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Challenges and Opportunities in Monitoring and Mitigating Sea Turtle Bycatch in Tuna Regional Fisheries Management Organizations

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ABSTRACT

Fisheries that target tunas and tuna-like species are managed by tuna regional fisheries management organizations (t-RFMO) and are known to interact with various bycatch species, including sea turtles, with potentially negative effects. Actions and management measures implemented by t-RFMO to monitor sea turtle fisheries interactions, reduce their bycatch in fisheries, and carry out best practices for the handling and safe release of sea turtles, with the ultimate aim of improving the conservation of sea turtles are revised. Specifically, the actions and regulations for each of the following areas are revised: (i) data collection requirements, (ii) bycatch estimates and assessments, (iii) management measures, and (iv) any other conservation and management actions for sea turtle conservation. The particular case of the Mediterranean Sea also was analyzed, given that it has the highest rate of sea turtle bycatch in the world. Tuna-RFMO have a great potential for reducing fisheries bycatch impacts in marine turtle populations globally, but their actions are limited by their geographic scopes and mandates and the variety of habitats used by sea turtles during their life history. Tuna-RFMO also have a potentially significant role in leading the reduction of incidental sea turtle mortality in fisheries under their purview, both regionally and globally, by bringing together different stakeholders and initiatives.

KEYWORDS

Bycatch; fisheries managements; marine turtles; marine reptiles

Introduction

Sea turtles are a unique group of aquatic reptiles that inhabit all oceans of the world (Rasmussen et al. 2011). There are currently seven recognized species of sea turtles (Table 1), all of which have a common general life history of foraging and copulating in marine waters and migrating to sandy beaches to lay eggs in nests dug in the sand (Davenport 1997). Each female may make several nests in each nesting season (Lutz and Musick 1996; Lasala et al. 2020; Rusli 2022) and eggs typically hatch after 40–60 days (Lutz and Musick 1996; Erb and Wyneken 2019; Rusli 2022). Five sea turtle species (green, *Chelonia mydas*, hawksbill, *Eretmochelys imbricata*, leatherback, *Dermochelys coriacea*, loggerhead, *Caretta caretta*, and the olive ridley, *Lepidochelys olivacea*) have circumglobal distributions in temperate and tropical waters of all oceans (Figure 1). Thus, hawksbill and olive ridley turtles have extended ranges in the tropical regions of all oceans, while loggerheads, green sea turtles, and leatherbacks have a wider range of global distribution, consequently overlapping with five t-RFMO zones

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Table 1. Summary of the maximum recorded size, number of eggs by net, diet, and their status according to IUCN standards for each species of sea turtle.

Scientific name	Common name	Maximum CCL (Ferri 2001)	Number of eggs (Ferri 2001)	Global IUCN status	Diet
Dermochelys coriacea	Leatherback	240	170	Vulnerable (Wallace, Tiwari, et al. 2013)	Feeds on gelatinous animals (jellyfishes, salps, and siphonophores)
Caretta caretta	Loggerhead turtle	200	200	Vulnerable (Casale and Tucker 2017)	Opportunistic omnivorous
Chelonia mydas	Green turtle	150	200	Endangered (Seminoff 2004)	Omnivorous, primarily herbivorous
Eretmochelys imbricata	Hawksbill turtle	90	160	Critically endangered (Mortimer and Donnelly 2008)	Spongivorous
Lepidochelys kempii	Kemp's ridley	70	140	Critically endangered (Wibbels and Bevan 2019)	Carnivorous
Lepidochelys olivacea	Olive ridley	70	100	Vulnerable (Abreu-Grobois and Plotkin 2008)	Carnivorous
Natator depressus	Flatback	100	50	Data deficient (Red List Standards and Petitions Subcommittee 1996)	Omnivorous, primarily herbivorous

CCL: curve carapace length in cm.
Given the plasticity between populations and individuals, approximations are given to the maximum recorded in size and number of eggs per clutch.

(Figure 1). Two species have more limited distributions, namely the Kemp's ridley, *Lepidochelys kempii*, which only inhabits the North Atlantic Ocean, and the flatback, *Natator depressus*, which only inhabits shallow coastal waters of Australia, Indonesia, and Papua New Guinea (Wallace, DiMatteo, et al. 2010). Despite their resemblance, there are two families of the sea turtles that separated during the Cretaceous: Dermochelyidae, which includes a single species, the leatherback turtle, and Cheloniidae, which includes the other six species (Naro-Maciel et al. 2008). Sea turtles vary greatly in their size, biology, and feeding ecology. All sea turtle species are classified globally as some degree of threatened (e.g., "critically endangered") in the IUCN Red List with the exception of the flatback (classified as "data-deficient") (see a summary in Table 1).

Despite differences in their life histories and ecology, all species of sea turtles are long-lived, slow growing, and have relatively late maturity. This renders these species vulnerable to anthropogenic and natural threats, and in particular to mortality at older life stages when animals have higher reproductive value (Maxwell et al. 2013; Wallace, Kot, et al. 2013; Lewison et al. 2014; Bellido López et al. 2018; Gray and Kennelly 2018). Among human-related causes, incidental capture and associated mortality in a variety of fisheries ("bycatch") is a major conservation threat to most sea turtle species (Domingo et al. 2006; Bolten et al. 2011; Guebert et al. 2013; Casale and Heppell 2016; Bellido López et al. 2018; López-Mendilaharsu et al. 2020) and is believed to be one of the main causes of specific population declines in some regions of the world (Lewison et al. 2004; Wallace, Lewison, et al. 2010). Global sea turtle bycatch have been estimated at between 85,000 and 250,000 individuals annually, mainly by pelagic fisheries targeting tuna and tuna-like species (Lewison et al. 2004; Wallace, Lewison, et al. 2010). As such, minimizing the impacts of fisheries by reducing incidental capture, improving handling and release techniques, and using other mitigation options are among the main conservation priorities for sea turtle species (Camiñas et al. 2021).

Tuna and tuna-like fish represent a significant part of the global seafood market with an annual value estimated between 34 and 42 billon USD$ (Pew Charitable Trusts 2016; Tidd et al. 2018), with a total catch of 7.5 million tons in 2016 (9% of the global marine fisheries production) (reviewed in Merino et al. 2020). The value is currently clearly higher than these previous values given inflation and other factors. The most commercially important tuna species are: albacore, *Thunnus alalunga*; Atlantic bluefin, *Thunnus thynnus*; Pacific bluefin, *Thunnus orientalis*; southern bluefin, *Thunnus maccoyii*; bigeye, *Thunnus obesus*; yellowfin, *Thunnus albacares*; and skipjack, *Katsuwonus pelamis*. Commercially important tuna-like species include the swordfish *Xiphias gladius*. The main fishing gears catching tuna and tune-like species include drifting pelagic longlines, gillnets, pelagic purse seines, trolling, and pole-and-line (baitboat) (Tidd et al. 2018). These gears, and in particular longlines (Clarke et al. 2014), purse seines (Hall and Roman 2013), and gillnets (Gautama et al. 2022) contribute most to the global bycatch sea turtles (Gray and Kennelly 2018; Savoca et al. 2020; Swimmer et al. 2020), however turtle bycatch can vary substantially between gears and regions (Lewison et al. 2014; Báez et al. 2019). There is therefore growing concern and an increasing amount of research being presented to and discussed in scientific committees of tuna Regional Fisheries Management Organizations (t-RFMO), regarding the provision of scientific management advice to monitor

and mitigate fisheries impacts on sea turtles (Camiñas et al. 2021).

Since their creation, t-RFMO have taken a series of research and management actions to monitor and estimate the extent of sea turtle bycatch, and to mitigate the impact of the interactions with the fisheries. Tuna RFMO have implemented resolutions and recommendations to collect bycatch data, including of sea turtles, primarily *via* observer programs, both human as well as with relatively recent implementation of electronic monitoring systems, most of which are currently in development with the aim to expand coverage and complement the role of human observers. Although observer programs are costly and complex to implement, they are the best currently available tool to monitor and estimate the extent of bycatch. In parallel, t-RFMO have also implemented a series of measures aimed at mitigating bycatch and reducing associated mortality, either by reducing captures and/or promoting onboard handling release methods that increase post-release survival (Gilman et al. 2014; Zollett and Swimmer 2019).

In this review, we examine the current role of t-RFMO and their potential to reduce the incidental capture of sea turtles associated with tuna fisheries. The management measures adopted to monitor and reduce sea turtle bycatch and associated mortality are revised. Specifically, the actions and regulations adopted by t-RFMO for each of the following areas are revised: (i) data collection and reporting requirements, (ii) bycatch estimates and assessment, (iii) management measures, and (iv) any other conservation actions for sea turtle conservation promoted by t-RFMO, for example, good practice guide for the handling and release methods of sea turtles caught incidentally. The particular case of the Mediterranean Sea also was analyzed, given that it has the highest rate of sea turtle bycatch in the world (Lewison et al. 2004, 2014). Finally, we discuss the current role of t-RFMO and their possible leadership to reduce the mortality of sea turtles associated with tuna fisheries, as well as the many obstacles that are usually encountered when implementing management actions.

