Temporal/seasonal management	Closure of fishing area during high-bycatch season or period of time
	• Alter the depth of fishing activity	For example, setting longline hooks at a depth unlikely to capture species of interest
Minimize Does the policy direct fisheries to minimize the likelihood that a non-target species or group will be captured?	• Regulate set type for purse seiners	For example, prohibit setting on whale sharks

	• Gear modifications to minimize capture:
	  • Alternative bait less likely to attract bycatch
	  • Shark repellent or deterrents
	  • Alter mesh size of purse seine
		Unlike a remediate approach, these interventions are designed minimize the likelihood of capture, not post-capture mortality

	• Alter fish aggregation devices (FAD) design	FADs designed to reduce likelihood of entanglement
	• Alter timing of set	Deploying nets or lines at times of day when non-target species are less active(e.g., night setting)
	• Total allowable bycatch limit • Effort limits	Bycatch limits allow bycatch up to a given threshold and do not avoid all bycatch
Remediate Does the policy direct fisheries to minimize the likelihood of mortality for a non-target species or group, given that it has been captured?	• Gear modification to minimize mortality: • Hook type/wire leader modification for longline gear	Unlike a minimize approach, these interventions are meant to increase survivorship; they are not meant to alter the likelihood of capture

	• Retention rules:
	  • Landing ban
	  • Full or partial dead retention mandate
		One or multiple species of conservation concern may be subject to a landing, retention and transshipment ban

	• Handling and release modification or guidelines • Requirement to carry handling gear onboard	For example, prohibition on gaffing mobulid rays

	• Finning regulations:
	  • Fin-to-carcass ratio
	  • Finning ban
		The fin-to-carcass ratio requires that the total weight of fins onboard must not exceed 5% of the dressed weight of the carcasses

Research Does the policy direct further research or better data collection for a non-target species or group?	• Stock or population assessment	Stock assessments describe stock status and require some knowledge of population status
	• Ecological risk assessment (Productivity-Susceptibility Analysis)	In data-poor situations, tRFMOs conduct risk-based prioritization analyses to identify species of highest priority

	• Study to gather data on:
	  • Life history characteristics
	  • Demography
	  • Efficacy of mitigation technology or handling modification
		For example, research directive to study the effectiveness of other mitigation interventions at reducing capture or mortality

	• Increased observer coverage • Data collection	For example, a requirement to increase available data on a high-priority species via increasing observer coverage

We examined whether the existence of a stock assessment was associated with the likelihood of adoption of single-species policy instruments. To do this, we matched single-species policies with corresponding stock assessments in the same ocean region to ask whether a species was more likely to have a single-species policy if it was assessed. We used a chi-squared test to test for independence of the existence of a stock assessment and the adoption of single-species policies.

2.5 | Data gap analysis

We used information available on tRFMO websites to evaluate data collection, availability, and transparency related to pelagic elasmobranchs and to identify areas for improvement. We scored each tRFMO against a rubric of seven categories (Table S4). These categories included the following: (1) precision of publicly available elasmobranch bycatch data, (2) precision of publicly available fishing effort data, (3) precision of public available spatially explicit data for elasmobranch capture, (4) inclusion of elasmobranchs in convention text (Table S1), (5) required observer coverage for purse seine vessels, (6) required observer coverage for longline vessels and (7) proportion of eligible captured elasmobranch species with stock assessments in that tRFMO. For the longline observer coverage category (5), following Babcock and Pikitch (2011) and used a threshold of 50% observer coverage, which is considered necessary to estimate rare bycatch events, and scored longline observer coverage as a proportion of this 50% threshold. For purse seine observer coverage category (6), because there are mandates for 100% observer coverage in purse seine fisheries, we used 100% as the observer coverage threshold. For the final category (7), which was concerned with the proportion of elasmobranch species assessed by stock assessments, we used the same criteria for inclusion as described above in the stock assessments section and divided the number of assessed species by the number of eligible species for each tRFMO (Table S3). Categories 1–4 were scored from 0–2 based on predefined rubric criteria; categories 5–7 were scaled as a proportion of 2 to match the weighting. Because some rubric categories are not independent of one another and because tRFMO contexts vary substantially from ocean to ocean, we did not produce an overall total score but instead present these as separate sub-categories for each tRFMO. For this analysis, unlike the policy analysis, we included CCSBT, as it could be scored independently of the other bodies. We note that CCSBT does not manage significant purse seine vessel activity, so we excluded this category for CCSBT.

3 | RESULTS

3.1 | Mitigation hierarchy

Of the five approaches of the bycatch mitigation hierarchy, *Research* was the most prevalent mitigation approach and was included in all 34 active policies (Figure 3). Examples of common *Research* approaches were requirements to conduct a stock assessment for a particular species, gather life history or biological data or increase observer coverage. This was followed by *Remediate* approaches which appeared in 23 policies. Frequently appearing *Remediate* policies included requirements to modify gear to reduce the likelihood of mortality, such as prohibiting the use of wire leaders (otherwise known as "shark lines"), finning regulations (e.g., rules regarding fin-to-carcass ratios) and prohibitions of harmful handling practices (e.g., prohibition on gaffing animals). *Minimize* approaches appeared less frequently, in just 8 policies, and included gear modifications to reduce the likelihood of capture, including alterations to bait type and the design of fish aggregation devices (FADs) so that they are less likely to entangle non-target species. Finally, just one of the 34 policies included *Avoid* approaches, and none included *Compensate* approaches (Figure 3a). The only policy containing an *Avoid* approach was adopted by IATTC and was concerned with avoiding pupping areas for silky shark (Resolution C-21-06).

