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Received: 3 February 2022 | Revised: 19 April 2022 | Accepted: 20 May 2022

DOI: 10.1111/faf.12687

ORIGINAL ARTICLE

FISH and FISHERIES WILEY

Assessing progress in data reporting by tuna Regional Fisheries Management Organizations

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Funding information
"la Caixa" Foundation; Australian Government; Bloomberg Philanthropies; David and Lucile Packard Foundation; >Forrest Research Foundation; Marisla Foundation; Minderoo Foundation; Oak Foundation; Paul M. Angell Family Foundation

Abstract

Tuna Regional Fisheries Management Organizations (RFMOs) are responsible for conservation and sustainable management of transboundary tuna resources in Exclusive Economic Zones and Areas Beyond National Jurisdiction (ABNJ). The data collected and analyses performed by tuna RFMOs are one of the main sources of scientific information supporting the management, sustainable use and conservation of biodiversity in the ABNJ. An understanding of the scope and availability of data provided by tuna RFMOs is timely, given the expected establishment of a new legally binding high seas agreement to protect marine biodiversity in the ABNJ. We examined official catch statistics and stock assessments that are accessible in the public domain for the five tuna RFMOs, and evaluated their taxonomic, spatial and temporal resolution. We found that the Atlantic and Indian Ocean tuna RFMOs report catches for a greater number of taxa compared to Pacific RFMOs. There are substantial gaps in the taxonomic resolution of sharks and rays and 'other teleosts', and only about half of the reported global catches are georeferenced, despite existing mandatory requirements. Additionally, the estimation and reporting of discards in all tuna RFMOs remains incomplete. Tuna RFMOs have made progress in implementing stock assessments for a wide range of taxa including targeted species with high economic value but also functionally important non-target species with lower economic value. However, assessments should be expanded to cover other bycatch species. We emphasize the importance of accessible and accurate statistics, for supporting the research and societal oversight needed under any future ABNJ biodiversity treaty.

KEYWORDS
CCSBT, data transparency, IATTC, ICCAT, IOTC, WCPFC

1 | INTRODUCTION

Overfishing is the dominant threat to marine biodiversity and resilience, in conjunction with climate change, habitat destruction, pollution, global trade and growing resource consumption (Dulvy et al., 2021; Merrie et al., 2014; Ramirez-Llodra et al., 2011; Selig et al., 2013). The spatial expansion and increase of commercial fisheries have also a large impact on marine ecosystems and the marine biodiversity embedded therein, both within national Exclusive Economic Zones (EEZs) and Areas Beyond National Jurisdiction

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(ABNJ) (Bongaarts, 2019; Miyake et al., 2004; Swartz et al., 2010; Tickler, Meeuwig, Bryant et al., 2018; Tickler, Meeuwig, Palomares et al., 2018). Uncontrolled growth in fishing leads to overcapacity and, if unrestrained, results in unsustainable fishing practices. Such practices may include overfishing of targeted and vulnerable and endangered species and an increase in illegal and unreported fishing (Agnew et al., 2009). The effective management of fisheries is crucial to the conservation of marine ecosystems, the optimal use of resources for global food supply and the employment of around 260 million people engaged directly and indirectly in fisheries sectors worldwide (Teh & Sumaila, 2013). If current and emerging human uses are not carefully managed, they will further harm and threaten marine ecosystems in national EEZs and the ABNJ (Reeve et al., 2012).

Tunas and other large pelagic species such as billfishes, sharks and rays are amongst the most economically important fishes in the world. Tunas alone had an estimated annual value of US$41 billion in 2018 (McKinney et al., 2020), and are estimated to supply annually around 5 million tonnes to global markets (Coulter et al., 2020; ISSF, 2021). Large pelagic species are generally highly migratory, with distributions ranging across the jurisdiction of multiple countries and high seas regions of the oceans. There is a need for international cooperation to foster improved management and conservation measures for tunas, billfishes, sharks and rays, given their high economic value and vulnerability to overfishing by multinational fisheries, as reflected in their continuing decline over the past decades (Collette et al., 2011; Juan-Jordá et al., 2011; Pacoureau et al., 2021; Pons et al., 2017). Globally at least 35% of tuna stocks are classified as overfished, which is equivalent to 13% of total reported catches (ISSF, 2021). Since 1970, the global abundance of sharks and rays has declined by 71% due to increased fishing pressure (Pacoureau et al., 2021).

Nearly a decade after initial discussions on a "biodiversity beyond national jurisdiction" (BBNJ) treaty, a new legally binding instrument for the conservation and sustainable use of marine biodiversity in the ABNJ under UNCLOS is in progress (Mendenhall et al., 2019;

Tiller et al., 2019; UNGA, 2004; Wright & Rochette, 2016). The new BBNJ agreement aims to strengthen the current fragmented ocean governance and lead to international ocean management actions for addressing critical issues including biodiversity loss, declining fisheries, pollution, climate change and ecosystem degradation in an integrated and ecosystem-based manner (Gjerde & Yadav, 2021). Currently, the responsibility for implementing international obligations to conserve marine biodiversity in the ABNJ is still distributed among a variety of global and regional regimes addressing specific activities, issues and regions that lack effective coordination and cooperation (Gjerde et al., 2019).

Five Regional Fisheries Management Organizations (RFMOs) specifically deal with fisheries for large pelagic fish species in EEZ and ABNJ waters, the so-called tuna RFMOs (Figure 1, Table S1). The oldest tuna RFMO, the Inter-American Tropical Tuna Commission (IATTC), was founded in 1949 and the youngest, the Western and Central Pacific Fisheries Commission (WCPFC) in 2004 (Table 1). These tuna RFMOs provide a formal mechanism for fishing countries to meet their international obligations to cooperate for the maintenance of sustainable populations and the integrity of marine ecosystems; ensure sustainable fishing operations and provide compatible management measures in national waters and the ABNJ (FAO, 2018). Effective fisheries management by these RFMOs

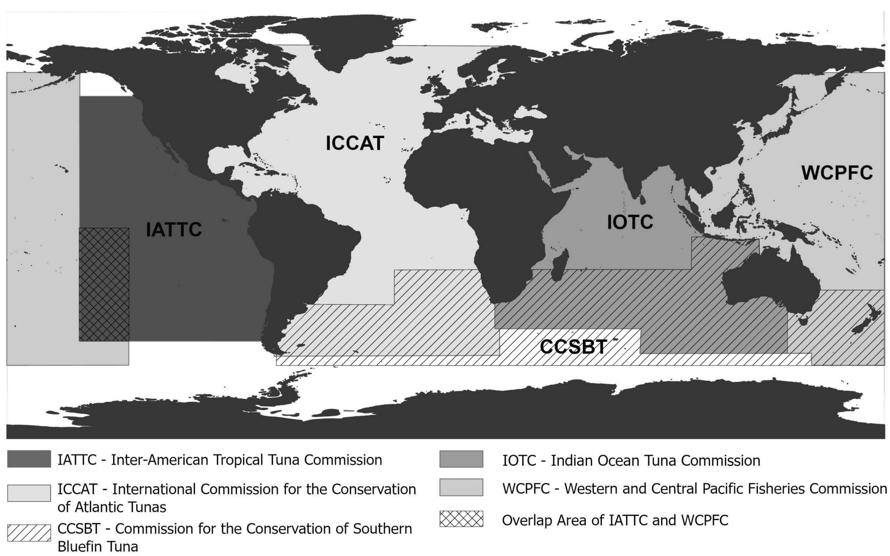

FIGURE 1 Area of jurisdiction (convention area) of the five tuna Regional Fisheries Management Organizations (RFMOs). All tuna RFMOs have specific areas of jurisdiction as defined by their conventions, except the Commission for the Conservation of the southern bluefin tuna (CCSBT). The CCSBT convention applies to only one species, the southern bluefin tuna – *Thunnus maccoyii*, throughout its range in the Southern Ocean. Convention areas can overlap between tuna RFMOs

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TABLE 1 Main fishery catch statistic datasets administered by tuna RFMOs, including their definition and a brief description of their coverage, structure and temporal and spatial resolution.

