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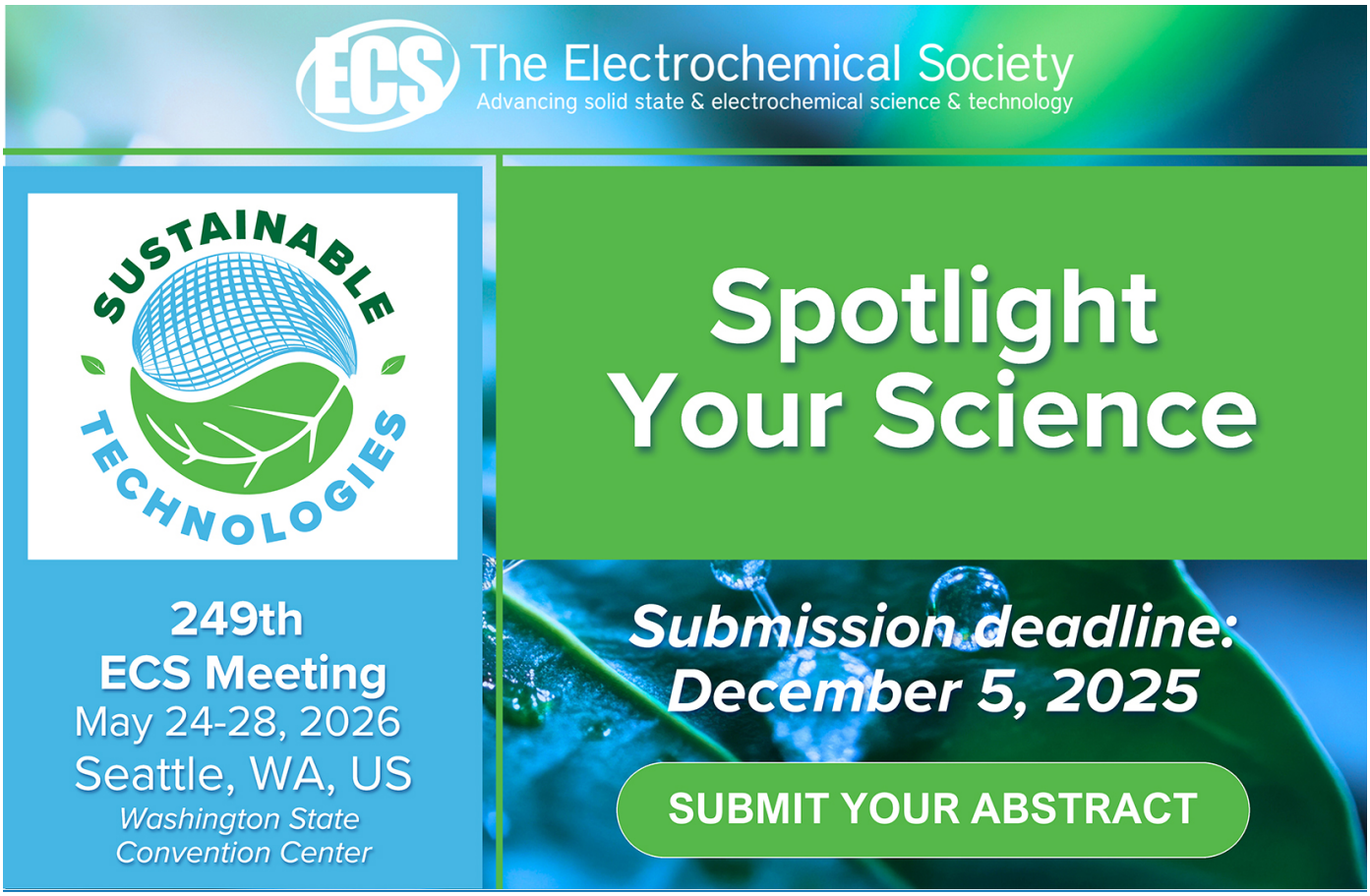

ENVIRONMENTAL RESEARCH
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TOPICAL REVIEW

An expanded evaluation of global fisheries management organizations on the high seas