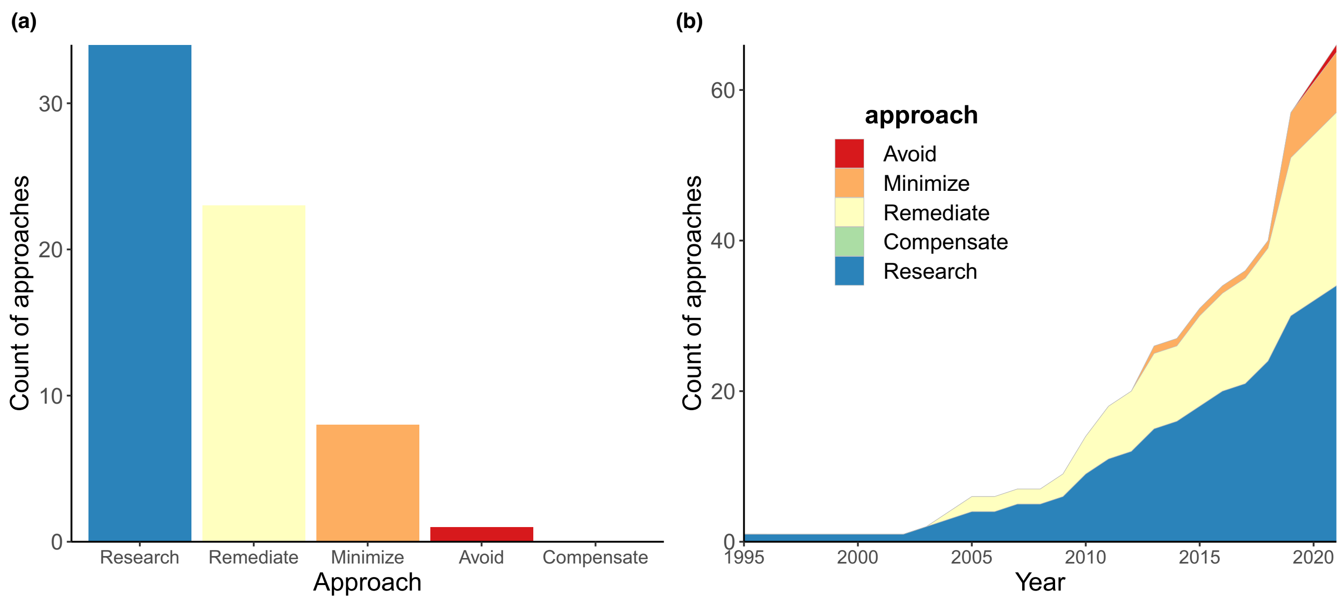

FIGURE 3 tRFMO policy approaches for pelagic elasmobranchs grouped by representation within the bycatch mitigation hierarchy. (a) Mitigation hierarchy approaches represented within tRFMO policy for pelagic elasmobranchs; (b) cumulative adoption of pelagic elasmobranch bycatch mitigation approaches adopted by tRFMOs since their inception in 1995

Together, *Minimize* and *Avoid* approaches were represented in ~24% (8 of 34) policies. Pelagic elasmobranch bycatch policies were first adopted in 1995, but have been increasing in number, particularly since 2010 (Figure 3b). The first policies to use *Minimize* and *Avoid* approaches were first adopted in 2013 (IOTC Resolution 13/05) and 2016 (IATTC C-16-06), respectively; tRFMO policies implemented prior to 2013 used *Remediate* and *Research* approaches exclusively.

When examining the strength of policy response, we found that non-binding policies for pelagic elasmobranchs were relatively uncommon; ICCAT was the only commission to adopt non-binding policy for elasmobranchs, representing just 2 of all policies examined.

3.2 | Research gaps

Given that we found a focus on research approaches in tRFMO policy, we next asked whether these research mandates in fact led to improved scientific knowledge, specifically in the form of stock assessments. Of those species with overlapping distributions with the five tRFMO Convention Areas, conclusive stock assessments have been conducted for ~16% ($n = 15$) of the 95 eligible populations (Data S3). The remaining ~84% ($n = 80$) of eligible pelagic elasmobranch populations were unassessed or had inconclusive assessments. Of those 15 populations with conclusive stock assessments, ~47% ($n = 7$) were determined to be overexploited, a group that includes *overfishing occurring* ($n = 4$), and both *overfished* and *overfishing* ($n = 3$). Eight populations (~53%) were determined to be *not overfished*.

3.3 | Policy gaps

We examined current gaps in active single-species policy for pelagic elasmobranchs. The species with the most active single-species policies were for blue ($n = 4$) and mako sharks (*Isurus spp*., Lamnidae; $n = 4$; though all of these policies were in a single tRFMO, ICCAT), followed by mobulids ($n = 3$), silky ($n = 3$), whale sharks (*Rhincodon typus*, Rhincodontidae; $n = 3$), and oceanic whitetip (*Carcharhinus longimanus*, Carcharhinidae; $n = 3$) sharks. Thresher and hammerhead (*Sphyrna* spp., Sphyrnidae) each had two policies, and porbeagle (*Lamna nasus*, Lamnidae) sharks had one policy (Figure S3B). Single-species policies were not more likely to be adopted in the year immediately after a major biodiversity treaty listing (e.g., CITES or CMS, Figure S3A).

Of the 75 eligible populations (this total excludes CCSBT, which follows the policy of other tRFMOs), just over half (53%, $n = 40$) had single-species policy measures. Of those subset single-species we examined, all but three of these measures were landing, retention and transshipment bans (orange cells, Table 3). Two populations had catch limit measures (shortfin mako and blue shark, both in ICCAT; yellow cells, Table 3), and one population had a spatial management measure (silky shark in IATTC; green cell, Table 3).

We then combined these single-species policies with our stock assessment data to ask whether there was a corresponding policy response to scientific information (e.g., a stock assessment) for 75 eligible populations (again, this total excludes CCSBT populations as CCSBT follows the single-species policies of other tRFMOs and therefore could not be included). Of the 15 populations with conclusive stock assessments, ~47% ($n = 7$) had single-species policies. Of the 60 unassessed but eligible populations, ~55% ($n = 33$) had single-species policies. A chi-square test of independence detected no significant association between these the existence of a stock assessment and the adoption of a single-species policy; in other words, an unassessed species was just as likely to have a single-species policy adopted as an assessed species (Figure S4, x^2 [1, $N = 75$] = 0.083, $p = .77$).

3.4 | Data collection and transparency gaps

We investigated the state of scientific data collection and transparency in each tRFMO regarding pelagic elasmobranchs (Figure 4). No tRFMO achieved the highest score in all categories, and the only high score achieved in the rubric categories was for purse seine observer coverage (ICCAT, IATTC, WCPFC) and the inclusion of elasmobranchs in convention text (ICCAT).

4 | DISCUSSION

The goal of this study was to assess the effectiveness of elasmobranch bycatch mitigation policy and identify data collection and transparency gaps in tuna management organizations. Given global pelagic elasmobranch declines, we identify three major concerns for threatened pelagic elasmobranch bycatch in tRFMO fisheries: (1) the majority of tRFMO policies concerning threatened pelagic elasmobranchs are focused on research (appearing in 100% of policies) and remediation (appearing in ~68% of policies), while few policies are directed at mitigation by avoiding, minimizing or compensating for bycatch, (2) major data collection and transparency gaps in all five tRFMOs prevent rigorous external science for these species, and (3) these policy and transparency deficits are concerning given our finding that few conclusive stock assessments are available for pelagic elasmobranch populations (15 of 95 eligible populations), and 7 of the 15 assessed populations are overexploited. We suggest that these shortcomings can be attributed to systemic challenges of conservation and fishery policymaking at the tRFMO level, including the inherent difficulty of managing transboundary resources, the differential costs and incentives of bycatch mitigation approaches, obstructive consensus-based decision-making processes in tRFMOs and lack of institutional commitment to the conservation of non-target species.