RFMO (Year of entry into force)	Nominal catch dataset	Spatial dataset	Relevant conservation and management measures
CCSBT (1994)	Estimated total global catch of southern bluefin tuna provided as whole weights in tonnes (not including estimates of past unreported catches), by vessel flag or fishing gear Source dataset: CatchBYMGOLoLa	Catch by year, month, fishing gear and ocean, separately provided for longline and surface fisheries (pole and line and purse seine) by CCSBT members, comprised of observations from a minimum of three vessels The spatial resolution of the grids ranges from purse seine and pole and line (1° × 1°) to longline (5° × 5°) Source dataset: CatchBYMGOLoLa	CCSBT Res. 2017: Rules and procedures for the protection, access to, and dissemination of data compiled by the CCSBT
IATTC (1949)	Annual report of estimated total catches by taxon, vessel flag and gear Source dataset: CatchByFlagGear	Annual report of catch and effort data disaggregated by taxon, vessel flag, and geographical grid cells The spatial resolution of the grids ranges from purse seine and pole and line (1° × 1°) to longline (5° × 5°) Source datasets: PublicPSTuna, PublicPSBillfish, PublicPSShark, PublicLLTunaBillfish, PublicLLShark, PublicPLTuna	IATTC Res. C-03-05: Resolution on data provision
ICCAT (1966)	Annual report of total catches (in live weight [kg][†]) including landings, dead discards and alive discards, disaggregated by vessel flag, taxon, fishing gear and major areas (sampling areas, and fishing zone). It should contain all catches (targeted, non-target/bycatch) including from recreational/sport fisheries, research and training vessels Source dataset: T1NC	Annual report of catch and effort statistics, disaggregated by fleet, fishing gear, taxon, time strata (year and month), and geographical grid cells The spatial resolution of the grids ranges from purse seine (1° × 1°) to longline (5° × 5°) to coastal fisheries (5° × 10°, 10° × 10°, 10° × 20°, 20° × 20°) Preferably, observed data should be obtained from various sources (logbooks, auction sales, port sampling, landing ports, transhipments etc.) and be comprised of observations from a minimum of three vessels Source dataset: T2CE	ICCAT Rec. 1966-01/12: Efforts to improve the completeness of Task I reported statistics ICCAT Rec. 2003–21: Resolution on improvement in data collection and quality assurance
IOTC (1996)	Annual report of total catches (in weights) (including discards), disaggregated by taxon (IOTC and non-IOTC species), fleet, gear and major Indian Ocean areas (East and West) Source dataset: NC-ALL	Annual report of catches (in weight or number) and effort, preferably raised to the nominal catch and fishing effort by month, fleet, gear, taxon (IOTC and non-IOTC species) and geographic grid cells The spatial resolution of the grids ranges from purse seine (1° × 1°) to longline (5° × 5°) to coastal fisheries (10° × 10°, 10° × 20°, 20° × 20°) Source dataset: CE surface fisheries, CE longline, CE other gears	IOTC Res. 15/02 and 17/08 established the mandatory statistical requirements for IOTC contracting and cooperating non-contracting parties
WCPFC (2004)	Annual report of total catch estimates by taxon, gear, vessel flag and stock areas for WCPFC convention area Source dataset: YB_WCP_CA	Annual aggregated catch and effort estimates are provided by year, month, latitude, longitude, fishing days and hooks for longline catch. These data are reported by contracting and cooperating non-contracting parties and are made up of observations from a minimum of three vessels The spatial resolution of the grids ranges from purse seine (1° × 1°) to longline, pole and line and driftnet (5° × 5°) Source datasets: DRIFTNET, WCPFC_L_PUBLIC_BY_FLAG_MON, POLE_AND_LINE_WCPFC_S_PUBLIC_BY_1X1_QTR_FLAG	WCPFC Res. C-12-05: Conservation and management measure on daily catch and effort reporting

Note: Most relevant conservations and management measures for reporting catch statistics are also included. Only major datasets available for download in the public domain are presented.

[†]This indicates Live weight is derived by the application of conversion factors to the actual landed or product weight to represent the actual weight of the fishery product before being subjected to any processing or other operations.

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faces numerous challenges: poor fisheries catch and effort statistics, weak enforcement of conservation and management measures, non-compliance with agreed management measures, a lack of strong Control, Monitoring and Surveillance (CMS) mechanisms and a lack of effective flag state control over fishing vessels operating in the ABNJ (Cullis-Suzuki & Pauly, 2010; Gianni et al., 2011; Pitcher & Cheung, 2013; Weaver et al., 2011; Wright et al., 2015). Growing criticism of the performance of tuna RFMOs has led to internal and external performance reviews recommending a variety of measures to strengthen governance and scientific processes (Ceo et al., 2012; Garcia & Koehler, 2014; IOTC, 2009). These recommended actions include the improvement of data collection and reporting, the implementation of rebuilding plans for overfished target species, the adoption of a more coordinated approach to ecosystem monitoring and research, and the increase of transparency in decision-making through, for example, harvest strategies (Ceo et al., 2012; Garcia & Koehler, 2014; IOTC, 2009).

Detailed fisheries that catch statistics at adequate temporal, spatial and taxonomic resolutions are needed for the accurate representation of population dynamics and thus the effective assessment and management of fisheries resources and protection of vulnerable species and ecosystems (Abella, 2011; Pauly et al., 2013). Unavailability and inaccuracy of fishery catch statistics, including the lack of temporal and spatial resolution, is an ubiquitous challenge and often recognized as an obstacle to fisheries research and management (Bradai et al., 2012; Ferretti et al., 2008). Highly taxonomically resolved catch data contribute to our understanding of the health of species and ecosystems, whereas low taxonomic resolution of catch time series hamper stock assessments and may lead to the provision of non-representative stock dynamics (Abella, 2011; Cavanagh et al., 2009; Chen, Chen et al., 2003; Chen, Jiao et al., 2003; Clarke et al., 2006; Zhou et al., 2011). Information about reported catches by gear type also enhances our understanding of the selectivity of the gears used in a particular fishery. For example, longline, gillnet and purse seine gears interact with higher numbers of bycatch species compared to other fishing gears such as pole-and-line and hand line (Arrizabalaga et al., 2011).

Spatially resolved catch data are fundamental to support fisheries research and management in tuna RFMOs. Yet, we still lack a precise understanding of the spatial and temporal footprint of fishing, particularly its spatial overlap with species distribution and movement, which limits our ability to quantify the response of global fleets and species to changes in climate, policy, economics and other drivers (Kroodsma et al., 2018). Efforts to produce comprehensive data on global fishing activities by combining information from electronic vessel monitoring systems, logbooks and observer programmes have resulted in fragmented data that are neither publicly available nor at a global scale. New technologies such as mapping and analysing fishing activity using satellite-derived AIS (Automatic Identification Systems) data have the potential to complement current spatial information of fishing activities (Global Fishing Watch, 2022).

Understanding the population dynamics of fish stocks and their exploitation status relative to established fisheries reference points is essential to developing effective fisheries management strategies. Stock assessment is a key tool to estimate biomass status and trends, and to determine appropriate levels of fishing mortality and total sustainable catch levels. The quantity and quality of available taxonomically and spatially resolved fisheries data for stock assessment models, along with information on growth, reproduction, natural mortality and recruitment, are recognised to be amongst the most limiting factors (Chen, Chen et al., 2003; Chen, Jiao et al., 2003). Understanding the impact of data quantity and quality on these stock assessment models is therefore crucial for their improvement and the development of precautionary management strategies (Restrepo, 1999; Schnute & Richards, 2001; Smith, 1993). A range of conservation and management measures such as catch and effort limits, gear restrictions and temporal and spatial closures has been implemented by RFMOs to counteract increased fishing efficiency, partially driven by continuous improvements in fishing gears, and maintain catches of target species at sustainable levels (Miyake et al., 2010). Moreover, knowledge of incidental catch (referred to here as bycatch) and its fate, whether retained or discarded, is fundamental to understanding the direct and indirect effects of fishing on fish populations and marine ecosystems and, thus, to tailoring those management measures to all species impacted by fishing. Traditionally, the effects of fishing on marine ecosystems have been assessed using data on retained (i.e. landed) catch only. A focus on retained catch however leads to a substantial misrepresentation of the total fishing mortality and impact on the ecosystem (Botsford et al., 1997; Pauly & Zeller, 2016; Zeller et al., 2018).

Our main objective is to assess the current and past state of data reporting in each tuna RFMO. We examine the availability and level of completeness of the fisheries catch statistics and stock assessments made publicly available by the tuna RFMOs. In doing so, we first examine the state of reporting of fisheries catches by evaluating the overall coverage, taxonomic and spatial resolution, and distribution of catch among different gear types. Second, we examine the state of stock assessments by quantifying the number of stock assessments carried out across tuna RFMOs. For all types of information, we consider their progression through time. Third, we examine the completeness of the reported discarded catches in publicly available datasets across tuna RFMOs. Finally, we review the tuna RFMO fisheries catch data reporting and stock assessment requirements. The data collected and fisheries analyses performed by tuna RFMOs over the last 70 years remain one of the main sources of information to support emerging scientific knowledge to help conserve and sustainably use marine biodiversity in the ABNJ. This analysis highlights areas that have undergone development in recent years and identifies aspects in urgent need of improvement.