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Abstract

The high seas comprise nearly half the Earth's surface and the 2023 United Nations Biodiversity Beyond National Jurisdiction agreement renewed efforts to better manage this vast area. Regional fisheries management organizations (RFMOs) are tasked with a UN dual-mandate to ensure the (1) long-term conservation of fish stocks and their associated ecosystems while managing the (2) sustainable use of high seas fisheries. Building on a previous analysis, we developed 10 questions each for our 10 categories (e.g. catch targets, transparency, bycatch). These 100 questions were both descriptive (e.g. are there quantitative results of bycatch improvement?) while others indicated intent (e.g. are there plans to rebuild all declining stocks?) and used publicly available information to evaluate 16 RFMOs (with a score of 0, 0.5, or 1). The average score for all RFMOs out of 100 was 46 (max 61.5, min 29.5). There were six questions for which all RFMOs received a 0, 90 questions for which at least one RFMO scored a one, and a 'best case' score of 76.5 that aggregated the highest RFMO score across the 10 categories. This indicates a competence gap; no RFMO is achieving what is empirically documented as possible in one RFMO or another. We also analyzed satellite-derived fishing activity and target stock status. Five RFMO convention areas had the highest overall and density of fishing effort. On average, 56% of stocks targeted in RFMO convention areas were considered overexploited or collapsed. We did not find that RFMO scores were correlated with better management outcomes (i.e. target stock status and fishing effort). However, we found correlations between better target stock status and questions assessing protected area adoption, banning transshipment at-sea, and reducing allowable catches in response to overfishing—policies that few RFMOs have fully adopted. These findings indicate ways for RFMOs to improve high seas fisheries management that are immediately available and effective.

1. Introduction

Industrial fisheries are the main driver of biodiversity loss in the open ocean due to cascading impacts from overfishing, destructive fishing gears, and bycatch, or the unintended catch of non-target species (Ortuño Crespo and Dunn 2017, Yan *et al* 2021). Regional fisheries management organizations (RFMOs) are the primary bodies that manage fisheries and their impacts in much of the high seas, the ∼60% of the ocean beyond a nation's 200 nautical mile exclusive economic zone (EEZ) (Brooks *et al* 2014, Blasiak

and Claudet 2024). A new UN Biodiversity Beyond National Jurisdiction treaty (BBNJ) aims to protect high seas marine life, and puts the current high seas RFMO regime in flux as a result (Haas *et al* 2021, Langlet and Vadrot 2023). However, RFMOs remain responsible, sharing a unified dual-mandate to: (1) manage the sustainable use and (2) ensure the long-term conservation of highly migratory and straddling fish stocks (the latter being both within and beyond one nation's jurisdiction) throughout their convention areas (UNFSA 1995). Further, the 1995 United Nations Fish Stocks Agreement (UNFSA) required all RFMOs to 'assess the impacts of fishing…on target stocks and species belonging to the same ecosystem' and to 'protect biodiversity in the marine environment' (UNFSA 1995).

Thirty years later, RFMOs are voluntary, treaty-based organizations each structured with distinct secretariats, staff, and nations. Specific nations are party to an RFMO as *contracting* or *cooperating* bodies with the priority to negotiate and vote on decisions regarding fish as 'resources' for the high seas fishing fleet (Brooks *et al* 2014, Telesca 2015). RFMOs also form committees; for example, scientific bodies that can identify the 'best available science' for potential conservation and management measures (CMMs).