4.1 | Improving data availability and assessments

The scarcity of stock assessments for pelagic elasmobranchs is notable, given the fact that 100% of the policies we examined contain

TABLE 3 Gaps in tRFMO policies for the conservation and management of pelagic elasmobranchs in tRFMOs. Colours indicate existing single-species measures for that species in each tRFMO. CCSBT is not included in this figure, as it follows single-species policies of the other tRFMOs when fishing in their convention areas

No measures	Landing ban	Catch limit	Spatial management	Not eligible

Common name	Inter-American Tropical Tuna Commission (IATTC)	International Commission for the Conservation of Atlantic Tunas (ICCAT)	Indian Ocean Tuna Commission (IOTC)	Western and Central Pacific Fisheries Commission (WCPFC)
Pelagic thresher	No measures	Not eligible	No measures	No measures
Bigeye thresher	No measures	Landing ban	Landing ban	No measures
Common thresher	No measures	Landing ban	No measures	No measures
Silky	Landing ban / Spatial management	Landing ban	No measures	Landing ban
Oceanic whitetip	Landing ban	Landing ban	Landing ban	Landing ban
Shortfin mako	No measures	Landing ban / Catch limit	No measures	No measures
Longfin mako	No measures	Landing ban	No measures	No measures
Porbeagle	No measures	No measures	No measures	No measures
Reef manta ray	Not eligible	Not eligible	Landing ban	Landing ban
Oceanic manta ray	Landing ban	No measures	Landing ban	Landing ban
Longhorned pygmy devil ray	Not eligible	Not eligible	Landing ban	Landing ban
West Atlantic pygmy devil ray	Not eligible	Not eligible	Landing ban	Landing ban
Shorthorned pygmy devil ray	Not eligible	Not eligible	Landing ban	Landing ban
Spinetail devil ray	Landing ban	No measures	Landing ban	Landing ban
Munk's devil ray	Landing ban	Not eligible	Not eligible	Not eligible
Sicklefin devil ray	Landing ban	No measures	Landing ban	Landing ban
Bentfin devil ray	Landing ban	No measures	Landing ban	Landing ban
Blue shark	No measures	Catch limit	No measures	No measures
Whale shark	No measures	No measures	Landing ban	Landing ban
Scalloped hammerhead	No measures	Landing ban	No measures	No measures
Great hammerhead	No measures	Landing ban	No measures	No measures
Smooth hammerhead	No measures	Landing ban	No measures	No measures

requirements for research, including stock assessments. This points to the significant challenges in assessing data-poor species lacking long time series catch data (Barker & Schluessel, 2005; Carvalho et al., 2018; Clarke et al., 2006). Yet surprisingly, we found that the existence of a stock assessment was not associated with a corresponding policy response; in fact, more unassessed populations have bycatch mitigation measures than populations *with* stock assessments. It is important to note that this finding does not suggest that an unassessed species is somehow more likely to be the subject of future policy adoption—rather, it more likely indicates that policy adoption is the result of complex political and legal processes that may or may not draw on stock assessments. Perhaps more importantly, this suggests that a stock assessment is not necessarily a prerequisite of mitigation policy, further implying that precautionary decision-making for elasmobranchs in tRFMOs is possible in the absence of high-quality data. This result is supported by a previous study by Galland et al. (2018), which reported that policymakers at two tRFMOs, ICCAT and WCPFC, followed the advice of their scientists in making fishery management decisions only 39% and 17% of the time, respectively. These findings are important in the context of threatened bycatch species, as they indicate that policymaking is not only possible in data-poor scenarios, but regularly occurs. They also lend momentum to recent urgent calls for tRFMOs to better implement precautionary approaches to fisheries management for non-target species (de Bruyn et al., 2013; Hewison, 1996; Restrepo et al., 2017). Still, these findings do not suggest that better data on elasmobranch bycatch is not useful or necessary; on the contrary, well-targeted and effective policy requires grounding in good science, as well as clear communication of that science to policymakers (Beddington et al., 2007; Caddy, 1999; Galland et al., 2018).

Nevertheless, for decades tRFMO managers and fishing flag state delegates have cited a lack of adequate data as a major hindrance for effective management and policy for pelagic elasmobranchs in tuna fisheries (Barker & Schluessel, 2005; Tolotti et al., 2015). Our finding that no tRFMO achieved a high score for data collection and transparency criteria supports this and points to areas that each tRFMO could focus on to improve the quality and availability of data received from countries. For instance, one potential remedy to increase data reporting is for tRFMOs to adopt and enforce measures that require countries to submit high-quality, publicly available data as a prerequisite to access the fishery. ICCAT has implemented a version of this in the form of "shark check sheets" that assess country compliance with regulations and are a requirement for participation in the fishery (ICCAT

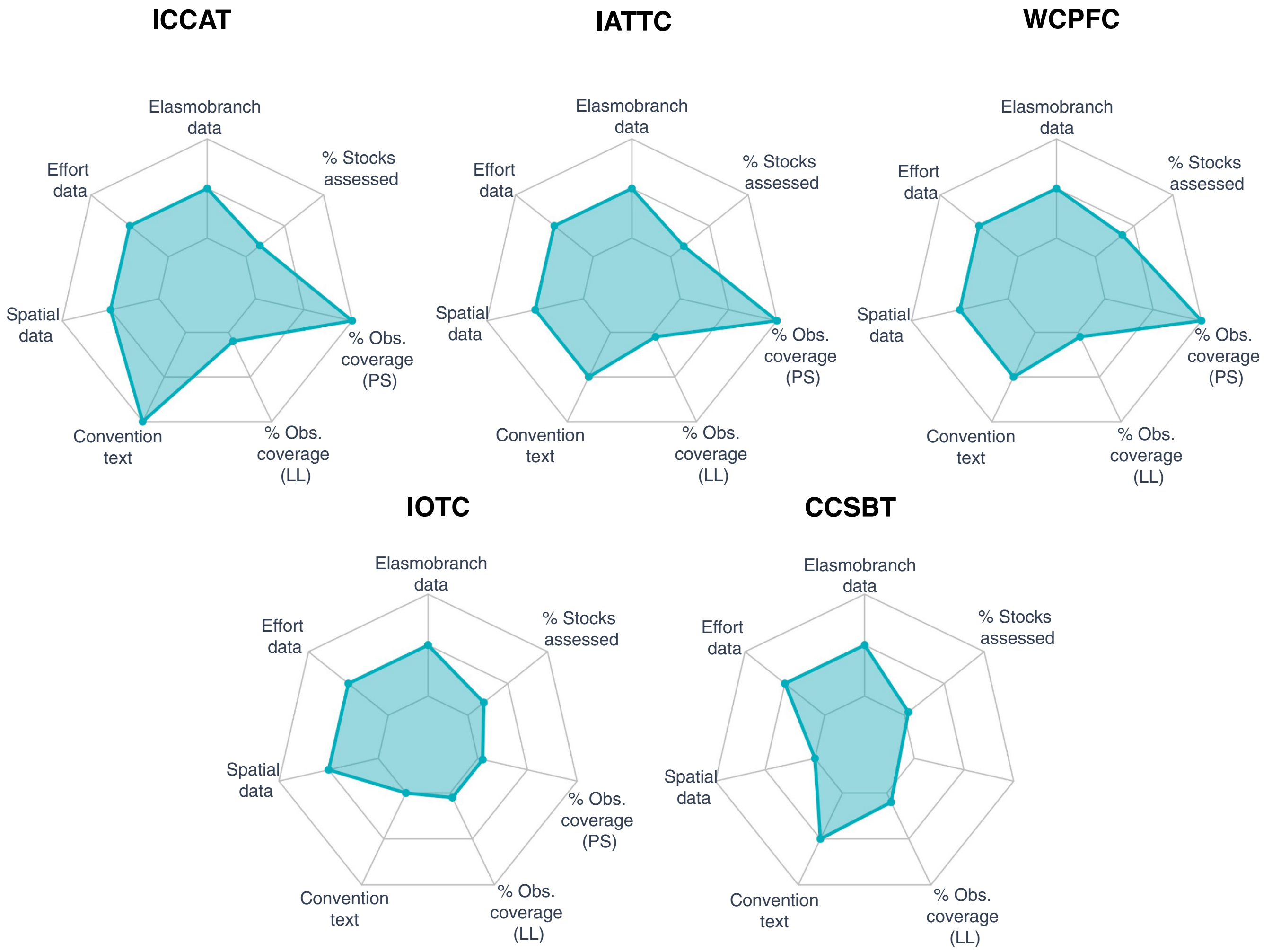

FIGURE 4 Data collection and transparency gaps in tRFMOs. Scores for each category ranged from 0 to 2 and points farther from the inside of the circle represent higher scores. Radar spokes represent scores for each rubric category

Recommendation 18-06). In addition, increasing observer coverage in these fisheries is a crucial component to producing better data, particularly in longline fisheries where observer coverage in most cases is insufficient to adequately estimate rare bycatch events (Babcock & Pikitch, 2011). Prioritizing international and in-country funding to address the data gaps identified in Figure 4, coupled with the use of recently emerging stock assessment methods for data-poor species, could help provide a fuller understanding of the status of these populations and their ability to withstand current levels of bycatch (Andrade, 2015; Clarke et al., 2018; Griffiths et al., 2019).