2 | METHODS

The data used in this study include nominal catch taken from the public fisheries statistics databases of each tuna RFMO (Figure 1, Table S1). The nominal catch dataset refers to the reported catch,

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which may differ considerably from the actual catch, as discards are not generally included, and in this case, it is the total quantity of fish landed at the end of a fishing trip, which is aggregated to annual catches by the tuna RFMOs (IOTC, 2019). Thus, we considered nominal catches as landings (catch that is retained on board and landed), bearing in mind that in some cases publicly reported catches may also include discards (non-retained catches). This nominal catch is typically reported annually by taxon, RFMO member (i.e. vessel flag), gear and large fishing or sampling areas (Table 1). In addition, we examined the reported georeferenced catch data, so-called catch and effort dataset, also obtained from public fisheries statistics databases, which include the reported catch data and associated effort, preferably raised to the nominal catch, by month, taxon, RFMO member (i.e. vessel flag), gear at a variety of spatial scales (Table 1). The fishery catch statistics in these two datasets (nominal catches and spatial catches) include the main targeted oceanic tuna species, that is Bigeye tuna (*Thunnus obesus*, Scombridae), Skkipjack tuna (*Katsuwonus pelamis*, Scombridae), Yellowfin tuna (*Thunnus albacares*, Scombridae), Albacore tuna (*Thunnus alalunga*, Scombridae), Atlantic bluefin tuna (*Thunnus thynnus*, Scombridae), Pacific bluefin tuna (*Thunnus orientalis*, Scombridae), Southern bluefin tuna (*Thunnus maccoyii*, Scombridae), and targeted and non-targeted species of billfishes, sharks, rays, neritic tuna species and other teleost fish species. For the purpose of this review, we grouped all species reported across the five tuna RFMOs, including target and non-target species, into five distinct species groups: oceanic tunas (i.e. main targeted oceanic tuna species listed above), neritic tunas, billfishes, sharks and rays and other teleosts fishes (Table S2). For convenience, the coastal tunas (e.g., *Auxis* and *Euthynnus* spp.), together with the bonitos and Spanish mackerels, were here grouped under neritic tunas since these species are typically assessed together by specialized scientific working groups within the tuna RFMOs. Other teleosts include species and taxa reported in the datasets that are not covered in the other four groups (Table S2). Incidental non-fish bycatch taxa such as sea turtles, marine mammals and seabirds were not considered in this study.

To address the first objective of evaluating the state of fisheries catch statistics across the five tuna RFMOs, we examined the (a) overall coverage, (b) taxonomic resolution, (c) distribution of catch among different gear types, and (d) spatial resolution of reported catches. We reviewed the publicly accessible information from tuna RFMO websites and other referenced sources of information for the evaluation of data availability and completeness within public domain datasets. We distinguished between species within and outside the individual tuna RFMO's mandate, hereafter referred to as mandate and non-mandate species. We first summarized the reported catches over the period 1950–2018 by major taxon groups and examined these across tuna RFMOs in order to determine their various contributions to global tuna fisheries and identify the proportion of target and non-target species groups reported in publicly available fisheries statistics. Second, we compared the taxonomic resolution of the catch statistics by major taxonomic groups across tuna RFMOs. We distinguish between 'good' and 'poor' taxonomic resolution, where 'good' is defined as catch reported at the species or genus level and 'poor' is defined as catch reported at family or higher level. Third, we summarized the reported catches over the period 1950–2018 by major gear types and compared these across tuna RFMOs, to determine the strongest contributor to global tuna fisheries by RFMO convention area. Finally, we compared the spatial resolution of the catch statistics by major taxonomic groups across tuna RFMOs. We distinguish between 'finer' and 'coarser' spatial resolution, where 'finer' is defined as catch reported at 1°×1° gridded cells and 'coarser' is defined as catch reported at 5°×5°, 5°×10°, 10°×10°, 10°×20° or 20°×20° gridded cells, as different gear types are required to report catches at different spatial resolutions (Table 1).

For the second objective, we examined the state of stock assessments by quantifying how many species and stocks are currently assessed in each tuna RFMO, and examining the changes in the assessment of these stocks between 1950 and 2018. Here, we reviewed all stock assessment reports from the individual tuna RFMO Scientific Committees to quantify how many stocks and species by species groups have been assessed in each tuna RFMO over time.

We then examined the completeness of the reported discarded catches in publicly available datasets across tuna RFMOs using three criteria: (a) full transparency, (b) partial transparency, and (c) no transparency of reported discarded catches. Full transparency of discard reporting applies when tuna RFMOs report discards in their public and official catch datasets and label them as such. Partial transparency holds when tuna RFMOs include estimates of discards in their publicly available domain but these are reported in working group meetings/reports, and no transparency applies when discard data are collected by the tuna RFMOs, but are not included or labelled in the publicly available datasets.

Finally, we reviewed the existing guidelines and mandatory fishery catch statistics and stock assessment requirements for member countries as outlined in the various convention mandates and other RFMO key documents, such as resolutions, recommendations, conservation measures, annual working group and scientific committee reports and meeting documents that are publicly available on tuna RFMO websites (Table S1). The aim was to understand the requirements for reporting catch statistics (including discards), and assessing species, as well as to gain an understanding of the coverage of species under RFMO mandate.

3 | RESULTS

All tuna RFMOs, except CCSBT, are responsible for the conservation and sustainable management of oceanic tunas, billfishes and neritic tunas in their convention areas, and in addition only IATTC and WCPFC include some oceanic shark species explicitly in their mandates (Table S2). However, in 2019, the ICCAT amended its convention to include pelagic sharks in their list of mandate species

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(ICCAT, 2019a). CCSBT is the only tuna RFMO responsible for the management of one species, southern bluefin tuna throughout its range in the Southern Ocean (Figure 1, Table S1). The area of responsibility covered by RFMOs includes the EEZ of states and the ABNJ in the Atlantic, Indian and Pacific Oceans (Figure 1, Table S1). The total reported catch in all the tuna RFMOs combined exceeded 6.5 million tonnes in 2018, representing a 16-fold increase since the start of the reporting in the early 1950s (Figure 2a). Reported catch increased over the entire period in all the tuna RFMOs with the exception of the CCSBT, where the reported catches of southern bluefin tuna have declined since the 1960s (Figure 2a, Figure S1). The WCPFC and the IOTC represent the largest tuna fisheries in the world, accounting for 43% and 32% of the total global reported catch of all the tuna RFMOs combined in 2018 (Figure 2a). The ICCAT and the IATTC, on the other hand, account for 12% and 10% respectively of total global reported catches in 2018 (Figure 2a). The ICCAT and the IOTC have improved their public accountability for reporting catches of taxonomic categories other than the economically important oceanic tunas in recent years and decades (Figure 2b,c, Table S2). The ICCAT has increased the reporting of sharks, rays and other teleosts from 4.5% of the total reported catch in 1950 to 13% of the total reported catch in 2018 (Figure 2b) and the IOTC increased the reporting of other teleosts from 0.38% of the total reported catch in 1950 to 7.87% in 2018 (Figure 2c). However, the IATTC mainly reports on oceanic tuna species and thus lags behind in comprehensive catch reporting (Figure 2d). The WCPFC only reports catches in the public database for a small fraction (12 out of 37) of the species under its mandate, most of which are oceanic tunas (Figure 2e, Table S2). The CCSBT only reports total catches of the mandated southern bluefin tuna and does not publicly report catch data for other bycaught taxa in these fisheries, some of which may be covered by other tuna RFMOs with overlapping jurisdiction areas (Figure 1, Figure S1).

Since the mid-1980s, catches for a wider range of species have increasingly been reported, many of which are not officially covered by the RFMO's mandate (Figure 3a, Table S2). This trend is largely driven by ICCAT and the IOTC, which show clear improvements in reporting taxa outside their core mandate, having doubled the number of non-mandate species reported by their member countries (Figure 3b,c). In contrast, the IATTC and the WCPFC substantially lag behind in public reporting of catches for species under their mandate. They only report catches of 12 of the 42 and 12 of the 37 mandated species, respectively (Figure 3d,e, Table S2).

Distinct differences between the tuna RFMOs are also evident in the taxonomic resolution of reported catches. Overall, the level of taxonomic resolution within the taxonomic groupings used here is good for oceanic tunas, neritic tunas and billfishes, where reporting is mostly at the species level, while higher and much less informative taxonomic levels predominate in the reporting of sharks and rays, and other teleosts in all tuna RFMOs, except for the ICCAT (Figure 4). The ICCAT and the IOTC report a wide range of taxa from different groups, including neritic tunas, sharks and rays, and other teleosts with a high taxonomic resolution (Figure 4a,b). The exception is poor taxonomic resolution for sharks in the IOTC, although the percentage of shark and ray catches reported at the species level has improved over the last decades, from 0.7% in 1950 to 53% in 2018 (Figure 4b). In the IATTC, there has been some improvement in the taxonomic resolution of catches, but to a much more limited extent (Figure 4c). Sharks and rays are only reported at higher aggregated level throughout the entire time series; however, the percentage of other teleost catches reported at the genus