Tuna Regional Fisheries Management Organizations: structure and function

Inter-governmental organizations, like t-RFMO, function under conventions that determine their objectives, structure, procedures, and the geographic and species scope of their mandates. There are currently five regional fisheries management organizations (RFMO) responsible for the management of tuna and tuna-like stocks: Commission for the Conservation of Southern Bluefin Tuna (CCSBT), Inter-American Tropical Tuna Commission (IATTC), International Commission for the Conservation of Atlantic Tunas (ICCAT), Indian Ocean Tuna Commission (IOTC), and Western Central Pacific Fisheries Commission (WCPFC) (Figure 1). These five t-RFMO are independent and guided by their own conventions, but operate under the principles of the United Nations on the Law of the Sea (UNCLOS) relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and the Food and Agriculture Organization (FAO) Code of Conduct for Responsible Fisheries. In effect, the IOTC was established under the Article XIV, of the FAO constitution (Anonymous 2016). All five t-RFMO are responsible for maintaining target stocks at sustainable levels, but in the last decades, the work of t-RFMO has intensified and expanded to other ecosystem impacts of fishing activity, with a particular focus on non-target species bycatch. This is also a mandate included in UNCLOS in relation to Conservation of living resources (UNCLOS Article 61, Conservation of the living resources).

Membership of the commissions of t-RFMO have changed over time, but in general includes most of coastal nations in the region, distant water fishing nations operating in the respective convention areas, and other nations with fishery interests in these areas. Their overall organizational structures are quite similar including a Scientific Committee that provides management advice to the Commission, which ultimately agrees on procedures and management measures (Figure 2). There are differences in how they work to provide management advice and how the various subsidiary science bodies are organized. Some have a Secretariat with large scientific staff (e.g., IATTC) or rely on an external science service provider (e.g., WCPFC) to carry out the bulk of scientific work, which is later to be considered by Scientific Committees. Alternatively, other t-RFMO have a smaller scientific Secretariat and rely on scientists from member countries (e.g., ICCAT and IOTC) to develop the scientific advice at the Scientific Committee meetings. Therefore, the scientific staff and/or Scientific Committees produce advice that may be translated into conservation and management measures when adopted by the Commissions by consensus of its member nations representatives. The measures adopted by the Commissions must be monitored and enforced by the member nations themselves, while the Commissions usually have a Compliance Committee that oversees the implementation of and compliance with management rules.

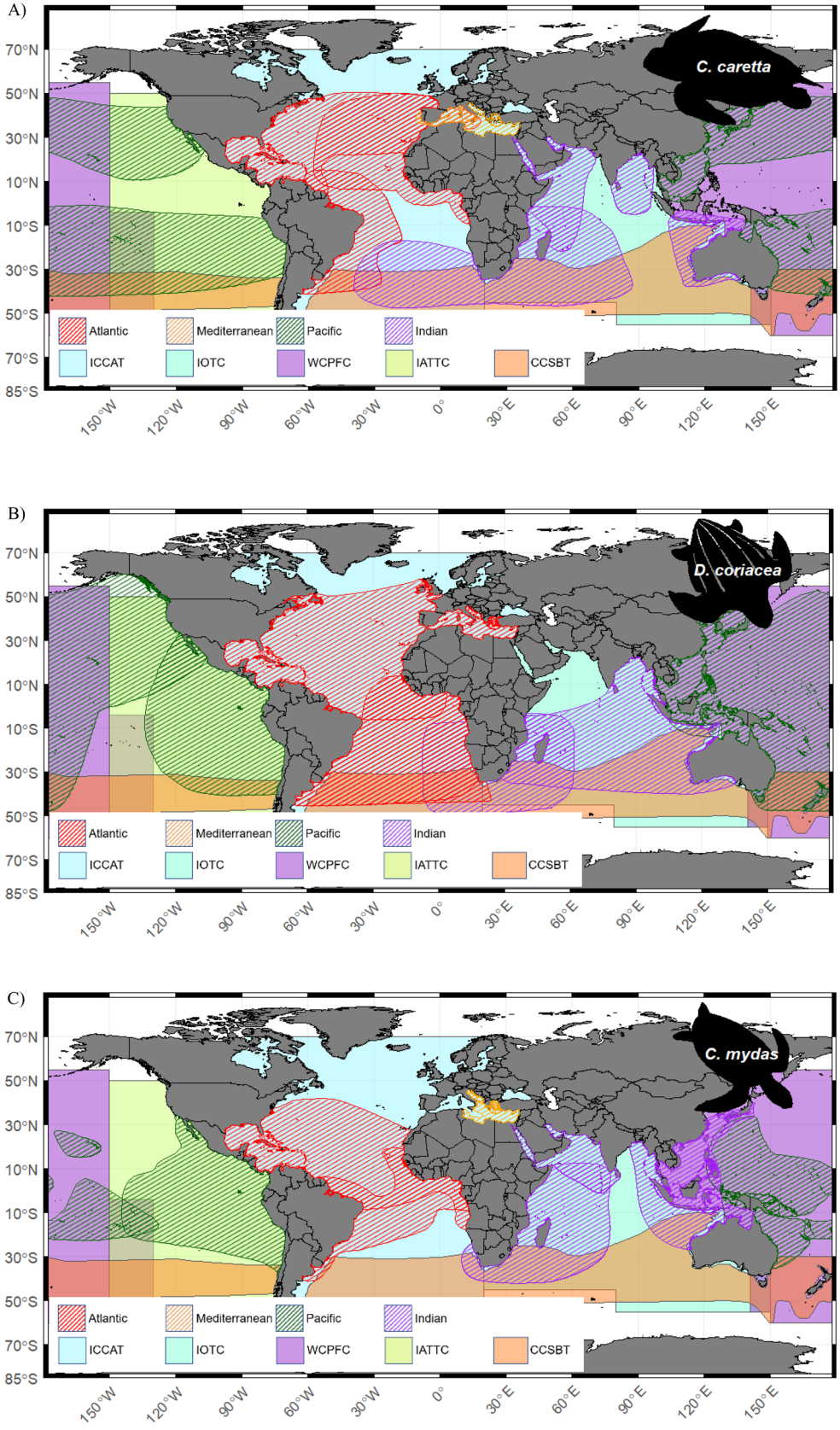


Figure 1. Overlap between area competence of the five t-RFMO and important marine turtle Regional Management Units (RMU) (Wallace et al. 2023) for the seven species of sea turtles: (a) loggerhead sea turtle (*Caretta caretta*), (b) leatherback sea turtle (*Dermochelys coriacea*), (c) green sea turtle (*Chelonia mydas*), (d) hawksbill sea turtle (*Eretmochelys imbricata*), and (e) olive ridley sea turtle (*Lepidochelys olivacea*); (f) Kemp's ridley sea turtle (*Lepidochelys kempii*); and (g) flatback sea turtle (*Natator depressus*).