4.2 | Moving beyond calls for more research

In contrast to the many *Research* approaches we identified among these policies, we found that policies that target the avoidance of capture were extremely rare, appearing in only one of the 34 active policies we reviewed. This is potentially concerning, as avoidance is widely considered the most effective bycatch mitigation approach for threatened pelagic elasmobranchs, particularly given that in tuna longline, purse seine and gillnet fisheries, a large portion of incidentally caught sharks die during or shortly after release (Booth et al., 2019; Gilman, 2011; Hutchinson et al., 2015; Poisson et al., 2014). Further, the single *Avoid* approach we reviewed was implemented by IATTC and directs counties to require vessels "to not fish in silky shark pupping area"—however, the policy neglects to define the geographic location of silky shark pupping areas (IATTC Resolution C-21-06). This renders it unlikely to meaningfully avoid silky shark bycatch as currently written. To address the lack of avoidance approaches, tRFMOs could begin by adopting policies that include static or dynamic spatiotemporal management in well-defined and biologically relevant bycatch hotspots, depth avoidance and total allowable bycatch limits for all high-risk species. These approaches are already widely used in the context of tRFMOs for target fish and other bycatch species (Grande, Ruiz, et al., 2019; IATTC, 2020; ICCAT, 2019) and have shown promising results for reducing bycatch mortality for pelagic sharks without significantly reducing target fish catch (Hazen et al., 2018; Kerwath et al., 2013; Maxwell et al., 2015; Watson et al., 2009).

Beyond avoiding important areas, research has established that one of the methods most likely to reduce the impact of bycatch on pelagic elasmobranchs is to reduce post-capture mortality, including using modified handling and release devices and practices (Grande, Murua, et al., 2019; Murua et al., 2021). While several of these methods and technologies are being tested in some tuna fisheries, they have not been widely adopted and their efficacy in reducing bycatch mortality remains largely uninvestigated (Cronin et al., 2022; Tolotti et al., 2015). Further work should seek to identify and scale up effective technologies so that they can be adopted across tuna fleets. Finally, reductions in fishing effort, particularly for gears with relatively high bycatch rates, can reduce interaction rates with pelagic elasmobranchs (Watson & Bigelow, 2014).

In addition to gaps in policy approaches, we identified taxonomic gaps in the representation of elasmobranch species within policies. In particular, nearly all policies we examined focused on sharks; we found no tRFMO policies for ray species other than mobulids (Figure S3). Mobulid policies have been recently adopted (since 2015), likely as a result of increasing global attention to their conservation (Lawson et al., 2017). However, the need for bycatch mitigation policies for other ray and skate species should be examined, as there is growing evidence that other rays and skates exhibit similarly vulnerable life histories (Dulvy et al., 2000; Dulvy & Reynolds, 2002) and are likely threatened by bycatch in tuna fisheries (Arrizabalaga et al., 2011; Báez et al., 2016).

This study examined policies adopted at the tRFMO level and did not investigate enforcement, monitoring, or compliance with fishing and bycatch regulations. Because tRFMOs are large multinational regulatory bodies composed of many CCMs, further work should investigate compliance and enforcement rates for bycatch policy at the flag state, company, and vessel levels. This would require the availability of tRFMO compliance reports, many of which are currently not publicly available. Similarly, limited access to research-grade, disaggregated datasets for bycatch species also prevents independent assessments of the efficacy of policy implementation on bycatch rates (Heidrich et al., 2022). Further work should seek to quantify the impact of a given policy approach on achieving bycatch reduction targets, as has been done for other technical bycatch interventions (Huang et al., 2016; Walsh et al., 2009; Watson et al., 2005).

4.3 | Aligning incentives for bycatch mitigation

Alongside the development and adoption of these mitigation strategies, it is important to consider their differential economic incentives and costs, which may help explain the patterns observed here (Squires & Garcia, 2018). Incentives for bycatch mitigation may include bycatch reduction awards, taxes or levies, individual transferrable quotas, retention requirements or penalties paired with total allowable catch quotas (Pascoe et al., 2010). Each of the mitigation approaches examined in this study comes with its own set of costs and potential incentives. For example, avoidance and minimization approaches like time-area closures and restrictions on fishing effort can be costly if they lead to foregone catch and consequentially negative socioeconomic impacts for fishers (Komoroske & Lewison, 2015; Pascoe et al., 2010). Additionally, they can risk inducing cross-taxa conflicts with other target or non-target species, as has occurred in the past with other bycatch mitigation interventions (Gilman et al., 2019). These factors may help explain why they are currently underutilized in the policies we examined. As a way forward, a growing body of research is concerned with identifying static or dynamic inefficiency areas where non-target catch is high and target catch is low, which can avoid or reduce bycatch without risking economic loss from foregone catch (Hazen et al., 2018; O'Keefe et al., 2021). Further analyses of tRFMO policy should seek to identify avoidance policies that can confer benefits to multiple taxonomic groups while minimizing harm to fishery yield.

In contrast, remediation approaches like gear changes and handling and release modifications are often considered more cost-effective and may be "lower hanging fruit" mitigation approaches (though they still may require training and specific onboard equipment), which may explain why they appear frequently in tRFMO policy. Fortunately, for some species, changes in handling and release such as those required by tRFMO policy can substantially improve likelihood of survival, and recent advances in innovative technology appear promising (Forget et al., 2021; Hutchinson et al., 2015; Swimmer et al., 2020; Zollett & Swimmer, 2019). However, significant knowledge gaps exist about the potential for these technologies to fully resolve bycatch problems alone, and these technologies are not always transferrable from one fishery context to another (Gilman et al., 2019; Poisson et al., 2022). The successful application of effective remediation technology will require better understanding of the utility and limits of these methods for elasmobranchs, particularly for species with high post-release mortality rates. These can be paired with tRFMO policies requiring their adoption as well as economic and social incentives like sustainability certifications or awards that reward the adoption of best practices.

Though requirements for research were found in every policy we examined, their economic implications vary widely depending on the type and rigour of research, data collection and personnel required to complete it. On the other hand, we did not identify a single tRFMO policy using a compensatory approach for elasmobranchs, despite the fact that this has been suggested as a relatively cost-effective and socio-politically feasible conservation strategy, especially for species with low survival (Booth et al., 2019; Pascoe et al., 2010; Wilcox & Donlan, 2007). However, substantial challenges associated with this approach exist, including concerns about the difficulty of fully compensating for the direct and indirect impacts of bycatch and the complexity of matching compensation to the scale of impact (Finkelstein et al., 2008). Further, to our knowledge, the compensatory mitigation approach has not yet been applied for sharks in any fishery context (Booth et al., 2019). Additional research could investigate whether it could be effectively adapted to the tuna fishery setting despite these challenges.