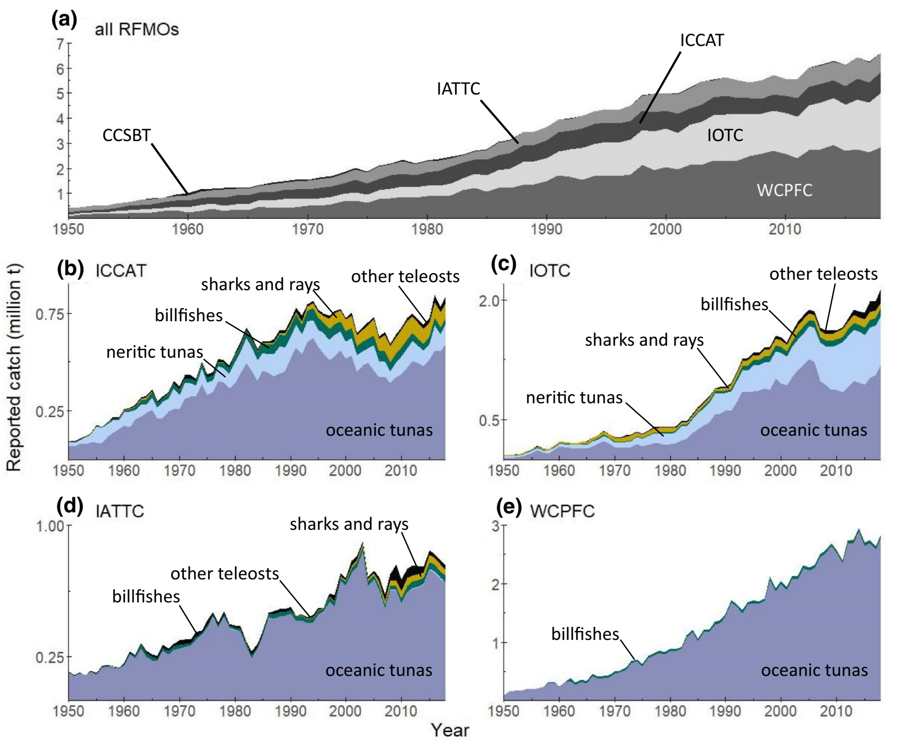

FIGURE 2 Total reported 'nominal' catches of oceanic tunas, billfishes, neritic tunas, sharks and rays, and other teleost fishes from 1950 to 2018 assembled from the publicly available catch datasets administered by tuna RFMOs: (a) all RFMOs, (b) International Commission for the Conservation of Atlantic tunas (ICCAT), (c) Indian Ocean tuna commission (IOTC), (d) inter-American tropical tuna commission (IATTC), and (e) Western and Central Pacific fisheries commission (WCPFC). IATTC makes neritic tuna catches publicly available since 1964 but in quantities too small to be visible in the graph. WCPFC only makes catches of sharks and rays publicly available since 1996, and in quantities too small to be visible in the graph

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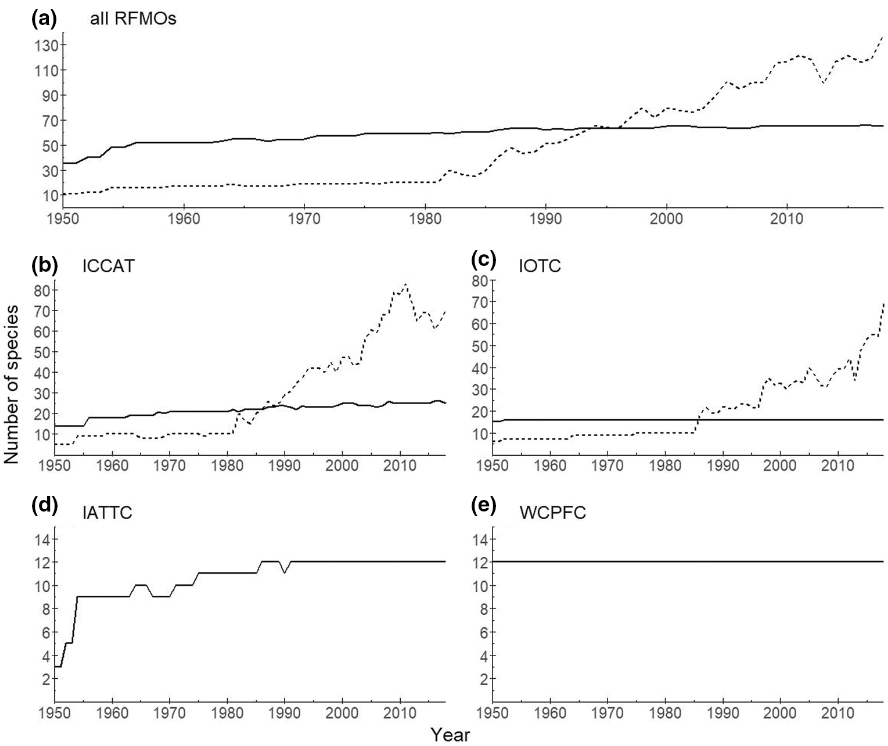

FIGURE 3 Total number of mandate (solid line) and non-mandate species (dotted line) for which catches are available in the public statistics from 1950 to 2018 for (a) all RFMOs, (b) International Commission for the Conservation of Atlantic tunas (ICCAT) with 26 mandated species, (c) Indian Ocean tuna commission (IOTC) with 16 mandated species, (d) inter-American tropical tuna commission (IATTC) with 42 mandated species, and (e) Western and Central Pacific fisheries commission (WCPFC) with 37 mandated species

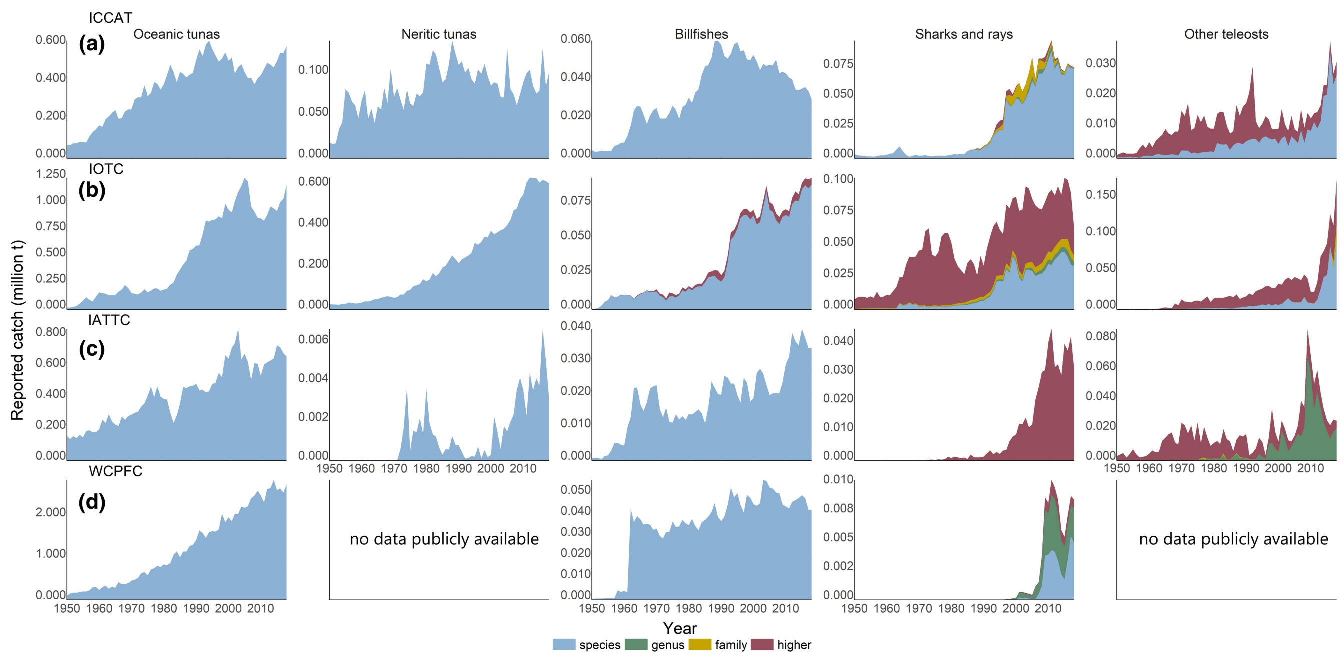

FIGURE 4 Taxonomic resolution of reported nominal catches by major taxonomic groups for each tuna RFMO (a–d) from 1950 to 2018. No data were available for the neritic tunas and other teleosts in the WCPFC public database

level has improved from 0.1% in 1950 to 81% in 2018 (Figure 4c). The WCPFC reports the majority of catches of species for oceanic tunas and billfishes. Catches of sharks and rays reported in the WCPFC data since 1996 are low and not fully reported at the species level (Figure 4d). Neither neritic tunas nor other teleosts catch data are publicly available for the WCPFC (Figure 4d).

Purse seine and longline gears land the majority of large pelagic species catches globally, with purse seines substantially outweighing all other gear types since the late 1980s (Figure 5a). Purse seines and longlines account for an average of 54% and 15% of reported catches in the 2010s, respectively, while all other gears combined accounted for the remaining ~31% (Figure 5a). Purse seine and longline gears dominate reported catches in the ICCAT area, with purse seine accounting for 48% and longline for 27%, while the remaining gear types account for only 25% of reported catches in the 2010s (Figure 5b). Reported catches in the IOTC convention area show a