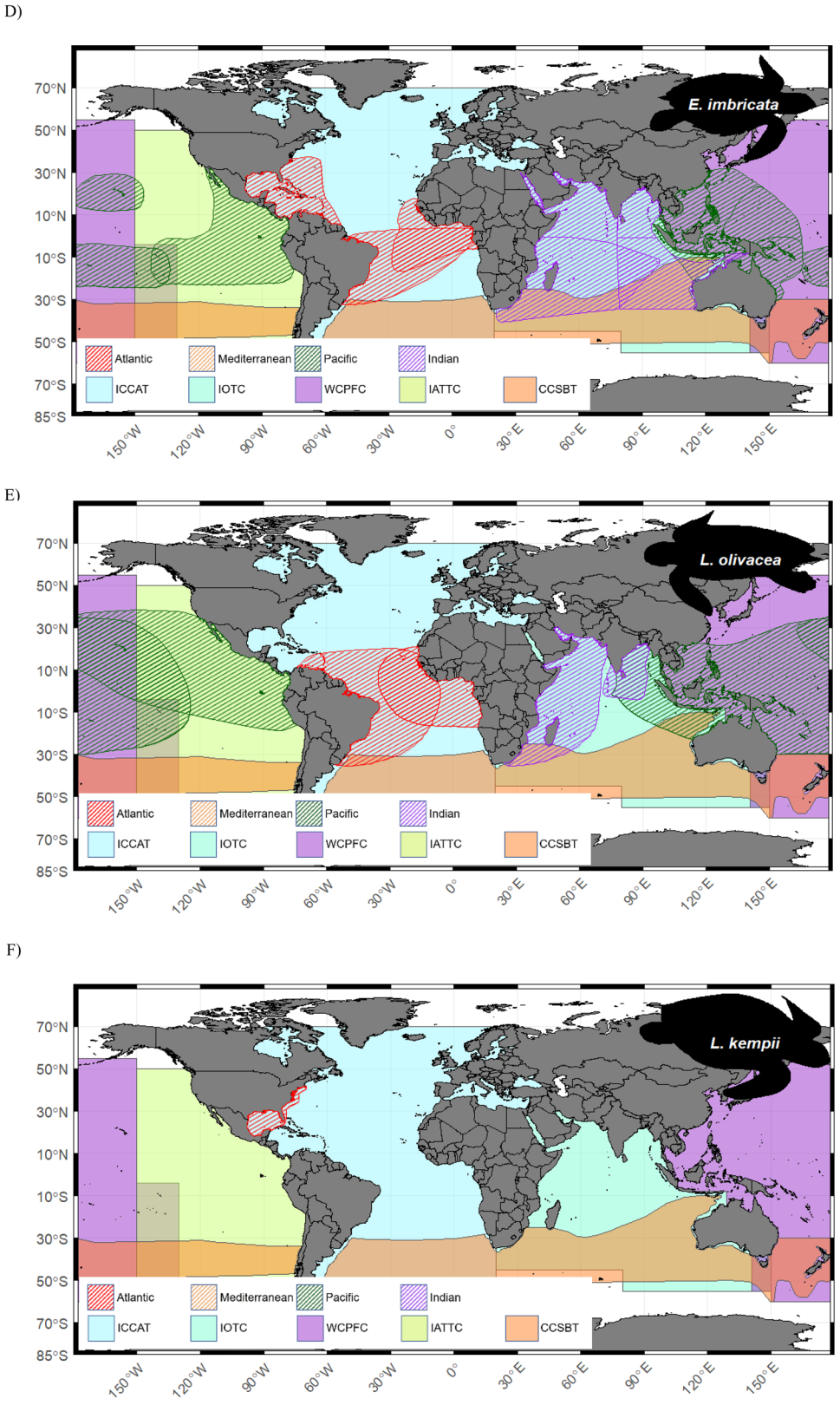
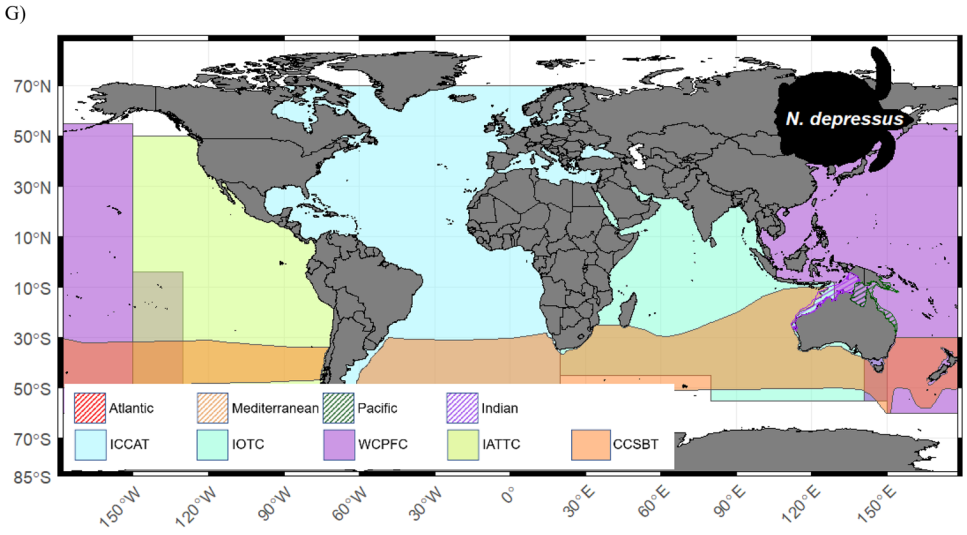


Figure 1. (*Continued*)

To provide scientific advice regarding the effective mitigation of sea-turtle bycatch, it is necessary to have enough reliable information to understand the magnitude of the problem and generate specific management measures. To this end, t-RFMO request that Contracting Parties (CPC) annually provide information on fishery statistics, including bycatch estimates and information recorded by onboard observers (see Figure 2), however, compliance with data collection and reporting varies among CPC. For example, many



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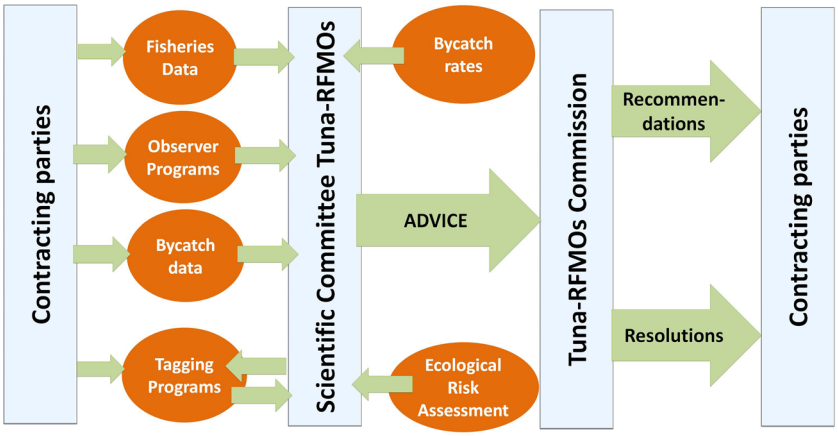

Figure 2. Flow chart outlining the relationship between the provision of data by the Contracting Parties to the t-RFMO (CPCs), the scientific committees, and the resolutions and recommendations adopted by the commission of each of the t-RFMO based on the advice received. The recommendations and/or resolutions are binding on CPCs and aim at improving the data provided, improving fisheries management, and the good management of by-catches.

fleets do not have adequate observer coverage to produce sound estimates, identify bycatch cause, or to verify compliance with adopted measures. Therefore, all t-RFMO have adopted specific resolutions related to the collection of bycatch data, including sea turtles (Table 2). It is important to note that while resolutions are non-binding in ICCAT, recommendations are binding. In the case of other t-RFMO, the opposite is true: recommendations are non-binding while resolutions are binding. This difference in the legal nature of these instruments emphasizes the importance of clear terminology within each t-RFMO for effective joint management. Furthermore, it highlights the need to establish joint mechanisms among all t-RFMO to ensure the sustainable management of shared fishery resources, particularly for highly migratory species, such as sea turtles.

On the one hand, the data necessary to assess bycatch interactions often requires spatiotemporal resolution of a quality that can only be collected by onboard scientific observers. On the other hand, the current level of observer coverage in each t-RFMO differs depending on the fishery, flag, gear, and nature of the observer program (i.e., voluntary *vs.* mandatory). In recent years, the development of electronic monitoring programs to increase the coverage on vessels for detailed data collection is encouraged by t-RFMO, which may be especially relevant for fleets with substantial logistical challenges (Swimmer et al. 2020; Brown et al. 2021). Moreover, the data collected in observer programs are often used to estimate bycatch rates per fishery and their relative changes over time in response to operational changes in the fishery and/or relative abundance of species or in

Table 2. List of active binding and non-binding conservation and management measures regarding sea turtle bycatch monitoring and mitigation measures of the five Tuna Regional Fishery Management Organizations (t-RFMOs).

t-RFMO	Recommendation/resolution	Data collection	Handling practices	Assessment	Bycatch mitigation
CCSBT	Resolution to Align CCSBT's Ecologically Related Species measures with those of other RFMOs	x	x		x
IATTC	Res-C-04-07				x
	Res-C-19-08	x			
	Res-C-19-04	x	x		x
	Res C-19-01	x			x
	Res C-21-04				x
ICCAT	Recommendation 11-10	x			
	Recommendation 13-11		x	x	
	Recommendation 19-11		x		x
	Recommendation 22-01				x
	Recommendation 22-12	x	x		x
IOTC	Resolution 23-02		x		x
	Resolution 18-04				x
	Resolution 17-07				x
	Resolution 15-01	x			
	Resolution 15-02	x			
	Resolution 12-04	x			x
WCPFC	CMM2018-04	x	x		x
	CMM2021-01				x

CCSBT: Commission for the Conservation of Southern Bluefin Tuna; IATTC: Inter-American Tropical Tuna Commission; ICCAT: International Commission for the Conservation of Atlantic Tunas, IOTC: Indian Ocean Tuna Commission, WCPFC: Western and Central Pacific Fisheries Commission.

Note: Each RFMO has different terminologies referring to their adopted management measures. Resolutions in IOTC are binding on Contracting Parties (CPC) while Recommendations are non-binding. In ICCAT, Recommendations are binding and Resolutions are non-binding.

response to adopted fishery mitigation measures. On the other hand, these estimates of bycatch rates have often been problematic due to statistical biases as a consequence of low coverage, underreporting, inconsistencies in data collection and reporting, lack of estimates of survival after release, uneven training and motivation of crews, etc. (Parga et al. 2015, 2020; Swimmer et al. 2020). Because turtles are long-lived species, long-time series are necessary to understand population trends, and most CPC observer programmes have only been implemented recently.