Finally, scrutiny of the potentially unequal distributional impacts of mitigation policies among country members and contracting parties is crucial, as mitigation measures may have downstream effects on seafood supply chains and therefore on human communities. Further, it is important to consider that societal values and norms also influence the acceptability of bycatch and bycatch regulations—and in some cases may be as or more powerful incentives than economic ones. Overall, developing appropriate social and economic incentives that complement the mitigation approaches identified in this study should accompany any existing or proposed mitigation policy.

4.4 | Implications for tRFMO governance

Given the importance of sharks and rays to the maintenance of many marine ecosystems and thus to oceanic ecosystem services, the shortcomings in tRFMO bycatch policy identified here present significant opportunities for improvement. Meaningful reform of bycatch policy in tRFMO-managed fisheries would involve binding research mandates that fill data gaps needed to assess the current status of pelagic elasmobranch populations and the adoption of more bycatch avoidance and minimization measures. The current mode of decision-making in tRFMOs, which relies heavily on consensus among country members, will make the development and implementation of such policies challenging (Pons et al., 2018). This consensus-based framework has been identified as an impediment to management progress in other related areas, including adaptive management in response to climate change (Pentz et al., 2018), ecosystem-based fishery management (Juan-Jordá et al., 2017) and equitable tuna stock allocation (Seto et al., 2021). tRFMOs could more readily utilize their established voting procedures instead of defaulting to consensus-based decision-making, as well as so-called "circuit-breaker" safeguard processes, for example, providing a neutral mediator to reconcile differences between opposing countries or a review panel to assess decisions (Lodge et al., 2007). As fishing activities continue to drive accelerating population declines, these policy and transparency modifications can help achieve conservation goals across enormous geographic scales for threatened pelagic elasmobranchs.

AUTHOR CONTRIBUTIONS

Melissa R. Cronin, Jennifer Jacquet, Donald A. Croll and Katherine L. Seto conceived of the study. Melissa R. Cronin and Julia E. Amaral collected the data. Melissa R. Cronin conducted the data analysis and wrote the first draft of the manuscript. All authors contributed to the writing and revision of the manuscript.

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CONFLICT OF INTEREST

The authors declare no competing interests.

DATA AVAILABILITY STATEMENT

The data used in this study are available in a supplemental file.

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REFERENCES

Andrade, H. A. (2015). *Preliminary stock assessment of blue shark (Prionace glauca) caught in the Indian Ocean using a Bayesian state-space production model Andrade*. IOTC.

Arlidge, W. N. S., Squires, D., Alfaro-Shigueto, J., Booth, H., Mangel, J. C., & Milner-Gulland, E. J. (2020). A mitigation hierarchy approach for Managing Sea turtle captures in small-scale fisheries. *Frontiers in Marine Science*, *7*(49), 1–26. https://doi.org/10.3389/fmars.2020.00049

Arrizabalaga, H., De Bruyn, P., Diaz, G. A., Murua, H., Chavance, P., De Molina, A. D., Gaertner, D., Ariz, J., Ruiz, J., & Kell, L. T. (2011). Productivity and susceptibility analysis for species caught in Atlantic tuna fisheries. *Aquatic Living Resources*, *24*(1), 1–12.https://doi.org/10.1051/alr/2011007

Babcock, E. A., & Pikitch, E. K. (2011). How much observer coverage is enough to adequately estimate bycatch? Pew Institute for Ocean Science Rosenstiel School of Marine and Atmospheric Science University of Miami 4600 Rickenba. November 2014.

Báez, J. C., Crespo, G. O., García-Barcelona, S., Ortiz De Urbina, J. M., & Macías, D. (2016). Understanding pelagic stingray (*Pteroplatytrygon violacea*) by-catch by Spanish longliners in the Mediterranean Sea. *Journal of the Marine Biological Association of the United Kingdom*, *96*(7), 1387–1394. https://doi.org/10.1017/S0025315415001253

Barker, M. J., & Schluessel, V. (2005). Managing global shark fisheries: Suggestions for prioritizing management strategies. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *15*, 325–347. https://doi.org/10.1002/aqc.660

Baum, J. K., Myers, R. A., Kehler, D. G., Worm, B., Harley, S. J., & Doherty, P. A. (2003). Collapse and conservation of shark populations in the Northwest Atlantic. *Science*, *299*(5605), 389–392. https://doi.org/10.1126/science.1079777

Beddington, J. R., Agnew, D. J., & Clark, C. W. (2007). Current problems in the management of marine fisheries. *Science*, *316*(5832), 1713–1716. https://doi.org/10.1126/science.1137362/suppl_file/beddington.som.pdf

Begg, G. A., Friedland, K. D., & Pearce, J. B. (1999). Stock identification and its role in stock assessment and fisheries management: An overview. *Fisheries Research*, *43*(1–3), 1–8. https://doi.org/10.1016/S0165-7836(99)00062-4

Bonfil, R. (1994). *Overview of world elasmobranch fisheries*. FAO. Fisheries Technical Paper.

Booth, H., Squires, D., & Milner-Gulland, E. J. (2019). The mitigation hierarchy for sharks: A risk-based framework for reconciling trade-offs between shark conservation and fisheries objectives. *Fish and Fisheries*, *2019*, 269–289. https://doi.org/10.1111/faf.12429

Caddy, J. F. (1999). Fisheries management in the twenty-first century: Will new paradigms apply? *Reviews in Fish Biology and Fisheries*, *9*(1), 1–43. https://doi.org/10.1023/A:1008829909601

Cardeñosa, D., Fields, A. T., Babcock, E. A., Zhang, H., Feldheim, K., Shea, S. K. H., Fischer, G. A., & Chapman, D. D. (2018). CITES-listed