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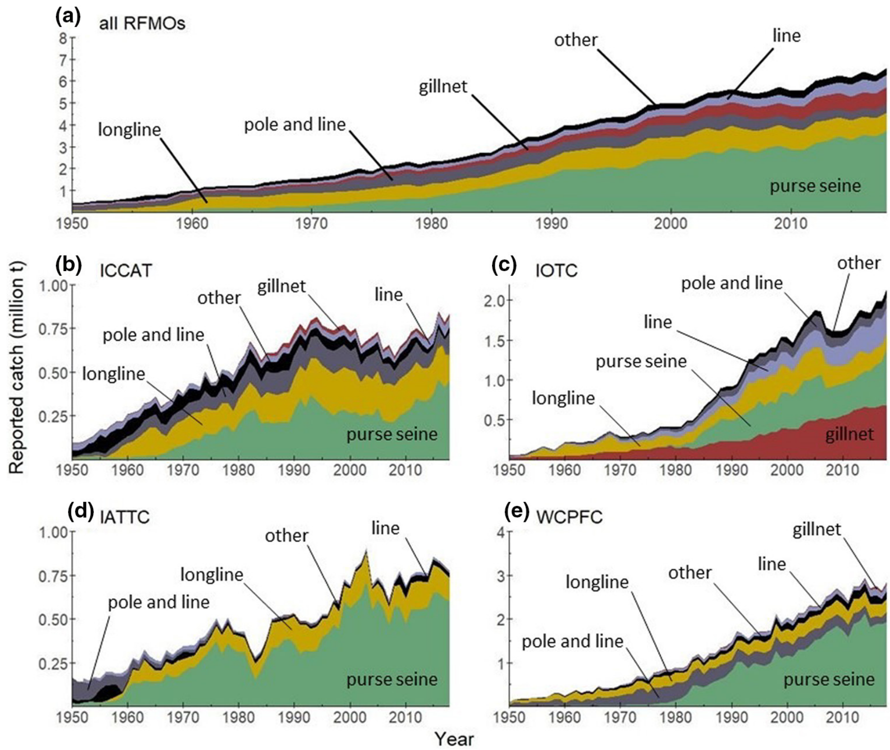

FIGURE 5 Total reported nominal catches of oceanic tunas, billfishes, neritic tunas, sharks and rays, and other teleost fishes by major gear types from 1950 to 2018 assembled from the publicly available catch datasets administered by tuna RFMOs: (a) all RFMOs, (b) International Commission for the Conservation of Atlantic tunas (ICCAT), (c) Indian Ocean tuna commission (IOTC), (d) inter-American tropical tuna commission (IATTC), and (e) Western and Central Pacific fisheries commission (WCPFC). IATTC makes gillnet catches publicly available since 1984, but in quantities too small to be visible in the graph

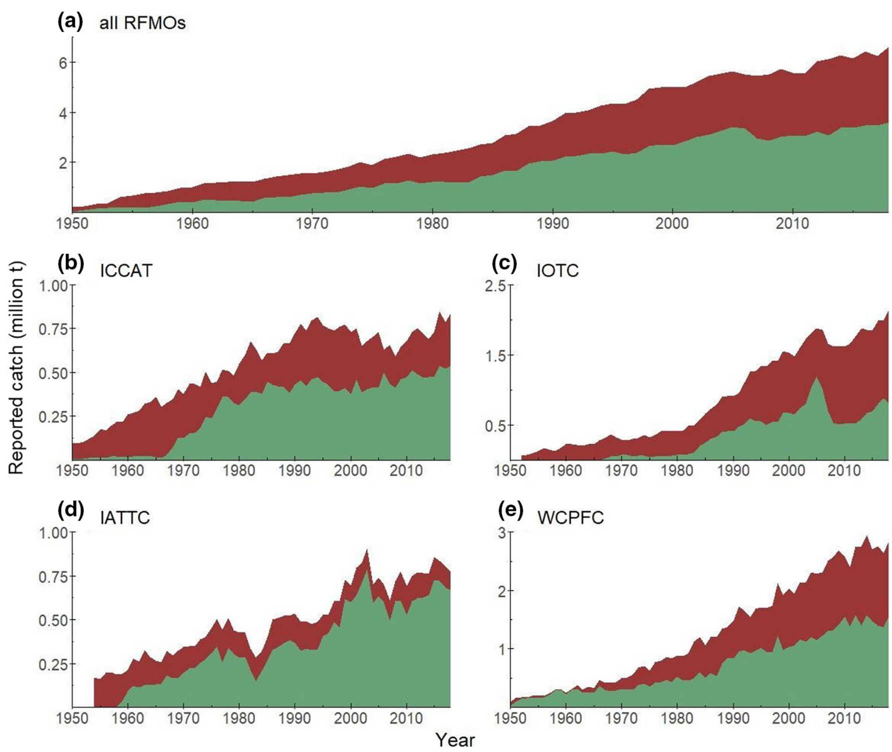

FIGURE 6 Share of the nominal reported total catch data with gridded spatial information (green) and without gridded spatial information (red) from 1950 to 2018: (a) all RFMOs, (b) International Commission for the Conservation of Atlantic tunas (ICCAT), (c) Indian Ocean tuna commission (IOTC), (d) inter-American tropical tuna commission (IATTC), and (e) Western and Central Pacific fisheries commission (WCPFC)

much broader distribution across gears, with gillnet (34%) and purse seine gears (26%) dominating reported catches in the 2010s, while longline and all other gears account for only 12% and 28%, respectively (Figure 5c). While much of the tuna fishing in the IATTC in the 1950s has been nearshore and therefore dominated by pole-and-line gear, since the 1960s, the catches reported by the IATTC were almost exclusively reported for purse seine and longline gears, which account for 75% and 19% of reported catches in the 2010s, respectively (Figure 5d). Purse seine gears also dominate in the WCPFC area, accounting for 69% of reported catches in the 2010s (Figure 5e). Longlines play a minor role, with 11% of reported catches in 2010s, while all other gears account for only 20% (Figure 5e). The CCSBT reports southern bluefin tuna catches mainly by longline and purse seine (Figure S2).

More than half (54%) of the total reported catch within the convention areas of all tuna RFMOs is currently reported as gridded

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spatial data, typically ranging from 1°×1° to 5°×5° grids depending on the gear types (Figure 6a, Figure S4). The ICCAT and the IOTC only started reporting considerable quantities of catches as spatial data with multiple grid resolutions (i.e. 1°×1° to 5°×5° grids) in the late 1960s and 1980s, respectively (Figure 6b,c, Figure S4). The IATTC and the WCPFC provide spatially gridded data for earlier periods, starting in the 1960s and 1950s, respectively (Figure 6d,e, Figure S4). The ICCAT and the IATTC have improved their spatial reporting over time and are increasingly reporting a greater proportion of their catches at spatial grid resolution, accounting for 64% and 87% of total reported catches in 2018, respectively, when considering all species groups (Figure 6b,d). In contrast, the IOTC and the WCPFC have much poorer and deteriorating coverage of gridded spatial data, accounting for <40% and <60% of the total catches in 2018, respectively (Figure 6c,e, Figure S3). However, the spatial resolution for different taxonomic groups by tuna RFMO can differ from the overall pattern (Figure S5). The majority of reported catches with gridded spatial resolution across all tuna RFMOs is reported at 1°×1° or 5°×5° grid cells (Figure S4). Gridded spatial data are more likely to be reported for the catches of mandated species (Figure S5), and most likely to be reported for oceanic tuna species and billfishes (Figure S5). Reported catches with gridded spatial information for less common non-targeted species, that is, sharks and rays and other teleosts, remain scarce (Figure S5). Longline fisheries typically report spatial data by 5°×5° resolution, purse seine and pole-and-line report by 1°×1° resolution, and so-called small-scale and fixed gears such as hand lines, gillnets and traps report at various higher resolutions (5°×10°, 10°×10°, 10°×20° or 20°×20°). The CCSBT reports all southern bluefin tuna catches with spatial information exclusively at the 5°×5° grid cell level.

The number of stocks of oceanic tunas, neritic tunas, billfishes and sharks subject to formal stock assessments has increased over time across all tuna RFMOs (Figure 7a, Table S5). Currently, a total of 69 stocks of 25 species (seven oceanic tuna, seven neritic tuna, seven billfish and four shark species) are routinely assessed by the tuna RFMOs. Starting in 1970 stock assessments have been carried out by some tuna RFMOs, but only for oceanic tunas and some billfish species (Figure 7a). Formal stock assessments for sharks and neritic tuna species only started in the early 2000s, while no assessments are carried out for other teleosts caught as bycatch by these fisheries (Figure 7a). The ICCAT, the IOTC and the WCPFC started to perform stock assessments at the beginning of their conventions (Figure 7b,c,e), while the IATTC only started conducting formal, state-of-the-art stock assessments in the late 1990s (Figure 7c). More recently, the ICCAT has started to routinely assess stocks of Blue shark (*Prionace glauca*, Carcharhinidae), Shortfin mako shark (*Isurus oxyrinchus*, Lamnidae), and Porbeagle shark (*Lamna nasus*, Lamnidae) since 2004, as well as 11 stocks of neritic tunas, including Wahoo (*Acanthocybium solandri*, Scombridae) and Atlantic bonito (*Sarda sarda*, Scombridae) since 2018 (Figure 7b). The IOTC has only