One possible approach attempt to overcome data deficiencies is using forms of semi-quantitative and quantitative Ecological Risk Assessments (ERA) which require fewer data inputs than conventional stock and population assessment models (Figure 2). Ecological Risk Assessments have been used to identify which sea turtle species and populations are most vulnerable to specific fishing gears under current fishing practices. Ecological Risk Assessments, such as the widely used Productivity-Susceptibility Analysis (PSA) (Stobutzki et al. 2001) are often limited to the use of only categorical data (e.g., low, medium, high) to score a range of attributes pertaining to a species' productivity (e.g., growth rate, age at maturity, longevity) and susceptibility to capture and mortality (e.g., gear selectivity, geographic overlap between the effort of fishery with that of the species). Species with high susceptibility scores and low productivity scores are deemed to be most vulnerable, or "at-risk," for a particular fishing gear. Other limitations of the PSA analysis include the estimation of relative risks instead of absolute risks and the difficulty of addressing cumulative impacts across multiple natural and anthropogenic threats, not just fisheries. While these semiquantitative ERA have been an effective tool within t-RFMO, a recent study identified contradictory findings for such approaches and proposed an ensemble modeling approach in data-limited situations (Gilman et al. 2021).

Finally, depending on received advice Commissions of the t-RFMO, requests further information from the CPC or issue resolutions or management recommendations to be adopted by the CPC. The resolutions and recommendations provided to each of the t-RFMO by their respective CPC are reviewed below.

Inter-American Tropical Tuna Commission (IATTC)

Inter-American Tropical Tuna Commission is the oldest t-RFMO and has had a relatively long history establishing Conservation and Management Measures (CMMs) specific to sea turtles (Table 2). The first (C-04-07) entered into force in 2004 and was a three-year program to mitigate the impact of tuna fishing on sea turtles, but largely made recommendations to CPCs to improve mitigation techniques and education of fishers. This resolution was extended and amended by resolution C-07-03, where CPCs were mandated, among other things, to implement the FAO Guidelines to reduce the bycatch, injury, and

mortality of sea turtles, and implement monitoring programs.

In addition to these resolutions, since 2001 IATTC has considered the issue of the entanglement of turtles with Fishing Aggregating Devices (FAD), encouraging vessel owners to explore ways to eliminate the entanglement with these devices (Res C-01-04, C-02-05, C-03-08, C-04-05). These resolutions were partially amended and replaced, among others, by the currently active resolutions C-19-01 and C-21-04, CMMs on FAD, and conservation of tropical tunas, respectively. All of these resolutions encourage better data collection of sensitive bycatch species, including sea turtles, through logbooks and observer programs for all purse-seine vessels operating in IATTC convention area. In addition, these resolutions promote and encourage research on non-entangling FAD design and use of non-entangling biodegradable FAD, while requiring all FAD to be constructed following low-entanglement risk designs. Similarly, resolution C-19-08 (amending and replacing C-11-08) intends to improve data collection of bycatch species by scientific observers for longline vessels operating in the eastern Pacific Ocean while resolution C-19-04 specifically mandates the collection of sea turtle interactions in vessel logbooks. Besides all these efforts, the quality of the data reported under these resolutions is unclear. Some recent efforts, however, have noted that the data reported by longline observers, for example, are not representative of target species (Griffiths et al. 2021) and therefore may not be reliable for bycatch species, including sea turtles.

Currently, IATTC relies on mitigation measures as the primary means by which sea turtle bycatch is minimized and managed in the Eastern Pacific Ocean (EPO). Resolution C-19-04 mandates, and makes recommendations for the use of measures to reduce sea turtle bycatch, and to increase safe release of bycatch sea turtles, in both purse seine and longline fisheries. In both fisheries, owners are required to carry onboard and use safe-handling tools for the release of sea turtles (e.g., de-hookers, line cutters, dip nets). In the longline fishery, an additional mitigation measure required under C-19-04 is the use of only large circle hooks or finfish for bait for shallow sets, however, as of 2024, the measure remained incomplete by the lack of a definition for a "large" circle hook.

The main source of data pertaining to sea turtle interactions in tuna fisheries managed by the IATTC has been collected through the Agreement on the International Dolphin Conservation Program (AIDCP 2009) observer program, which has 100% coverage for the fleet of large purse-seine vessels (>363 mt) in the EPO (note that the "La Jolla" agreement in 1992 also required 100% observer coverage in large purse-seiners). Initially developed to monitor dolphin interactions in the EPO tuna purse seine fisheries, the scope of the program has expanded significantly since its inception in 1999 to include sea turtles, elasmobranchs, seabirds, teleosts, and other marine mammals. On board observers have collected geo-referenced species-specific (where possible) sea turtle interaction and length data since 1990 (Fuller et al. 2022). Prior to going to sea, observers are trained and provided with comprehensive hard copy and video (https://www.iattc.org/Downloads.htm) field guides on sea turtle identification. From 2001, information on sightings and interactions in purse-seine sets is recorded on the "Sea Turtle Record" form.

Inter-American Tropical Tuna Commission has produced annual fleet estimates of interactions and release condition of sea turtles in their Ecosystem Considerations report. These annual estimates show that the magnitude of interactions within the purse-seine fishery is small relative to the longline fishery. For example, in 2020 a total of 291 sea turtle interactions (zero mortalities) were recorded by observers in the purse seine fishery where there was 100% observer coverage, while 71 interactions (with 11% mortalities) were recorded in the longline fishery where observer coverage is 5% or less (IATTC 2021). In 2011 IATTC adopted resolution C-11-08—later superseded by the currently active C-19-08—that mandated CPCs to ensure 5% observer coverage of their tuna longline fleets from 2013 and to submit to IATTC the information collected by observers on the previous fishing activities of year, including catches of sea turtles. Unfortunately, several contracting parties (i.e., 4 CPC out of a total of 9 CPC reporting longline data) failed to meet the minimum 5%, prompting IATTC to request improvements on data collections by the longline fleets (Griffiths et al. 2021). In 2017, a set of minimum data fields to be recorded by observers on longline vessels was proposed (Wiley et al. 2017) that essentially harmonized with existing WCPFC observer data fields, and was adopted in resolution C-19-08.

Since continuous variables (e.g., growth rate) are categorized in PSA, they are useful to assess only relative vulnerability as the susceptibility and productivity scores have no biological meaning that can be assessed against biological reference points, such as those used in stock assessments to determine stock status (e.g., B_{msy}). Inter-American Tropical Tuna Commission staff addressed this shortcoming by developing the EASI-Fish methodology (Griffiths et al. 2019), which has similar elements to PSA that

make it suitable for data-limited settings but uses continuous variables to estimate fishing mortality, which is subsequently used in a simple length-based per-recruit model to provide a more definitive assessment of vulnerability by using proxies for traditional fisheries biological reference points. A proof-of-concept study of EASI-Fish (Griffiths et al. 2019) demonstrated that it could be simultaneously applied to the range of species groups impacted by tuna fisheries including teleosts, elasmobranchs, cetaceans, and sea turtles. Soon after, it was applied in a 2-year collaborative project between the Inter-American Convention on the Protection and Conservation of Sea Turtles (IAC), the IATTC, and international sea turtle experts to the critically endangered leatherback turtle population in the EPO. The project sought to assess the potential efficacy of a "menu" of permitted measures defined in the recently adopted resolution C-19-04 measure. In particular, the use of circle hooks and finfish baits in shallow longline sets and the cumulative impacts of multiple fisheries in the EPO under a range of other plausible scenarios, such as temporal and spatio-temporal closures were investigated. A total of 70 different hypothetical conservation and management measures scenarios were simulated for the EPO industrial (purse-seine and longline) and artisanal (longline and gillnet) fisheries for 2018. Conservation and management measures tested included decreasing post-capture mortality, implementing the use of circle hooks in longline fisheries, and various spatial and temporal closures adjacent to important nesting beaches of the EPO. The "status quo" scenario revealed that a proxy for fishing mortality ($\tilde{F}_{2019}$) and for the spawning stock biomass per recruit in 2019 (BSR_{2019}) exceeded precautionary biological reference points ($F_{80\%}$ and $BSR_{80\%}$), classifying the East Pacific leatherback turtle stock as "most vulnerable." Of the 70 scenarios, 42 were predicted to result in the species being classified as "least vulnerable." The majority of scenarios involving a single conservation and management measure resulted in a significant reduction in vulnerability to "least vulnerable." While the use of multiple measures in concert, such as the use of large circle hooks baited with fish bait combined with the use of best handling and release practices resulted in the most significant reductions in vulnerability. The project provided an important first step toward assessing the potential effects of conservation and management measures under IATTC resolution C-19-04 and serves as a blueprint for future work that could assess other species of sea turtles and be used in other t-RFMO.