sharks remain among the top species in the contemporary fin trade. *Conservation Letters*, *11*, e12457. https://doi.org/10.1111/conl.12457
Carvalho, F., Lee, H. H., Piner, K. R., Kapur, M., & Clarke, S. C. (2018). Can the status of pelagic shark populations be determined using simple fishery indicators? *Biological Conservation*, *228*, 195–204. https://doi.org/10.1016/j.biocon.2018.09.034
Clarke, S., Sato, M., Small, C., Sullivan, B., Inoue, Y., & Ochi, D. (2014). *Bycatch in longline fisheries for tuna and tuna-like species: A global review of status and mitigation measures*. FAO.
Clarke, S. C., Harley, S. J., Hoyle, S. D., & Rice, J. S. (2013). Population trends in Pacific oceanic sharks and the utility of regulations on shark finning. *Conservation Biology*, *27*(1), 197–209. https://doi.org/10.1111/j.1523-1739.2012.01943.x
Clarke, S. C., Langmuller, A., Lennert-Cody, C., Aires-da-Silva, Maunder, A., & Maunder, M. (2018). Pacific-wide Silky Shark (*Carcharhinus falciformis*) Stock Status Assessment. WCPFC 14th SC, SA-WP-08.
Clarke, S. C., McAllister, M. K., Milner-Gulland, E. J., Kirkwood, G. P., Michielsens, C. G. J., Agnew, D. J., Pikitch, E. K., Nakano, H., & Shivji, M. S. (2006). Global estimates of shark catches using trade records from commercial markets. *Ecology Letters*, *9*, 1115–1126. https://doi.org/10.1111/j.1461-0248.2006.00968.x
Cronin, M. R., Croll, D. A., Hall, M. A., Lezama-Ochoa, N., Lopez, J., Murua, H., Murua, J., Restrepo, V., Rojas-Perea, S., Stewart, J. D., Waldo, J. L., & Moreno, G. (2022). Harnessing stakeholder knowledge for the collaborative development of Mobulid bycatch mitigation strategies in tuna fisheries. *ICES Journal of Marine Science*, 1–15. https://doi.org/10.1093/icesjms/fsac093
Cullis-Suzuki, S., & Pauly, D. (2010). Failing the high seas: A global evaluation of regional fisheries management organizations. *Marine Policy*, *34*(5), 1036–1042. https://doi.org/10.1016/j.marpol.2010.03.002
Davidson, L. N. K., Krawchuk, M. A., & Dulvy, N. K. (2016). Why have global shark and ray landings declined: Improved management or overfishing? *Fish and Fisheries*, *17*, 438–458. https://doi.org/10.1111/faf.12119
de Bruyn, P., Murua, H., & Aranda, M. (2013). The precautionary approach to fisheries management: How this is taken into account by Tuna regional fisheries management organisations (RFMOs). *Marine Policy*, *38*, 397–406. https://doi.org/10.1016/j.marpol.2012.06.019
Dulvy, N. K., Baum, J. K., Clarke, S., Compagno, L. J. V., Cortés, E., Domingo, A., Fordham, S., Fowler, S., Francis, M. P., Gibson, C., Martínez, J., Musick, J. A., Soldo, A., Stevens, J. D., & Valenti, S. (2008). You can swim but you can't hide: The global status and conservation of oceanic pelagic sharks and rays. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *18*, 459–482. https://doi.org/10.1002/aqc.975
Dulvy, N. K., Fowler, S. L., Musick, J. A., Cavanagh, R. D., Kyne, P. M., Harrison, L. R., Carlson, J. K., Davidson, L. N. K., Fordham, S. V., Francis, M. P., Pollock, C. M., Simpfendorfer, C. A., Burgess, G. H., Carpenter, K. E., Compagno, L. J. V., Ebert, D. A., Gibson, C., Heupel, M. R., Livingstone, S. R., … White, W. T. (2014). Extinction risk and conservation of the world's sharks and rays. *eLife*, *3*, e00590. https://doi.org/10.7554/eLife.00590.001
Dulvy, N. K., Metcalfe, J. D., Glanville, J., Pawson, M. G., & Reynolds, J. D. (2000). Fishery stability, local extinctions, and shifts in community structure in skates. *Conservation Biology*, *14*(1), 289–293. https://doi.org/10.1046/j.1523-1739.2000.98540.x
Dulvy, N. K., Pacoureau, N., Rigby, C. L., Pollom, R. A., Jabado, R. W., Ebert, D. A., Finucci, B., Pollock, C. M., Cheok, J., Derrick, D. H., Herman, K. B., Sherman, C. S., VanderWright, W. J., Lawson, J. M., Walls, R. H. L., Carlson, J. K., Charvet, P., Bineesh, K. K., Fernando, D., … Simpfendorfer, C. A. (2021). Overfishing drives over one-third of all sharks and rays toward a global extinction crisis. *Current Biology*, *31*, 4773–4787. https://doi.org/10.1016/J.CUB.2021.08.062
Dulvy, N. K., & Reynolds, J. D. (2002). Predicting extinction vulnerability in skates. *Conservation Biology*, *16*(2), 440–450. https://doi.org/10.1046/j.1523-1739.2002.00416.x
Finkelstein, M., Bakker, V., Doak, D. F., Sullivan, B., Lewison, R., Satterthwaite, W. H., McIntyre, P. B., Wolf, S., Priddel, D., Arnold, J. M., Henry, R. W., Sievert, P., & Croxall, J. (2008). Evaluating the potential effectiveness of compensatory mitigation strategies for marine bycatch. *PLoS One*, *3*(6), e2480. https://doi.org/10.1371/journal.pone.0002480
Forget, F., Muir, J., Hutchinson, M., Itano, D., Sancristobal, I., Leroy, B., Filmalter, J., Martinez, U., Holland, K., Restrepo, V., & Dagorn, L. (2021). Quantifying the accuracy of shark bycatch estimations in tuna purse seine fisheries. *Ocean & Coastal Management*, *210*, 105637. https://doi.org/10.1016/J.OCECOAMAN.2021.105637
Gallagher, A. J., & Hammerschlag, N. (2011). Global shark currency: The distribution frequency and economic value of shark ecotourism. *Current Issues in Tourism*, *14*(8), 797–812. https://doi.org/10.1080/13683500.2011.585227
Galland, G. R., Nickson, A. E. M., Hopkins, R., & Miller, S. K. (2018). On the importance of clarity in scientific advice for fisheries management. *Marine Policy*, *87*, 250–254. https://doi.org/10.1016/j.marpol.2017.10.029
Gilman, E., Chaloupka, M., Dagorn, L., Hall, M., Hobday, A., Musyl, M., Pitcher, T., Poisson, F., Restrepo, V., & Suuronen, P. (2019). Robbing Peter to pay Paul: Replacing unintended cross-taxa conflicts with intentional tradeoffs by moving from piecemeal to integrated fisheries bycatch management. *Reviews in Fish Biology and Fisheries*, *29*(1), 93–123. https://doi.org/10.1007/s11160-019-09547-1
Gilman, E., Clarke, S., Brothers, N., Alfaro-Shigueto, J., Mandelman, J., Mangel, J., Petersen, S., Piovano, S., Thomson, N., Dalzell, P., Donoso, M., Goren, M., & Werner, T. (2008). Shark interactions in pelagic longline fisheries. *Marine Policy*, *32*(1), 1–18. https://doi.org/10.1016/j.marpol.2007.05.001
Gilman, E., & Kingma, E. (2013). Standard for assessing transparency in information on compliance with obligations of regional fisheries management organizations: Validation through assessment of the Western and Central Pacific Fisheries commission. *Ocean and Coastal Management*, *84*, 31–39.https://doi.org/10.1016/j.ocecoaman.2013.07.006
Gilman, E., Passfield, K., & Nakamura, K. (2014). Performance of regional fisheries management organizations: Ecosystem-based governance of bycatch and discards. *Fish and Fisheries*, *15*(2), 327–351. https://doi.org/10.1111/faf.12021
Gilman, E. L. (2011). Bycatch governance and best practice mitigation technology in global tuna fisheries. *Marine Policy*, *35*(5), 590–609. https://doi.org/10.1016/j.marpol.2011.01.021
Grande, M., Murua, J., Ruiz, J., Ferarios, J. M., Murua, H., Krug, I., Igor, Arregui, Zudaire, I., Goñi, N., & Santiago, J. (2019). Bycatch mitigation actions on tropical tuna purse seiners: Best practices program and bycatch releasing tools.
Grande, M., Ruiz, J., Murua, H., Murua, J., Goñi, N., Krug, I., Arregui, I., Salgado, A., Zudaire, I., & Santiago, J. (2019). Progress on the code of good practices on the tropical tuna purse seine fishery in the Indian Ocean. IOTC-2019-WPEB15-33.
Griffiths, S. P., Kesner-Reyes, K., Garilao, C., Duffy, L. M., & Román, M. H. (2019). Ecological assessment of the sustainable impacts of fisheries (EASI-Fish): A flexible vulnerability assessment approach to quantify the cumulative impacts of fishing in data-limited settings. *Marine Ecology Progress Series*, *625*, 89–113. https://doi.org/10.3354/meps13032
Grubbs, R. D., Carlson, J. K., Romine, J. G., Curtis, T. H., McElroy, W. D., McCandless, C. T., Cotton, C. F., & Musick, J. A. (2016). Critical assessment and ramifications of a purported marine trophic cascade. *Scientific Reports*, *6*(1), 1–12. https://doi.org/10.1038/srep20970
Hall, M., & Roman, M. (2013). Bycatch and non-tuna catch in the tropical tuna purse seine fisheries of the world. *In FAO Fisheries and Aquaculture*, *62*(5), 1–80. https://doi.org/10.3138/ptc.2009-09-s1