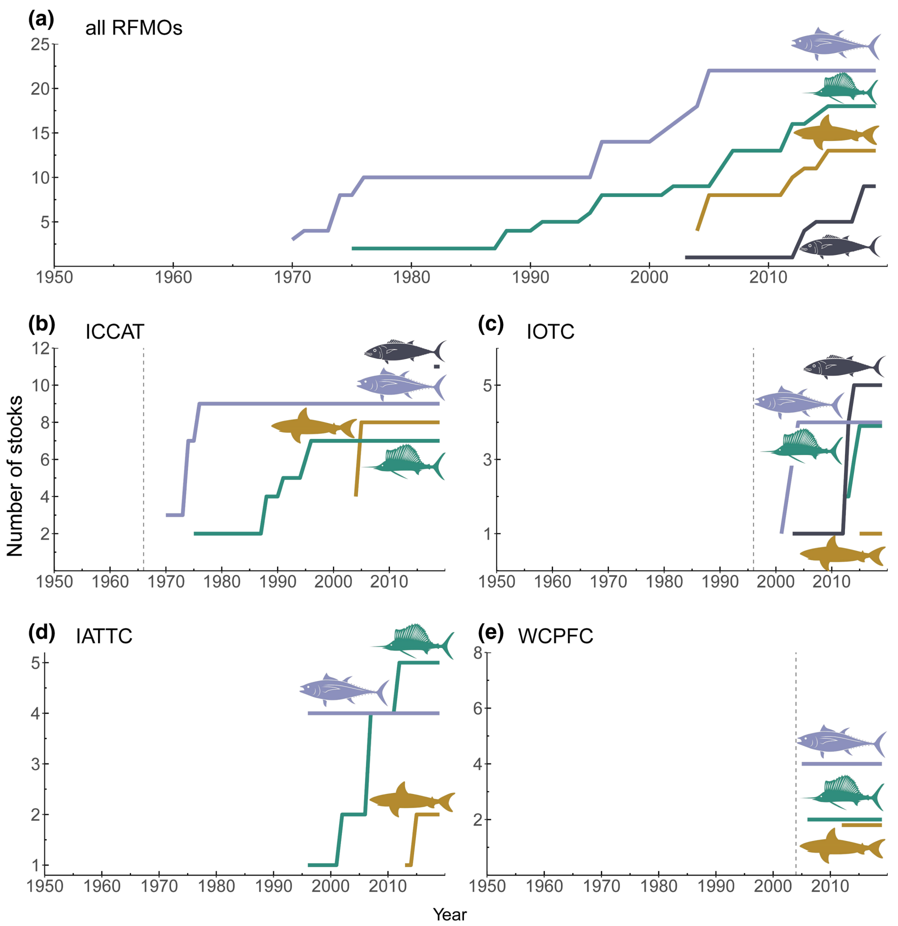

FIGURE 7 Number of stock assessments carried out by tuna RFMO (oceanic tunas – Light blue, neritic tunas – Dark blue, billfishes – Green, sharks – Gold) from 1950 to 2018 for: (a) all RFMOs, (b) International Commission for the Conservation of Atlantic tunas (ICCAT; 1966), (c) Indian Ocean tuna commission (IOTC; 1996), (d) inter-American tropical tuna commission (IATTC; 1949) and (e) Western and Central Pacific fisheries commission (WCPFC; 2004). Dashed vertical lines indicate the establishment of the convention. The dashed line for the IATTC is not visible in the graph as the convention was established in 1949

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begun assessing shark stocks in the last decade including one shark species – the blue shark since 2015, and several neritic tunas, i.e. Kawakawa (*Euthynnus affinis*, Scombridae), Longtail tuna (*Thunnus tonggol*, Scombridae) and Narrow-barred mackerel (*Scomberomorus commerson*, Scombridae) since 2012 (Figure 7c). The IATTC and the WCPFC have also recently begun to routinely assess sharks, that is Blue shark, Shortfin mako, Oceanic whitetip shark (*Carcharhinus longimanus*, Carcharhinidae) and Silky shark (*Carcharhinus falciformis*, Carcharhinidae) since 2012 (Figure 7d,e). The ICCAT is the leader in assessing catches of neritic tuna (76.3%), followed by the IOTC with 51.7%, while the tuna RFMOs in the Pacific, that is the IATTC and the WCPFC, do not conduct stock assessments for neritic tuna species (Figure 7d,e). The proportion of catches for which stock assessments are available is relatively high, accounting for 77% of total catches reported by the RFMOs, but varies by taxonomic group. The proportion of catches of assessed oceanic tuna and billfish ranges from 57% to 99.7% in all tuna RFMOs. The ICCAT assesses almost 90% of the reported sharks and rays catches, while in the other tuna RFMOs, the proportion of the shark catches for which stock assessments are available remains low (34.9% in the IOTC, 18.6% in the WCPFC, not available in the IATTC). However, as shark catches are not included in the public domain catch data in IATTC, we were unable to evaluate how much of the total reported shark catches have been assessed.

All tuna RFMOs acknowledge the need to improve the availability and quality of data on discards used for the provision of scientific advice, and require that their member countries report data on both retained and discarded catches via logbooks or regional observer programs (Figure 8, Table S4). However, the ICCAT and the IOTC are the only two tuna RFMOs that report discards in a partially transparent manner in their public domain data (Table 1, Table S3). The ICCAT has made efforts to strengthen data collection and transparent reporting of discards, especially for vulnerable bycatch species in the public domain data. Yet, the amount of discards reported in the official ICCAT nominal catch dataset is still low and mostly only available for some purse seine and longline fisheries (Tables S1 and S3). If discards are not, or only partially reported to the Commission, the staff of the IOTC and the IATTC estimate retained and discarded catch of target and non-target species and produce summary reports independently to the official public fishery nominal catch statistics datasets (IATTC, 2019; IOTC, 2021c). The IOTC has improved the provision of discard and bycatch data outside the official nominal catch statistic datasets, summarizing them publicly for the Working Party on Ecosystems and Bycatch (WPEB) since the implementation of the resolution on mandatory statistical requirements for member countries (IOTC, 2015). Discard data in this separate summary report; however, only dates back to 2009 and is still very patchy and therefore considered preliminary. We also note that the regional observer programmes responsible for collecting bycatch and discard data in the Pacific tuna RFMOs (the IATTC and the WCPFC) make these data fully available to the scientific staff of each commission; however, the observer data have not been made publicly available. The WCPFC and the CCSBT show no transparency of reported discarded catches and have yet to produce public domain summaries of discards data (Table S3).

Since their creation, each tuna RFMOs has adopted a myriad of conservation and management measures (binding and non-binding) that articulate the fishery catch data reporting requirements of members for species covered in their mandate as well as other species and taxa groups also being caught in their fisheries (Figure 8, Table S4). Over time, these management and conservation measures have resulted in an increase in the number of species being reported in the nominal catch, yet the fisheries catch data reporting requirements vary greatly by taxa and tuna RFMOs (Figure 8, Table S4). The ICCAT and the IOTC management and conservation measures require their member countries to report fishery catch statistics of all their mandated species (26 and 16 species, respectively) and non-mandated species (including sharks and rays and other teleosts) via logbooks and observer programs (Figure 8, Tables S2 and S4). Similarly, the IATTC and the WCPFC require to report fishery catch statistics for all its mandate species (including oceanic tunas, neritic tunas, billfishes, sharks and other teleost) via both logbooks and observer programs. The catch data collected in the IATTC and WCPFC are largely reported through the 100% regional observer programs for large purse seines, which are classified as confidential and publicly not available. Rays are not included in any of the tuna RFMOs mandates, except for the IATTC, which is responsible for the Pelagic stingray (*Pteroplatytrygon violacea*, Dasyatidae) yet IOTC is the only RFMO requiring the collection of catch data on rays via logbooks whereas all the RFMOs are mandated to report catches of rays via the observer programs (Figure 8, Tables S2 and S4). The CCSBT is responsible for the management of one species, Southern bluefin tuna, under its mandate, but is required to collect and report catches of ecologically related species (predators and prey of Southern bluefin tuna) via the observer programs, which are summarized separately outside the official catch statistics (Figure 8, Table S4) (CCSBT, 1994).

4 | DISCUSSION

Tuna RFMOs strive to address weaknesses in their data and analytical systems that hinder their ability to operate effectively and that have been highlighted in the past (Pentz et al., 2018). Yet, they continue to face multiple challenges that limit their effectiveness in sustaining pelagic fish populations while safeguarding marine ecosystems (Wright et al., 2015; Takei, 2006). Here, we focused on the individual performance of tuna RFMOs in monitoring and reporting fisheries catch statistics and found that the extent to which these data are complete and publicly available does not meet the required standards as established in their own mandates and conservation and management measures. Overall, individual tuna RFMOs compile, analyse and report their member countries' fisheries statistics with considerable variation in the level of detail, completeness, transparency and public availability. There is substantial room for improvement in all RFMOs, particularly in the areas of taxonomic