International Commission for the Conservation of Atlantic Tunas (ICCAT)

Since 2010, ICCAT recommendation 10-10 (currently not active) established a minimum of 5% observer coverage of fishing effort in the pelagic longline, purse seine, and bait boat fisheries, measured in number of sets or trips for purse seine, in fishing days, number of sets, or trips for pelagic longlines, and in fishing days for bait boats. This coverage must guarantee a temporal and spatial representativeness of the operation of the fleets. Recommendation 10-10 requires data collection and the quantification of total target catch and bycatch, including sharks, sea turtles, marine mammals, and seabirds. This recommendation reinforced the previous recommendation and recalled the necessary steps to fulfill the data requirements on bycatch species.

Regarding sea turtles, ICCAT resolution 03-11 from 2003 (replaced by recommendation 10-09 in 2010 and more recently by recommendation 22-12 in 2022) supported efforts of FAO to address sea turtle conservation and management. It encouraged CPCs to collect and provide the SCRS (Standing Committee on Research and Statistics, Scientific Committee of ICCAT) with all available information on interactions with sea turtles in ICCAT fisheries, including incidental catches and other impacts, such as nesting site deterioration and ingestion of marine debris. Resolution 03-11 also promoted the release of incidentally caught live sea turtles and the sharing of information to reduce incidental catch and ensure safe handling to improve survivorship. It further advocated for developing data collection and reporting methods for sea turtle bycatch in tuna and tuna-like species fisheries.

In 2010, recommendation 10-09 replaced resolution 03-11, requiring each CPC to collect and annually report information on fleet interactions with sea turtles by gear type. This included catch rates considering gear characteristics, times, locations, target species, and disposition status (discarded dead or released alive). The data recorded and reported were to include a breakdown by sea turtle species and, where possible, details on the nature of hooking or entanglement, bait type, hook size and type, and the size of the animal. Contracting Parties were strongly encouraged to use onboard observers for data collection. This recommendation also specified operative practices for safely managing sea turtles on purse seiners and longlines and encouraged the SCRS to assess the impact of incidental sea turtle catch from ICCAT fisheries and provide mitigation advice to the Commission.

In 2013, ICCAT recommendation 13-11 amended recommendation 10-09 to incorporate specific SCRS recommendations related to safe-handling and release practices, including using line cutters and de-hooking devices. This recommendation also urged the SCRS to continue and improve the Ecological Risk Assessment (ERA) for sea turtles initiated in 2013. Lastly, ICCAT recommendation 22-01 mandated the use of non-entangling FAD to avoid entanglement and mortality of sea turtles and other sensitive species.

Finally, during the last annual Commission meeting that took place in November 2022, a new sea-turtle specific recommendation was adopted (recommendation 22-12) which expanded many provisions of the previous recommendations on several important aspects. One main provision was the adoption of mitigation measures to reduce bycatch and increase post-release survival of sea turtles, by requiring shallow-set longline vessels to use only large circle hooks, use only finfish bait, or adopt any other measure or approach reviewed and considered effective by the Scientific Committee. Contracting Parties were also required by using at least one of the following bycatch mitigation measures: (i) alternative or new gear types and gear modifications; (ii) time-area fishing restrictions and closures based on advice from the Scientific Committee in instances where there is a higher risk of interaction with sea turtles; (iii) effective static net gears' marking allowing their detection by sea turtles (such as the use of net colors, light passive reflectors, thicker twine diameter, corks or other materials within the net); or (iv) modifications in fishing behavior and strategy (e.g., reduced soaking time). This new recommendation also requires that purse seine vessels avoid encircling sea turtles to the extent practicable, release encircled or entangled sea turtles, including on FAD, and ensure that FAD are constructed according to guidelines provided for reducing the ecological impact of FAD in ICCAT fisheries. Fishery operators are also required to take all reasonable steps to ensure the safe release of sea turtles in a manner that maximizes the likelihood of their survival. For this reason, compliance with FAO (2009) guidelines on best practices for the handling and release of sea turtles is encouraged.

In terms of data collection, recommendation 22-12 endeavors CPC to increase scientific observer coverage of longline fishing vessels to a minimum level of 10% by January 2024, which may be achieved through human observers and/or Electronic Monitoring Systems. In terms of research, CPC are encouraged to continue research trials aimed at mitigating bycatch and reducing bycatch mortality and increasing post release survival of sea turtles, and the Scientific Committee is required to develop indicators to assess the effectiveness of the mitigation measures detailed in the recommendation.

Several sea turtle estimation studies on bycatch and mortality rates have been performed in the framework of ICCAT. In 2013 the SCRS reviewed sea turtle interactions mainly with pelagic longlines, purse seines, driftnets, and tuna traps, compiling catch rates estimates of the interaction of the various species with the different fisheries (Coelho et al. 2013a). The SCRS also reviewed possible methods to analyze the impacts of fisheries on sea turtle populations (Coelho et al. 2013b), and also reviewed sea turtle mitigation measures across the five t-RFMO and other fisheries management organizations (Coelho et al. 2013c).

An estimate of the general catch rate of sea turtles in longline fisheries directed at tunas and tuna-like species was conducted (Gray and Díaz 2017). This bycatch assessment ranked sea turtle species in relation to the impact of ICCAT longline fisheries on their populations, resulting in the greatest longline impact on loggerheads, followed by leatherbacks. The number of interactions with the purse-seine fishery is small relative to the longline fishery, in a relation 1/275 (Lewison et al. 2004; Bourjea et al. 2014).

In 2013 a PSA-type ERA assessed the risk to turtles from the impacts of tuna fishing in the ICCAT region (Angel et al. 2014). This risk assessment was hampered by significant data gaps and highly variable bycatch rate estimates. Bycatch rates were scaled to mean annual fishing effort, per Regional Management Unit (RMU) (Wallace, DiMatteo, et al. 2010; Wallace et al. 2023). According to this risk assessment, ICCAT longline fishing poses a greater threat to turtles compared to purse seining. The east Atlantic olive ridley, the South Caribbean green turtle, and South-West Atlantic leatherback turtle RMU were consistently among the most vulnerable from both gear types. Conversely, the West Atlantic olive ridley turtles showed the lowest risk. Regions where turtles are at the highest risk include South Caribbean and tropics (20°N-15°S, both gear types), and loggerhead turtles in the Mediterranean (longline only). Despite recommendation 13-11 encouraging the SCRS to continue improving this ERA, no further risk assessments have been conducted.

Indian Ocean Tuna Commission (IOTC)

Indian Ocean Tuna Commission resolution 22/04 established a minimum of 5% observer coverage of the number of operations/sets for each gear type of

IOTC fisheries for vessels 24 meters overall length (LoA) and over, and under 24 meters if they fish outside their Exclusive Economic Zone (EEZ). Indian Ocean Tuna Commission also encourages a representative temporal and spatial coverage of the operation of the fleets, considering the characteristics of the fleets and fisheries. Data collection requirements includes quantifying total target catch and bycatch, including shark, sea turtles, marine mammals, and seabirds (resolution 22/04).

Moreover, IOTC resolution 12/04 requests members collect (through logbooks and observer programs) and provide to the IOTC Secretariat, data on all interactions of fishing vessels with sea turtles. The same resolution also requests that data on the level of logbook, observer coverage, and an estimation of total mortality of sea turtles incidentally caught in their fisheries should be provided. Indian Ocean Tuna Commission resolution 12/04 also requests IOTC resolution 12/04 also requests that CPC report to the IOTC Scientific Committee information on successful mitigation measures used by vessels and about other impacts on sea turtles in the IOTC area, including impacts different from fisheries, such as the deterioration of nesting sites and swallowing of marine debris. In the annual reports submitted by CPC to the IOTC Scientific Committee, there is a specific section on ecosystem and bycatch issues that includes a section for reporting those issues, as well as the annual interactions with sea turtles, including mortalities and live releases. Resolution 12/04 also requests that CPC implement the FAO (2009) Guidelines to reduce the bycatch, injury, and mortality of sea turtles, and to use best practices for mitigation, identification, handling, and de-hooking techniques and keep on board all necessary equipment for the release of marine turtles in accordance with handling guidelines in the IOTC Marine Turtle Identification Cards. Moreover, it encourages the use of specific gear configurations (e.g., whole finfish bait) and best handling and release practices in all tuna fisheries to reduce interactions with sea turtles and to increase their post-release survival.

Indian Ocean Tuna Commission resolution 12/04 also urged the Scientific Committee to develop regional standards regarding data collection, data exchange, and training and to develop improved Fish Aggregating Device (FAD) designs to reduce the incidence of entanglement of sea turtles, including the use of biodegradable materials. Contracting Parties are also encouraged to undertake research trials of circle hooks and finfish for bait. According to the IOTC sea turtle handling guidelines, any captured sea turtles that are comatose or inactive are encouraged to be brought on board, if practical, as soon as possible. In addition, IOTC resolution 23/02 requests the use of non-entangling FAD.