Hazen, E. L., Scales, K. L., Maxwell, S. M., Briscoe, D. K., Welch, H., Bograd, S. J., Bailey, H., Benson, S. R., Eguchi, T., Dewar, H., Kohin, S., Costa, D. P., Crowder, L. B., & Lewison, R. L. (2018). A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. *Science Advances*, *4*(5), 1–8. https://doi.org/10.1126/sciadv.aar3001

Heidrich, K. N., Juan-Jordá, M. J., Murua, H., Thompson, C. D. H., Meeuwig, J. J., & Zeller, D. (2022). Assessing progress in data reporting by tuna Regional Fisheries Management Organizations. *Fish and Fisheries*, 1–18. https://doi-org.oca.ucsc.edu/10.1111/faf.12687

Hewison, G. J. (1996). The precautionary approach to fisheries management: An environmental perspective. *International Journal of Marine and Coastal Law*, *11*(3), 301–332. https://doi.org/10.1163/157180896X00168

Hilborn, R., & Walters, C. (1992). *Quantitative fisheries stock assessment: Choice, dynamics and uncertainty—Google books*. Springer-Science+Business Media.

Huang, H. W., Swimmer, Y., Bigelow, K., Gutierrez, A., & Foster, D. G. (2016). Influence of hook type on catch of commercial and bycatch species in an Atlantic tuna fishery. *Marine Policy*, *65*(March), 68–75. https://doi.org/10.1016/j.marpol.2015.12.016

Hutchinson, M. R., Itano, D. G., Muir, J. A., & Holland, K. N. (2015). Post-release survival of juvenile silky sharks captured in a tropical tuna purse seine fishery. *Marine Ecology Progress Series*, *521*, 143–154. https://doi.org/10.3354/MEPS11073

IATTC. (2020). Report on the tuna fishery, stocks, and ecosystem in the Eastern Pacific Ocean in 2020.

ICCAT. (2019). Chair's report of the 1st joint tuna RFMO by-catch working group meeting.

IOTC. (2014). 18th session of the Indian Ocean tuna commission (S18) | IOTC.

Juan-Jordá, M. J., Murua, H., Arrizabalaga, H., Dulvy, N. K., & Restrepo, V. (2017). Report card on ecosystem-based fisheries management in tuna regional fisheries management organizations. *Fish and Fisheries*, *19*(2), 321–339. https://doi.org/10.1111/faf.12256

Kerwath, S. E., Winker, H., Götz, A., & Attwood, C. G. (2013). Marine protected area improves yield without disadvantaging fishers. *Nature Communications*, *4*, 2347. https://doi.org/10.1038/ncomms3347

Koehler, H. R. (2013). *Promoting compliance in tuna RFMOS: A comprehensive baseline survey of the current mechanics of reviewing, assessing and addressing compliance with RFMO obligations and measures*. International Seafood Sustainability Foundation.

Komoroske, L. M., & Lewison, R. L. (2015). Addressing fisheries bycatch in a changing world. *Frontiers in Marine Science*, *2*(83), 1–11. https://doi.org/10.3389/fmars.2015.00083

Lawson, J. M., Fordham, S. V., O'Malley, M. P., Davidson, L. N. K., Walls, R. H. L., Heupel, M. R., Stevens, G., Fernando, D., Budziak, A., Simpfendorfer, C. A., Ender, I., Francis, M. P., Notarbartolo di Sciara, G.,& Dulvy, N. K. (2017). Sympathy for the devil: A conservation strategy for devil and manta rays. *PeerJ*, *5*, e3027. https://doi.org/10.7717/peerj.3027

Lodge, M. W., Anderson, D., Lobach, T., Munro, G., Sainsbury, K., & Willcock, A. (2007). Recommended best practices for regional fisheries management organizations. *Technical Study*, *91*, 141.

Mandelik, Y., Dayan, T., & Feitelson, E. (2005). Planning for biodiversity: The role of ecological impact assessment. *Conservation Biology*, *19*(4), 1254–1261. https://doi.org/10.1111/J.1523-1739.2005.00079.X

Maxwell, S. M., Hazen, E. L., Lewison, R. L., Dunn, D. C., Bailey, H., Bograd, S. J., Briscoe, D. K., Fossette, S., Hobday, A. J., Bennett, M., Benson, S., Caldwell, M. R., Costa, D. P., Dewar, H., Eguchi, T., Hazen, L., Kohin, S., Sippel, T., & Crowder, L. B. (2015). Dynamic Ocean management: Defining and conceptualizing real-time management of the ocean. *Marine Policy*, *58*, 42–50. https://doi.org/10.1016/j.marpol.2015.03.014

Milner-Gulland, E. J., Garcia, S., Arlidge, W., Bull, J., Charles, A., Dagorn, L., Fordham, S., Graff Zivin, J., Hall, M., Shrader, J., Vestergaard, N., Wilcox, C., & Squires, D. (2018). Translating the terrestrial mitigation hierarchy to marine megafauna by-catch. *Fish and Fisheries*, *19*, 547–556. https://doi.org/10.1111/faf.12273

Miyake, M. P., Miyabe, N., & Nakano, H. (2004). *Historal trends of tuna catches in the world*. FAO Fisheries and Aquaculture Technical Paper. https://doi.org/10.1021/jz401847d

Molina, J. M., & Cooke, S. J. (2012). Trends in shark bycatch research: Current status and research needs. *Reviews in Fish Biology and Fisheries*, *22*(3), 719–737. https://doi.org/10.1007/s11160-012-9269-3

Murua, J., Ferarios, J. M., Grande, M., Onandia, I., & Santiago, J. (2021). Improving on deck best handling and release practices for sharks in tuna purse seiners using hopper with ramp devices. WCPFC-SC17-2021/EB-IP-13.