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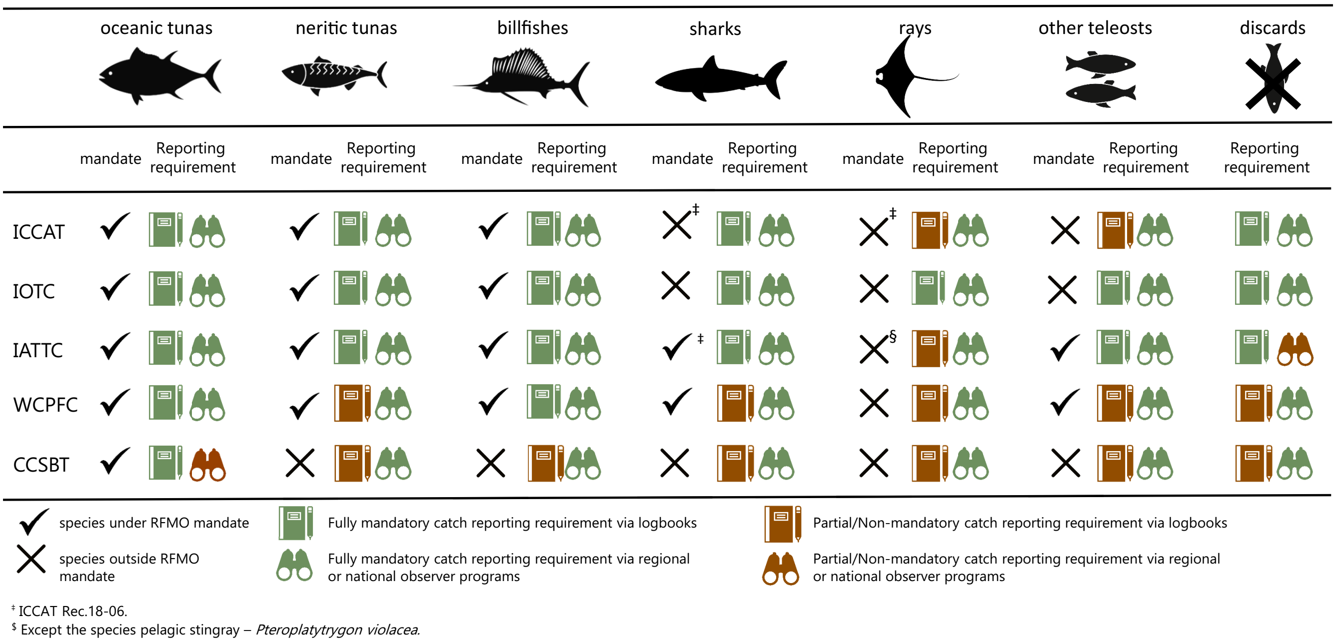

FIGURE 8 Requirements for reporting landed and discarded catch data in tuna RFMOs. Fully mandatory catch reporting requirements via logbooks or observer schemes are shown in green, while partial or non-mandatory catch reporting requirements are shown in red. Tickmarks and crosses indicate the inclusion of the taxa group within (tickmark) or outside (cross) RFMO convention mandates

and spatial data resolution of their catch statistics, and the collecting and reporting of discard data.

We found significant gaps in taxonomic data coverage, a substantial divergence in tuna RFMO data collection requirements and a lack of effective implementation. These results are coherent with findings that had already been highlighted more than a decade ago (Lodge et al., 2007). Reporting fisheries catches at a high taxonomic resolution for both mandatory target and non-targeted species is vital, as detailed fisheries catch data are needed for the effective assessment of the impacts of fishing on populations and ecosystems and thus the management of fisheries resources (Abella, 2011; Clarke et al., 2006; Pauly et al., 2013). Yet, our analysis supports previous findings that accurate reporting of landed and discarded catches is still lacking for formerly non-targeted species groups such as sharks or for species with relatively low-economic value such as neritic tunas, which support important fisheries in all tuna RFMOs and are now increasingly targeted and incidentally caught as bycatch (Clarke et al., 2006; Clarke et al., 2007; Sembiring et al., 2015).

Our results indicate that tuna RFMOs need to substantially improve the reporting of catch data for nertic tunas, sharks, rays and other teleosts fishes, for example dolphinfishes. All tuna RFMOs acknowledge the large underreporting of catches for neritic tunas, sharks, rays and other teleost, and increasingly recognize the need to reconstruct catch time series due to limitations and uncertainties in the nominal catch data (IOTC, 2021a, 2021d). However, we found that only the ICCAT and the IOTC have made progress in reporting catch statistics for neritic tunas and sharks (ICCAT, 2019b; IOTC, 2017). The ICCAT as of 2004 requires all member countries to report catches of sharks caught in association with their tuna fisheries. The IOTC has carried out several ‘fact finding missions’ to a multitude of developing coastal states, for example Oman, Sri Lanka, Tanzania, Kenya, Indonesia and Thailand since 2002, with the aim to assess issues, recover historical data and improve the accuracy of data collection and statistical analysis of catches (OFC, 2007, 2010, 2013). However, although the IOTC data reporting seems to have improved compared to the other tuna RFMOs, catch underreporting and the high uncertainties in the reported catches in IOTC remains a challenge, particularly in the coastal and artisanal fisheries of the regions (IOTC, 2021b).

A range of fishing gears dominates the global tuna fisheries. Purse seine, pelagic longline and pole-and-line remain the primary commercial fishing gears used in global tuna fisheries, although variations occur between ocean basins. Our research showed that purse seine gears are still predominantly used in the Atlantic and Pacific Oceans, whereas gillnets, which account for a smaller share of the tuna fisheries on a global scale, is the most popular gear type in the Indian Ocean since the mid-1980s. Overall, a very high proportion of the tuna global catches are derived from gillnets, longlines and purse seiners (including those using fish aggregating devices [FADs]), which cause in different proportions important bycatch mortality of juvenile target and vulnerable species (Garcia & Herrera, 2018; Griffiths et al., 2019). Among those gears, gillnets are known to catch the highest amount of vulnerable and endangered bycatch species (Ardill et al., 2013). Multiple calls for banning those destructive gears have led to a prohibition of drifting gillnets from international waters in 1992 followed by a ban in EU waters in 1998 (Goydan, 1992). Pakistan's gillnet fisheries shifted from surface to subsurface gillnetting in recent years in an attempt to reduce bycatch of vulnerable species (Moazzam & Khan, 2019). However, in other national waters, for example in the Mediterranean and the Indian Ocean, driftnets

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are still allowed and remain a popular legal (<2.5 km length) and illegal (>2.5 km length) fishing gear (Baulch et al., 2014; Moir, Clark et al., 2015;). Indian Ocean rim countries have relatively easy access to gillnets, and simultaneously face difficulties in enforcing controls on the growing and expanding fleets. Particularly, the growth of fishing capacity in artisanal and semi-industrial fisheries is characterized by the predominant use of gillnets, and fostered by the requirements of local markets. Gear technology approaches to reduce problematic bycatch of seabirds, turtles, mammals and sharks are being developed (Gilman et al., 2003; Godin et al., 2012; Watson et al., 2005); however, further investment in research and development is needed to reduce or eliminate bycatch.

Spatially resolved catch data are fundamental to support fisheries research and inform spatial management in tuna RFMOs yet we found that nearly half of the reported total catches in tuna RFMOs are not georeferenced and are reported without the required gridded spatial resolution. Historically, tuna RFMOs have agreed to report their catches in relatively large, coarse, aggregated grid cells to avoid legal issues and to prevent unwanted disclosure of confidential data with detailed geolocations of catches (IATTC, 2013; ICCAT, 2009; IOTC, 2015; WCPFC, 2016). However, this coarse spatial resolution often hinders detailed spatiotemporal analyses of fisheries interactions with species and the inferences that may be derived from them that can reveal important insights into the sustainability of tuna fisheries (Hoyle & Langley, 2020). For example, vessel monitoring systems (VMS) are unfortunately still treated as confidential by some member countries, and are thus not shared with RFMOs to improve the management of public common resources (Seto & Hanich, 2018). New technologies such as AIS (automatic identification system), space-based radar, and satellite imaging systems, in conjunction with the current VMS, can provide highly resolved data on fishing effort (Kroodsma et al., 2018; Li et al., 2021; Woodill et al., 2021) and have the potential to complement current spatial information of fishing (Global Fishing Watch, 2022). Therefore, there are several technological advances that can help to overcome on-going resistance to provide more detailed spatial information of catches and fishing effort by tuna RFMO members. In this age of inexpensive and globally obtainable GIS data, the continuing, uninformative broad spatial resolution of much of the catch data, and the considerable fraction of reported catches without spatial information, should be resolved by RFMO members as soon as possible; which in turn will reduce undocumented and non-transparent fishing activities and facilitate identifying illegal behaviour at sea, which could be related to human rights violations, as found previously (Tickler, Meeuwig, Bryant et al., 2018; Tickler, Meeuwig, Palomares et al., 2018). Moreover, we found that current data reporting in all tuna RFMOs by so-called artisanal fisheries is particularly scarce in terms of spatial information. This data scarcity is evident, for example, in the decline of spatially resolved catch data with the increasing coverage and inclusion of the fishing fleets classified as artisanal by the IOTC in reported nominal catches over the past decade. While we recognize the difficult for monitoring the artisanal fisheries, both for total catch and spatial catch information, we encourage member countries and RFMO to explore new technologies (e.g. electronic monitoring systems – EMS) to improve the statistics of those fisheries.