A "good practices" guides for the safe handling of sea turtles specific to gillnet fisheries have been presented and discussed by the IOTC Working Party on Ecosystems and Bycatch (Razzaque et al. 2020). This is of particular importance given the considerable use of this type of gear in some of the more coastal areas of the Indian Ocean. More recently, IOTC resolution 21/01 on the yellowfin tuna plan encourages CPC to phase out or convert gillnet fishing vessels to other gears, considering the huge ecological impact of these gears. In any case, resolution 21/01 requires CPC to set their gillnets at least 2 m deep from the surface from 2023 onwards, which has been demonstrated to reduce the bycatch of sea-turtles and other sensitive species (Moazzam and Nawaz 2017).

Several PSA-type ERA have been conducted within the IOTC convention area, one in 2013 and 2018 covering purse seine, longline, and gillnet fisheries and one in 2012 focusing on artisanal fisheries. These ERA assessed the risk to turtles from the impacts of several IOTC fisheries in the region (Kiszka 2012; Nel et al. 2013; Williams et al. 2018). The assessments were hampered by significant data gaps, particularly limited data on sea turtle bycatch (numbers and rates) as well as fishing effort information for longlines and purse seine and an absence of fishing effort or turtle bycatch data in gillnets. The ERA was carried out for the 20 populations or RMU identified for the six species of sea turtles (i.e., flatback, green sea turtle, hawksbill, leatherback, loggerhead, and olive ridley) across the Indian Ocean. In general, the studies concluded that sea turtles were more vulnerable to gillnet and longline fisheries than purse seine fishing, because of the larger spatial fishing areas and depth distribution of longline fishing and the assumed higher post-capture mortality of sea turtles in gillnet fisheries, due to longer duration of forced submergence (Nel et al. 2013; Williams et al. 2018). Nel et al. (2013) found that loggerheads in small RMU (i.e., Bay of Bengal and South Western Indian Ocean) were vulnerable to longline and purse seine and particularly to gillnets. They also found that green turtles, despite being the least vulnerable due to their large population, were vulnerable to gillnetting in the Arabian Gulf. They also found that the three leatherback turtle RMU (southwest Indian Ocean, Northeast Indian, and West Pacific) and hawksbill turtle populations (i.e., the East Central Indian Ocean) were vulnerable to all fishing pressures (particularly gillnetting) due to their

small size. In general, for those fisheries, the sea turtles most at risk of fishing were identified to be green turtles, loggerhead turtles, and hawksbill turtles, particularly in the Arabian Sea and Bay of Bengal (Nel et al. 2013; Williams et al. 2018). Kiszka (2012) identified 5 species of sea turtles (i.e., loggerhead, green, hawksbill, olive ridley, and leatherback turtles) that were particularly vulnerable to artisanal fisheries bycatch in the southwest Indian Ocean.

Western and Central Pacific Fisheries Commission (WCPFC)

Conservation and Management Measure (CMM) 2007-01 established the Commission Regional Observer Program (ROP) and required (since 30 June 2012) a minimum of 5% coverage (with some exceptions) in the fisheries under the jurisdiction of the Commission. Conservation and Management Measure 2008-01 (a measure for bigeye and yellowfin tuna) established a requirement for 100% observer coverage for purse seiners fishing in the area 20°N to 20°S during seasonal FAD closures. This 100% coverage requirement became a year-round mandate since the adoption of CMM 2012-01.

Non-binding resolution 2005-04, to mitigate the impact of fishing for highly migratory fish species on sea turtles, recommended the implementation (without specific timelines) by members of the FAO Guidelines to Reduce Sea Turtle Mortality in Fishing Operations and included several recommendations like: enhancing the implementation of mitigation measures in place, collecting and providing information on interactions, avoiding intentional encirclement in purse seine fisheries or carrying out research on circle hooks. This resolution was replaced by CMM 2008-03 (in turn superseded by CMM 2018-04), which included specific binding measures, like: report the progress of implementation of the FAO Guidelines and on the measure itself, provide all data collected by the WCPFC Regional Observer Program, bring onboard comatose or inactive any captured hard-shell turtle as soon as possible and foster its recovery, avoid, to the extent practicable, encirclement of sea turtles by purse seine vessels, and carry and use dip nets, as well as line cutters and de-hookers in the case longline vessels. This CCM also required that, starting in January 2010, longline fisheries targeting swordfish in shallow-sets shall implement at least one of the following measures: use of large circle hooks, only finfish as bait, or any other measure or plan subject to the approval of the Commission to reduce the interaction with sea turtles. As of 2018, the current sea turtle Conservation Measure (2018-04) applies to all longline fishing vessels fishing in a shallow-set manner, no longer specifying that the target species is limited to swordfish. There remains no specification for "large" circle hooks, yet a reference is made to an FAO document referencing "16/0" as "large" (https://www.fao.org/3/bq849e/bq849e.pdf). On the one hand, the CMM states that shallow-set pelagic longline fisheries, "are generally considered those in which the majority of hooks fish at depth shallower than 100 meters," but members are directed to adopt their own definition. On the other hand, the measures' hook and bait requirements need not to be applied to those shallow-set longline fisheries that have a minimal interaction rate over a three year period and with a level of observer coverage of at least 10% during each of these years. The "minimal" catch rate threshold was defined by the Scientific Committee of Commission as 0.019 turtles per 1000 hooks (WCPFC 2009, 2018). This threshold bycatch rate was based on the turtle catch rate of swordfish of Hawaii longline fishery after regulations on hook and bait type came into effect (WCPFC 2009). Western and Central Pacific Fisheries Commission has not assessed the performance of the measure.

No mitigation measures, however, are required by the WCPFC specifically for deep-set longline fisheries to reduce catch rates of sea turtles, although CCM with longline fisheries other than shallow-set swordfish fisheries are urged to undertake research trials of circle hooks and other mitigation methods and report the results of these trials to the Scientific and Technical and Compliance Committees. Interaction rates in deep-set longline fisheries tend to be lower relative to shallow-set fisheries; however, the sea turtle mortality magnitudes may be much higher in deep-set fisheries as regional deep-set effort is much higher than that of shallow-set longline fisheries. In addition to the above, the most recent management measure on tropical tunas (CMM 2021-01) prohibits, as of 1st January 2024, the use of mesh net for any part of an FAD, and only non-entangling materials can be used for the subsurface structure and when the raft is covered. Until then, non-entangling FAD designs are mandatory, because they reduce the risk of mortality due to the inability of entangled sea turtles to surface to breathe. In addition, the WCPFC has adopted guidelines for the handling of sea turtles.

The high observer coverage in the purse seine fishery has allowed for an accurate estimation of sea turtle bycatch. Peatman and Nicol (2021) provided estimates of bycatch for the large-scale purse seine fishery operating primarily in tropical waters of the WCPFC Convention Area east of 140°E. These large

vessels, typically >500 tons carrying capacity, have been responsible for ~85% of the purse seine catch of tropical tunas in recent years. Raised estimates for the period 2003–2019 indicate an average annual bycatch of 295 marine turtles (range: 201–483). Proportional bycatch species composition included green (24.7%), olive ridley (23.8%), loggerhead (20.9%), hawksbill (15.9%), leatherback (3.0%) and unidentified marine turtles (11.6%). These authors also provided estimates of bycatch rate by type of association for the period 2016–2020. Sets on free-schools accounted for c. 65% of the catches, followed by sets on drifting FAD (23%), logs (7%), and anchored FADs (4%). This bycatch rate is minor as compared to the estimates for the longline fishery. In spite of the difficulties to obtain reliable estimates of longline catches from observer data, given the relatively low level of coverage and the lack of balance both between fleets and spatially, Peatman and Nicol (2021) estimated a median annual bycatch for the period 2003–2018 of c. 21500 turtles in the WCPFC Convention Area (excluding domestic longline fisheries in the west-tropical WCPFC). Proportional bycatch species composition included olive ridley (53%), green (12%), loggerhead (15%), leatherback (5%), hawksbill (4%) and unidentified marine turtles (10%). The relative contribution of olive ridley turtles was significantly above previous estimates and the authors concluded the relative contribution of this species could be overestimated.

In addition to the difference in bycatch interaction rates, it is generally considered that overall mortality from purse seine fisheries is minimal compared to longline fisheries (Angel et al. 2014). An analysis of observer datasets from longline fisheries in the Pacific Ocean indicated that around 30% of the sea turtles caught were dead at capture, while 48% were recorded as alive and 21% with unknown status (Common Oceans 2017). On the contrary, most of the sea turtles (>90%) caught by purse seiners are released alive (Bourjea et al. 2014; Restrepo 2014).

While some information exists with respect to the bycatch of sea turtles in the Pacific from industrial fisheries, such as the tuna purse seines and to a lesser extent longline sectors, less is known about levels of use of sea turtles by coastal communities and impacts of small-scale fisheries across the Pacific (Pilcher 2021). In this context, the Bycatch And Integrated Ecosystem Management Initiative, funded by the Pacific-European Union Marine Partnership Programme, has reviewed information on sea turtle reproductive biology, movements, connectivity, and potential threats (Pilcher 2021).