O'Keefe, C. E., Cadrin, S. X., Glemarec, G., & Rouxel, Y. (2021). Efficacy of time-area fishing restrictions and gear-switching as solutions for reducing seabird bycatch in gillnet fisheries. *Reviews in Fisheries Science & Aquaculture*, 1–18. https://doi.org/10.1080/23308249.2021.1988051

Oliver, S., Braccini, M., Newman, S. J., & Harvey, E. S. (2015). Global patterns in the bycatch of sharks and rays. *Marine Policy*, *54*, 86–97. https://doi.org/10.1016/j.marpol.2014.12.017

Pacoureau, N., Rigby, C. L., Kyne, P. M., Sherley, R. B., Winker, H., Carlson, J. K., Fordham, S. V., Barreto, R. P., Fernando, D., Francis, M. P., Jabado, R. W., Herman, K. B., Liu, K.-M., Marshall, A. D., Pollom, R. A., Romanov, E. V., Simpfendorfer, C. A., Yin, J. S., Kindsvater, H. K., & Dulvy, N. K. (2021). Half a century of global decline in oceanic sharks and rays. *Nature*, *589*(July), 2019. https://doi.org/10.1038/s41586-020-03173-9

Pascoe, S., Innes, J., Holland, D., Fina, M., Thébaud, O., Townsend, R., Sanchirico, J., Arnason, R., Wilcox, C., & Hutton, T. (2010). Use of incentive-based management systems to limit bycatch and discarding. *International Review of Environmental and Resource Economics*, *4*, 1–39. https://doi.org/10.1561/101.00000032

Pentz, B., Klenk, N., Ogle, S., & Fisher, J. A. D. (2018). Can regional fisheries management organizations (RFMOs) manage resources effectively during climate change? *Marine Policy*, *92*, 13–20. https://doi.org/10.1016/j.marpol.2018.01.011

Poisson, F., Budan, P., Coudray, S., Gilman, E., Kojima, T., Musyl, M., & Takagi, T. (2022). New technologies to improve bycatch mitigation in industrial tuna fisheries. *Fish and Fisheries*, *23*(3), 545–563. https://doi.org/10.1111/faf.12631

Poisson, F., Séret, B., Vernet, A. L., Goujon, M., & Dagorn, L. (2014). Collaborative research: Development of a manual on elasmobranch handling and release best practices in tropical tuna purse-seine fisheries. *Marine Policy*, *44*, 312–320. https://doi.org/10.1016/J.MARPOL.2013.09.025

Pons, M., Melnychuk, M. C., & Hilborn, R. (2018). Management effectiveness of large pelagic fisheries in the high seas. *Fish and Fisheries*, *19*, 260–270. https://doi.org/10.1111/faf.12253

Queiroz, N., Humphries, N. E., Couto, A., Vedor, M., da Costa, I., Sequeira, A. M. M., Mucientes, G., Santos, A. M., Abascal, F. J., Abercrombie, D. L., Abrantes, K., Acuña-Marrero, D., Afonso, A. S., Afonso, P., Anders, D., Araujo, G., Arauz, R., Bach, P., Barnett, A., … Sims, D. W. (2019). Global spatial risk assessment of sharks under the footprint of fisheries. *Nature*, *572*(7770), 461–466. https://doi.org/10.1038/s41586-019-1444-4

Restrepo, V., Dagorn, L., Itano, D., Justel-Rubio, A., Forget, F., & Moreno, G. (2017). *A summary of bycatch issues and ISSF mitigation activities to date in purse seine fisheries, with emphasis on FADs*. ISSF.

Ricard, D., Minto, C., Jensen, O. P., & Baum, J. K. (2012). Examining the knowledge base and status of commercially exploited marine species with the RAM legacy stock assessment database. *Fish and*

Fisheries, *13*(4), 380–398. https://doi.org/10.1111/J.1467-2979.2011.00435.X

Seto, K., Galland, G. R., McDonald, A., Abolhassani, A., Azmi, K., Sinan, H., Timmiss, T., Bailey, M., & Hanich, Q. (2021). Resource allocation in transboundary tuna fisheries: A global analysis. *Ambio*, *50*(1), 242–259. https://doi.org/10.1007/s13280-020-01371-3

Squires, D., & Garcia, S. (2018). The least-cost biodiversity impact mitigation hierarchy with a focus on marine fisheries and bycatch issues: Least-cost mitigation of biodiversity effects. *Conservation Biology*, *32*(5), 989–997. https://doi.org/10.1111/cobi.13155

Swartz, W., Sala, E., Tracey, S., Watson, R., & Pauly, D. (2010). The spatial expansion and ecological footprint of fisheries (1950 to present). *PLoS One*, 5(12), e15143. https://doi.org/10.1371/journal.pone.0015143

Swimmer, Y., Zollett, E. A., & Gutierrez, A. (2020). Bycatch mitigation of protected and threatened species in tuna purse seine and longline fisheries. *Endangered Species Research*, *43*, 517–542. https://doi.org/10.3354/esr01069

Techera, E. J., & Klein, N. (2011). Fragmented governance: Reconciling legal strategies for shark conservation and management. *Marine Policy*, *35*(1), 73–78. https://doi.org/10.1016/j.marpol.2010.08.003

Tolotti, M. T., Filmalter, J. D., Bach, P., Travassos, P., Seret, B., & Dagorn, L. (2015). Banning is not enough: The complexities of oceanic shark management by tuna regional fisheries management organizations. *Global Ecology and Conservation*, *4*, 1–7. https://doi.org/10.1016/j.gecco.2015.05.003

Vincent, A. C. J., Sadovy de Mitcheson, Y. J., Fowler, S. L., & Lieberman, S. (2014). The role of CITES in the conservation of marine fishes subject to international trade. *Fish and Fisheries*, *15*(4), 563–592. https://doi.org/10.1111/faf.12035

Walsh, W., Bigelow, K. A., & Sender, K. L. (2009). Decreases in shark catches and mortality in the Hawaii-based longline fishery as documented by fishery observers. *Marine and coastal fisheries: Dynamics, management, and ecosystem science*, *1*, 270–282. https://doi.org/10.1577/C09-003.1

Watson, J. T., & Bigelow, K. A. (2014). Trade-offs among catch, bycatch, and landed value in the American Samoa longline fishery. *Conservation Biology*, *28*(4), 1012–1022. https://doi.org/10.1111/cobi.12268

Watson, J. T., Essington, T. E., Lennert-Cody, C. E., & Hall, M. A. (2009). Trade-offs in the design of fishery closures: Management of silky shark bycatch in the Eastern Pacific Ocean Tuna fishery. *Conservation Biology*, *23*(3), 626–635. https://doi.org/10.1111/j.1523-1739.2008.01121.x

Watson, J. W., Epperly, S. P., Shah, A. K., & Foster, D. G. (2005). Fishing methods to reduce sea turtle mortality associated with pelagic longlines. *Canadian Journal of Fisheries and Aquatic Sciences*, *62*(5), 965–981. https://doi.org/10.1139/f05-004

WCPFC. (2022). *Public domain bycatch data*. WCPFC.

Wilcox, C., & Donlan, C. (2007). Compensatory mitigation as a solution to fisheries bycatch-biodiversity conservation conflicts. *Frontiers in Ecology and the Environment*, *5*, 325–331. https://doi.org/10.1890/1540-9295(2007)5[325:CMAAST]2.0.CO;2

Zollett, E. A., & Swimmer, Y. (2019). Safe handling practices to increase post-capture survival of cetaceans, sea turtles, seabirds, sharks, and billfish in tuna fisheries. *Endangered Species Research*, *38*, 115–125. https://doi.org/10.3354/esr00940

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