Stock assessments are key to effective fisheries management of resources. We found that all tuna RFMOs have made progress in implementing stock assessments for a wide range of taxa including not only targeted species with high economic value but also functionally important non-target species to the ecosystem with low economic value (e.g. neritic tunas). However, the stock assessments for neritic tunas, shark and rays remain scarce, and those available are still mostly considered highly uncertain and preliminary (ICCAT, 2010). The incomplete catch, effort and length data hinders the reliable estimation of stock trajectories and reference points as part of the evaluation of the stock status. This limited data availability is also often linked to challenges in species identification, e.g. sharks and rays are often difficult to identify to the species level by fishers and even on board observers (Tillett et al., 2012; Williams et al., 2018). Furthermore, the low commercial value of sharks, except for their fins, results in limited data collection and therefore often prevents data-rich stock assessments from being carried out (Clarke et al., 2006). For data-poor stocks such as sharks and neritic tunas, the tuna RFMOs have recently started to use established quantitative methods for data-limited situations, such as length-based methodologies (Chong et al., 2020; Froese et al., 2018; Hordyk et al., 2014; Le Quesne & Jennings, 2012), stock depletion techniques (Dick & MacCall, 2011; Haltuch et al., 2008) or surplus production models (Froese et al., 2017). We recommend the use of these well-established data-limited assessment methods for a larger number of stocks and species, in conjunction with improving the collection, estimation and reconstruction of catch, effort, length and life history data on which these methods rely.

The reporting and estimation of discards in tuna RFMOs remains heavily incomplete and lacks public transparency, and consequently the quality and availability of data on discards in global tuna fisheries are still extremely limited (Gilman et al., 2017). We found that member countries still largely fail to comply with existing requirements for reporting discards. In particular, discards of sharks and rays are generally not recorded in logbooks and only partially recorded through limited observer programmes (Clarke et al., 2006; Dulvy et al., 2014). This large underestimation of discards is acknowledged by the ICCAT, the IOTC and the IATTC (IATTC, 2019; ICCAT, 2016; IOTC, 2016). Over the past 10 years, all tuna RFMOs have extended their monitoring requirements for member countries via observer programs in order to more comprehensively estimate the entire catch, including retained and discarded components (IATTC, 2004; IOTC, 2011; WCPFC, 2018). We found that available estimates of catches including discards from observer programmes are typically classified as incomplete and too preliminary, due to low observer coverage in most fisheries (e.g. <5% in longline fisheries) to be included in the public databases. Additionally, observer data on catches including discards are largely considered confidential and thus not publicly released. The lack of the public's ability to monitor fishery management decisions through its access to

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observer data, and the associated non-transparency is particularly challenging for the evaluation and assessment of vulnerable species such as sharks, which has major species conservation implications (Dulvy et al., 2014; Pacoureau et al., 2021). Therefore, it is urgently needed to increase the observer coverage, by either human observers or electronic monitoring, to ensure accurate bycatch and discard estimates in those tuna fisheries with low observer coverage. We emphasize the critical importance of strengthening comprehensive data submission by and accountability of RFMO member countries, while substantially increasing the number of observers and reducing public distrust of confidentiality rules to obtain comprehensive, publicly available datasets on global tuna fishing activities. Only a substantial increase in observer programs, with coverage well beyond the current 5% of fishing trips across tuna RFMOs can provide comprehensive insights into the sustainability of their fisheries (Ewell et al., 2020). The additional use of tools such as EMS can provide efficient and cost-effective complements to human observers present on most fishing vessels, if implemented successfully at a broad scale (Banks et al., 2016). These EMS are increasingly being tested and refined, and have already been implemented in some tuna fisheries, for example in the EU purse seine tuna fishery and the Hawaii and Fiji longline tuna fishery (Gilman et al., 2020; Ruiz et al., 2014).

Scientists, non-governmental organizations, politicians and the public increasingly view the performance of tuna RFMOs critically. Here, we have highlighted several challenges regarding data collection and sharing that tuna RFMOs are facing, and that need addressing to enable effective and appropriate management of fisheries. Key strategies to ensure data quantity and quality, and ultimately improve the performance and effectiveness of tuna RFMOs may include: expand the mandatory requirement to collect data to all species interacting with tuna fisheries, collect and report finer scale operational fishery data; substantially expand and strengthen observer programs and mandate electronic monitoring systems (EMS); use alternative technological tools to collect fishery data (e.g. AIS for fishing effort); build capacity to improve the collection, analysis and dissemination of fishery statistics of artisanal fisheries and support the data science infrastructure in developing nations. All these data would address current gaps for improved science-based stock assessment and management advice that will increase and ensure public data transparency across all tuna RFMOs.

Another practical next step to address quality issues in the fisheries catch statistics would be to strengthen the establishment and review of standards for coverage and quality of data collection protocols. For example, regular analysis of correspondence between logbook data and observer data or statistics from seafood markets and processors could help validate nominal catch data (Gilman & Hall, 2015; Lewis & Williams, 2016). These methods may include the enhancement of the secretariats' capacities to provide support to member countries, such as the 'fact finding missions' that have been carried out by the IOTC in the past (OFC, 2007, 2010, 2013). Additionally, data collection and data reporting require a high degree of international cooperation, and a far higher level of prioritization and expenditure than they receive at present, since good data are the cornerstone for the provision of quality scientific advice in support of sustainable fisheries management.

The improvements in data collection and reporting by individual tuna RFMOs also need to be undertaken with adequate retroactive corrections of earlier data, as catch statistics in tuna RFMOs suffer extensively from the presentist bias (Zeller & Pauly, 2018). Tuna RFMOs continuously update, correct and reconstruct some historical data as member states submit revised catch data. Yet, we found that the lack of resources and capacity, as well as consideration of this task as low priority, hinder the adequate corrections of historical data (Fortibuoni et al., 2017; Martin & Shahid, 2021). One example is the considerable underreporting of catches of bluefin tuna from the East Atlantic and the Mediterranean between the mid-1990s and 2007, despite the bluefin tuna belonging to one of the best monitored species in the Atlantic Ocean (Die, 2016). Similarly, the existence of large unreported catches of southern bluefin tuna can have wide implication for the reliability of catch and effort data, and consequently stock assessments and management (Polacheck & Davies, 2008). We recommend that methods now well-established and documented for non-tuna fisheries, such as historical data reconstructions should be included in the standard practices of tuna RFMOs for those species with uncertain historical catch data (Pauly & Zeller, 2016; Zeller et al., 2016).

Transparency in international marine governance has been discussed for almost 30 years (De Bruyn et al., 2013; Lodge et al., 2007) and most tuna RFMOs now incorporate basic elements of transparency into their operations, for example the inclusion and labelling of discard data in the publicly available datasets at the IOTC and the ICCAT, respectively. Yet, we found that the focus to increase transparency has still mostly been on compliance documents, resolutions and management measures, suggesting that the provision of publicly available, comprehensive and transparent data still needs improvement. Even the no-cost registration requirement for so-called public data via the WCPFC is questionable in terms of unrestricted public transparency and accountability, given the WCPFC's requirement for personal identification. We recognize that collecting these information may be solely for the purpose of collecting information about downloads but we emphasize that no other tuna RFMO, nor the FAO require such personal information to access their public data. Data on catch composition and georeferenced catch and effort data as well as bycatch and discard information from observers, which are public, common pool resources due to their straddling stock nature, must be freely accessible to any stakeholder to improve the science underpinning the management advice and sustainability of the resources but also transparency of fishing operations. Only this will ensure public trust in the management actions around these resources.

Improving publicly available, highly taxonomically and spatially resolved databases will likely be an important step in managing the future of global tuna resources as well as inform other future international instruments such as the new ABNJ treaty. Tuna RFMOs and their member countries must commit to their responsibility to improve public accounting and address the deficiencies highlighted here. The variability between the tuna RFMOs in the

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level of detail, completeness and public availability alone suggests a strong need for improvements in monitoring and reporting systems and capacity building in member countries to improve data quality, quantity and public transparency. We recognize the limitations some countries may have in terms of capacity and resources to design and maintain accurate data collection systems, the observer programmes and the data science infrastructure but emphasize that strengthening data collection systems and observer programmes for tuna RFMOs is critical to obtaining the data needed on fishing activities to ensure the sustainability of our oceans. Tuna RFMOs represent a global organizational network for monitoring fisheries and fish stocks in ABNJ waters and, in principle, are well suited to collect, process and report fisheries statistics to support the provision of scientific advice, and manage the species under their mandates; however, they must strengthen their performance and collaboration among their members to improve data collection and transparency. They are, after all, important regional bodies for international fisheries management of many of the world's highest valued fisheries.

AUTHOR CONTRIBUTIONS

KH and MJJ conceived the study. KH analysed the data and drafted the manuscript. All authors contributed to the manuscript revision, read and approved the submitted version.

ACKNOWLEDGEMENTS

This research was supported by an Australian Government Research Training Program (RTP) Scholarship. Kristina Heidrich was also supported by the Forrest Research Foundation. Maria José Juan-Jordá was supported by *'la Caixa'* Foundation Postdoctoral Junior Leader Fellowship under agreement N° 847648. General Sea Around Us research is supported by the Oak Foundation, the Paul M. Angell Family Foundation, the Marisla Foundation, the David and Lucile Packard Foundation, the Minderoo Foundation and Bloomberg Philanthropies via Rare. However, no specific or dedicated funds were provided to support this specific research project. The views and opinions of authors expressed herein do not necessarily state or reflect those of the funding organizations as they had no involvement in the design or production of the study. Open access publishing facilitated by The University of Western Australia, as part of the Wiley - The University of Western Australia agreement via the Council of Australian University Librarians.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this manuscript are publicly available and accessible at the individual tuna RFMO websites. A reference to the location of the material is provided in the Supplementary information.

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How to cite this article: 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*, *23*, 1264–1281. https://doi.org/10.1111/faf.12687

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