Commission for the Conservation of Southern Bluefin Tuna (CCSBT)

Commission for the Conservation of Southern Bluefin Tuna does not identify a specific geographical area to be covered by its provisions, however, given the convention mandate, it is assumed that Convention Area of CCSBT is the distribution of southern bluefin tuna. Commission for the Conservation of Southern Bluefin Tuna represent an unusual t-RFMO case because it has no convention area and vessels fishing for southern bluefin tuna must comply with the bycatch management measures of the other RFMO in whose waters they fish. This was made explicit by the adoption in 2018 of a "Resolution to Align CCSBT's Ecologically Related Species measures with those of other RFMO" (https://www.ccsbt.org/sites/default/files/userfiles/file/docs_english/operational_resolutions/Resolution_ERS_Alignment.pdf). In accordance with the Resolution to Align CCSBT's Ecologically Related Species measures with those of other tuna RFMO, sea turtle-specific measures of IOTC, WCPFC, or ICCAT are binding on Members of the CCSBT when fishing within the relevant area of competence.

Sea turtle mitigation from non-tuna RFMO: the case of the General Fisheries Commission for the Mediterranean (GFCM)

Loggerhead and green turtles are the only two sea turtle species to reproduce in the Mediterranean Sea. The region is also visited by loggerheads from the North Atlantic and North-east Atlantic areas (Lescure et al. 2015; Casale et al. 2018) and by green turtles from the East Atlantic areas. Leatherback turtles also regularly visit the area for foraging but do not reproduce in the region. There are also occasional observations of hawksbill, olive, and Kemp's ridley turtles (Casale et al. 2020).

The Mediterranean Sea represents a particularly important area because it has some of the highest sea turtles bycatch rates in the world (Lewison et al. 2004), with recent studies estimating 132,000 interactions resulting in about 44,000 deaths per year for all gears combined (Casale et al. 2020). Intentional mortality of sea turtles is also reported by many countries in the region, highlighting the potentially significant impact of small-scale fisheries. Boat strikes, marine debris pollution, and chemical pollutants constitute additional threats (Casale et al. 2020).

Fisheries in the Mediterranean are collectively managed by an RFMO named the General Fisheries Commission for the Mediterranean (GFCM), which

entered into force in 1952. General Fisheries Commission for the Mediterranean established a Scientific Advisory Committee (SAC) and the Sub Committee on Marine Environment and Ecosystems in 1997, which are responsible for providing scientific advice on bycatch and marine protected species issues including sea turtles. The first meeting of the SAC in 1998 already noted the work of the ad hoc joint Working Group GFCM/ICCAT on Large Pelagic Fishes. This working group facilitated the implementation of recommendations implemented by ICCAT in the Mediterranean region. Sea turtle-fishery related issues were initially addressed during the first meeting of the Sub-Committee on Marine Environment and Ecosystems (GFCM 2001). A recommendation on incidental bycatch of sea turtles in fisheries in the GFCM region (GFCM/35/2011/4) was endorsed in 2011 encouraging good handling and release practices for sea turtles, encouraging fishers to record their catches in logbooks and prohibiting encirclement of sea turtles by purse seiners. The recommendation was focused on the implementation of fisheries management measures to mitigate the bycatch of sea turtles, such as the appropriate handling and release of sea turtles accidentally taken in fishing gears, avoid onboard any captured marine turtle, tranship and land sea turtles unless otherwise required to rescue and to secure that animals is assisted at a rescue center, and the recording of sea turtle events in the logbooks. Moreover, vessels using longlines and bottom-set nets are required to carry onboard safe handling, disentanglement, and release equipment, to release sea turtles unharmed and in a manner that maximizes the probability of survival.

Annual data on the number of individuals caught per fleet segment and/or per fishing gear, are required to be reported by the member countries aggregated by GSA (the Geographical Sub Areas Adopted by the Commission) and by species group and/or family if detailed information by species is not available (Data Collection Reference Framework, FAO 2018b).

General Fisheries Commission for the Mediterranean acknowledges that the information remains biased, as its coverage is not distributed evenly over the Mediterranean, the incidental catch is neither systematically logged nor reported, and programmes do not cover the entirety of a fleet, often showing patchiness in location and time (FAO 2022). General Fisheries Commission for the Mediterranean estimated that longlines and bottom trawlers are the vessel groups with the highest incidental bycatch of sea turtles, accounting for 38.6 and 36.7% of the total sea turtle bycatch, in the area respectively. The incidental catch in Small Scale Fisheries represents 17.7% and other fisheries 7%. The most reported interaction involved the loggerhead turtle (around 99%). General Fisheries Commission for the Mediterranean pointed out that according to the analysis carried out by the organization using available data, the incidental bycatch of sea turtles along the whole region during the period 2000–2022 accounted for around 470,000 individuals (FAO 2022).

There are some guidelines to reduce sea turtle mortality and to implement good practices on board fishing vessels in the Mediterranean mainly developed by experts, including onboard observers from some countries (e.g., Poisson et al. 2016), which were built upon using the FAO Guidelines to reduce sea turtles mortality in Fishing Operations (FAO 2009).

Other guidelines prepared by Mediterranean national teams in national languages facilitate the interpretation of the measures by local fishers and the implementation of conservation measures for sea turtles (e.g., guidelines prepared by the Groupe Tortues Marines France in collaboration with the National Museum of Natural History from Paris, available at http://gtmf.mnhn.fr/informations-aux-pecheurs/).

General Fisheries Commission for the Mediterranean has developed two guidelines for data collection activities (FAO 2018a, 2018b) to provide a harmonized methodological framework. Several regional programs have also developed good practice guides (e.g., FAO and ACCOBAMS 2018).

The State of Mediterranean and Black Sea Fisheries reports (FAO 2020, 2022) include an overview of regional sea turtle bycatch from 2000 (Carpentieri et al. 2021). Most reported information comes from the western and central Mediterranean subregions, representing an unbalance in the reported data compared to the eastern subregion. Moreover, most nesting sites, and therefore concentrations of breeders, are found in the eastern and central Mediterranean. Both facts underline the importance of monitoring these regions, in relation to the bycatch of sea turtles in the eastern and central Mediterranean fisheries. General Fisheries Commission for the Mediterranean is concerned by the underestimation of sea turtle bycatch (FAO 2022), as GFCM sea turtle bycatch estimates show the highest rates of sea turtles captures in fisheries operating in coastal waters or near-shore zones (potential feeding areas for sea turtles) which are not accounted for in FAO estimates.

Discussion

Limitations and weaknesses of the t-RFMO for sea turtle conservation

Sea turtles frequently undertake trans-oceanic movements between important coastal nesting areas and feeding areas. Thus nesting coastal areas and territorial are not part of t-RFMO convention areas. In addition, within t-RFMO convention areas, other non-tuna fisheries frequently exist, such as trawl fisheries for shrimp and bony fishes, purse seine fisheries for clupeoids (e.g., herring, anchovies), artisanal and small-scale coastal longlines and gillnet fisheries targeting non-tuna species. Although these non-tuna fisheries have been documented to have a significant impact on sea turtles (Domingo et al. 2006; Babcock et al. 2018; Blades et al. 2019), they are not accounted for in the bycatch and risk assessments and management measures of t-RFMO as they do not target tuna or tuna-like species.

The Regional Management Units (RMU) framework is a solution to the challenge of how to organize marine turtles into units of protection above the level of nesting populations (Wallace, DiMatteo, et al. 2010). The convention areas of t-RFMO cover a great part of the distribution of all marine turtles and their respective RMU. By virtue of this extensive overlap, t-RFMO have enormous potential for reducing fisheries bycatch impacts that may improve the long-term sustainability of marine turtle populations globally.

Except for the case of the RMU in southern Africa that spans the Convention areas of ICCAT, IOTC, and CCSBT for loggerhead, leatherback, and green sea turtles and the specific case of the *Natator depressus*, which is distributed across two t-RFMO (IOTC and WCPFC), the remaining RMU can be managed by a single t-RFMO (e.g., Angel et al. 2014; Williams et al. 2018). In contraposition to the share RMU, the management of the not-share RMU under a unique t-RFMO can facilitate the implementation of specific conservation and management measures, as it depends only on the coordination of a single scientific committee (under the mandate of a specific t-RFMO), rather than requiring coordination among different commissions. This can facility the implementation of mitigation measures. In addition, evaluating the effectiveness of these measures in reducing sea turtle interactions and mortalities by fisheries is more easier, as data collection and analysis would rely on the same scientific committee.

Tunas RFMO are limited by their geographic scopes and mandates, given that their objectives and boundaries are determined by the species distribution and fisheries under their remit. Moreover, the areas of competence of the t-RFMO do not cover all key habitats for sea turtles, such as archipelagic waters, territorial seas, or inland habitats, such as coastal nesting areas. Therefore, the actions of t-RFMO are limited in geographic and population ranges, particularly for nesting females, hatchlings, and adults with in the neritic phase. Other potential limitations of t-RFMO in the management of sea turtles are the mixture of artisanal coastal *vs.* industrial long-distant nations fleets, sometimes with different areas of impact on sea turtles. Thus, the spatio-temporal distribution patterns of these fleets also vary significantly, with industrial fleets often covering vast oceanic areas and operating year-round, while artisanal fleets may be more seasonally and locally confined. This variation in effort levels, vessel sizes, and fishing characteristics results in differential impacts on sea turtles, necessitating tailored approaches that consider the specific dynamics of each fleet type. In this context, data reporting, monitory and control, and enforcement of binding resolutions are some examples of important obstacles.

Finally, another weakness of t-RFMO for effective sea turtle is the way t-RFMO make decisions (described in Figure 2); there is usually a long time-gap between data reporting and decision-making processes (Sinan and Bailey 2020), but critically endangered populations may need more urgent action. On the other hand, the fishing industry is highly dynamic and flexible and can change its behavior to adapt to new measures quickly, which can sometimes trigger unwanted and unexpected results (Báez et al. 2019). For example, changes in the fishing strategy of the Spanish longline fleet targeting swordfish operations in the Mediterranean, in response to new regulations on maximum allowable swordfish catches, have led the fleet to direct its efforts toward deep water column fishing. This adjustment has significantly reduced the Spanish incidental capture of loggerhead turtles in the western Mediterranean, and affecting fragile deep fishes populations (Báez et al. 2019). Therefore, t-RFMO should explore mechanisms to conserve threatened species in a more agile manner.

The role of t-RFMO in international cooperation for sea turtle conservation

Tuna RFMO could play a key role in sea turtle conservation at both regional and global levels by bringing together the efforts of different stakeholders for

the conservation of sea turtles. Many stakeholders including conservationists, fisheries biologists, NGO, and administrations are involved in sea turtle conservation including bycatch mitigation and reduction measures. Yet despite working on the same issues, they often address them separately without any coordination (Salomon et al. 2011). Regional efforts for the management and conservation of vulnerable species and the involvement of all stakeholders are needed for exploring technological innovations within the social and economic conditions of the fishery sector. Tuna RFMO can play a role in forging those alliances. At the same time, for sustainable management and conservation of sea turtles, ecosystem approaches excluding large and ecologically significant portions of the ocean will not be successful. It is also important to consider that taxa-specific efforts undertaken to mitigate bycatch, such as for sea turtles, could also unexpectedly increase the bycatch of other species (e.g., see Andraka et al. 2013; Báez et al. 2019). Therefore, cross-taxa management solutions which result in intentional and acceptable tradeoffs across species should be promoted (Gilman et al. 2019). This is also an important topic that could be addressed at the t-RFMO level with specialized technical groups. As an example, ICCAT has established a scientific working group aimed at evaluating technical gear changes which, among others, is investigating the efficacy of large circle hooks in longline as a measure to reduce bycatch across multiple taxa groups and evaluate potential tradeoffs across taxa (ICCAT 2022). Workshops aimed at reducing the bycatch of a particular gear focused on multiple taxa (IOTC 2022), some with a particular focus on sea turtles (IATTC 2022) are also being promoted.

A clear example of regional overlap between RFMO is demonstrated by ICCAT and GFCM in the Mediterranean Sea. Although each RFMO has different scopes in terms of species and fisheries, both manage fisheries with sea turtle bycatch in the Mediterranean Sea. Thus, ICCAT imposes stricter requirements for monitoring and mitigating sea turtle bycatch compared to the GFCM. Consequently, reinforce cooperation and harmonization of management measures between these two RFMO should be further considered to ensure that the impacts on sea turtles in the Mediterranean are effectively mitigated across all fisheries. Recent efforts of GFCM to improve data collection and involvement of this Commission in a regional project on bycatch (FAO 2018b) with other regional organizations are paving the way to a post-project regional strategy to establish a permanent regional monitoring system on sea turtle bycatch. The new regional strategy (FAO 2021) will provide advice on the development and implementation of management measures to reduce interactions between fisheries and sea turtles.

International collaborative research allows for the sharing of information, expertise, and experiences from different areas and countries, and has the potential to introduce into different fisheries and cultures the fundamental concepts of conservation and management which are necessary to slow down the population decline of species and the disturbance of ecosystems that contain them (Domingo et al. 2016). These collaborative processes, which foster greater understanding, respect, trust, and knowledge by informing management measures adopted by consensus within t-RFMO, have the potential to accumulate actions toward achieving the sustainability of these species. It is necessary to understand that additional actions must also be taken in other non-tuna fisheries that interact with sea turtles, as well as in nesting beaches, which are increasingly subject to human pressure as a result of the tourism industry and egg collection. In this sense, an important recommendation is to strengthen greater coordination among scientists from other RFMO, sea turtle conventions, and sea turtle experts working on sea turtle bycatch in non-tuna fisheries and sea turtle impacts in coastal areas.

Moreover, there is a need for greater collaboration and coordination across t-RFMO for the effective conservation of sea turtle populations to achieve a significant reduction in the impact of tuna fisheries on sea turtles at a wider global scale. Together t-RFMO could reach minimum conservation standards, jointly monitor and use population indicators in all phases of the life cycle of the species, and agree on a common framework to reduce the anthropogenic-induced mortality of turtles. There have been several recent initiatives among t-RFMO related to sea turtles, including risk assessments (Nel et al. 2013; Williams et al. 2018) and reviews of bycatch mitigation measures for pelagic fisheries management (FAO 2007; Coelho et al. 2013c). Another exemplary initiative of collaboration between scientists involved in advisory processes in ICCAT has been the regional evaluation of the incidental catch of sea turtles in the pelagic longline and purse-seine fleets in the Atlantic and Indian Oceans and Mediterranean Sea (Anonymous 2020). Similarly, there have been several initiatives within the framework of other t-RFMO, ranging from actions of individual research groups to coordinated basin-scale or global initiatives (Camiñas et al. 2021). These efforts are compiled in the Bycatch Mitigation Information System (https://www.bmis-bycatch.org/),

a reference and educational tool aiming to inform the adoption and implementation of science-based management measures to comprehensively manage bycatch in tuna fisheries worldwide. This initiative was initially launched by the WCPFC and has later been expanded and supported by the FAO Common Oceans Tuna Project (Fitzsimmons et al. 2019).

Knowledge gaps and future research

The lack of high-quality data with adequate spatio-temporal coverage across the different fleet segments is one of the key gaps in knowledge for sea turtles species. The availability of this information is fundamental to advance the knowledge and the management of these species. Until sufficiently high-quality data are collected, estimates of turtle bycatch across gears and t-RFMO will remain uncertain. The reasons behind this key gap are diverse. Tuna RFMO work has traditionally focused on the assessment and management of target species; the development of activities that consider broader ecosystem impacts of fishing is relatively recent. Another explanation is the different levels of development and capabilities of CPC, such as different observer programs, as well as means for research (Sinan and Bailey 2020). The differences in various observer programs encompass varying levels of coverage, as well as disparities in the training and professionalism of scientific observers, and the implementation of electronic monitoring systems, among other factors. Moreover, these data are extremely expensive to obtain, for this need funding and support from developed countries. The lack of stable national observer programs on board the different fleets that capture turtles in the Mediterranean region is a major problem in understanding the real extent of this interaction in two fragile loggerhead and green populations.

For this reason, on many occasions, the different Ecosystem and Bycatch Working Groups prioritized adopting minimum data fields and standardized collection protocols to enable interoperability of the tuna RFMO' observer-collected bycatch datasets (Gilman 2015). Furthermore, much of the information is collected by the fishermen themselves, who may have ulterior motives in regard to reporting captures of protected species. The integration of Artificial Intelligence (AI) and long-distance Electronic Monitoring Systems (EMS) (Mion et al. 2015), together with the presence of physical scientific observers holds great significance in enhancing the quality of scientific data in tuna fisheries. This synergistic approach may facilitate a comprehensive and accurate assessment of fishing activities, contributing to more robust data and subsequently lead to efficient fisheries management decisions. Members of developed CPC can play a pivotal role by assisting developing CPC to further advance and facilitate the adoption of AI-driven EMS, at a minimum by providing technical support.

Regarding other knowledge gaps that must be resolved for better management of sea turtle populations within t-RFMO, the following additional key research priorities are recommend: (i) identify the genetic populations of sea turtle RMUs affected by both tuna and non-tuna fisheries to provide a global risk assessment of sea turtle bycaught, or most vulnerable to bycatch around the world, (ii) map the migratory routes of the different species of sea turtles highlighting the main foraging and reproductive areas, (iii) improve the design of fishing gear to reduce sea turtle bycatch and/or increase survivorship after capture, (iv) conduct assessments for the species to better understand the status of the populations, and lastly, to (v) develop harmonized best handling and releasing practices for sea turtles for each fishery and species.

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