Yet, RFMOs have faced consistent criticism for failing to meet both ends of their dual-UN mandate given the decline of high seas fish and related biodiversity that has occurred under their tenure (Cullis-Suzuki and Pauly 2010, 2016). Previous studies found that three-quarters of RFMO-managed fish stocks were considered depleted or overfished (Cullis-Suzuki and Pauly 2010, 2016). The reduced relative abundance and spatial range of target and non-target species in RFMO-managed fisheries have possibly impacted the open ocean's overall resilience to future anthropogenic impacts, including climate change (Ortuño Crespo and Dunn 2017). RFMOs have also been criticized for management gaps surrounding the bycatch of non-target migratory (e.g. marine mammals, turtles, seabirds, sharks, etc) and deep-sea species, including deep-sea structural habitats found on the high seas (Gianni 2004, Gilman *et al* 2014, Ortuño Crespo and Dunn 2017, Cronin *et al* 2022, Elliott *et al* 2023). Migratory species bycatch includes 300 000 cetaceans annually, millions of sea turtles killed from 1990–2008, and ∼320 000 seabirds killed annually from longlines alone (most common high seas gear (hours fished/year)) (Read *et al* 2006, Wallace *et al* 2010, Anderson *et al* 2011, Harrison *et al* 2018, Carmine *et al* 2020). Further, oceanic sharks overlap with these longline vessels and are also frequently caught as bycatch (Queiroz *et al* 2016). Oceanic sharks and rays experienced a 71% global decrease in their abundance correlated with an 18-fold increase in fishing pressure over 50 years, which has not been resolved despite management measures (Pacoureau *et al* 2021, Worm *et al* 2024). Fishing vessels associated with higher levels of bycatch and illegal, unreported, and unregulated (IUU) practices launder their catch into the global seafood market via transshipment at-sea; whereby a refrigerated cargo vessel meets a fishing vessel at-sea to transport its catch to port, which can cloud the seafood supply (Ewell *et al* 2017, Boerder *et al* 2018).

The legally-binding United Nations Biodiversity Beyond National Jurisdiction agreement (UN BBNJ) treaty has the objective to 'protect, preserve, restore, and maintain biological diversity and ecosystems' on the high seas (UN BBNJ 2023). After entry into force in January 2026, the BBNJ conference of the parties (COP) will have the authority to establish marine protected areas (MPAs) on the high seas. However, the future BBNJ COP cannot '*undermine existing legal instruments and frameworks and relevant global, regional and sectoral bodies,*' which includes RFMOs (Langlet and Vadrot 2023, UN BBNJ 2023). While RFMOs are empowered components of high seas governance, they have left 95% of high seas fish biodiversity unassessed, and may need to collaborate with BBNJ goals given the impact of RFMO-managed industrial fishing on high seas biodiversity (Crespo *et al* 2019). This collaboration may require independent reviews of RFMO-managed activities and overall RFMO performance.

Independent performance reviews are distinct from *official* RFMO performance reviews, while official reviews must include 'some element of independent evaluation,' they are not required to be independent from the institution (Regional Fishery Body Secretariats' Network 2016). The last comprehensive independent performance review in 2010 demonstrated RFMOs were performing on average at 57% of best governance and policy practices on paper (determined at that time), with no correlative relationship between performance questions and target stock status (Cullis-Suzuki and Pauly 2010). This suggested that adopted policies had not achieved commensurate management goals for RFMO targeted fish, concluding that RFMOs had 'failed the high seas' (Pitcher *et al* 2009, Cullis-Suzuki and Pauly 2010). Subsequent RFMO reviews examined a single aspect of performance (e.g. transparency, bycatch, or transshipment) or focused on a subset of RFMOs (e.g. tuna RFMOs) (Gilman *et al* 2014, Clark *et al* 2015, Ewell *et al* 2017, 2020, Juan-Jordá *et al* 2018, Haas *et al* 2019, Cronin *et al* 2022, Elliott *et al* 2023).

Here, we reviewed the performance of sixteen RFMOs in ten evaluation categories, with ten questions in each category (100 questions total/RFMO). These ten evaluation categories assessed the dual-mandate of RFMOs; the sustainable use-oriented goals (management, compliance, and enforcement, set catch targets, flags and ownership, access and equity/provisions for developing states, illegal, IUU fishing prevention, and transparency) and long-term conservation goals (bycatch reduction, incorporation

of scientific knowledge, spatial management, stakeholder involvement). These 100 questions built on previously assessed RFMO performance best practices from (2007) and (2010) while adding to these heuristics for modern fisheries performance. This review also expanded on previous efforts by incorporating satellite-derived fishing activity in each RFMO convention area, updated questions on transshipment, and added two new categories: stakeholder engagement and spatial management including MPAs. We further paired these findings with updated Sea Around Us target stock status plots to provide an updated evaluation of global high seas fisheries management. Our analysis examined the relationship between these variables since an RFMO with stronger adherence to governance and policy best practices should be correlated with better target stock status or less total fishing activity in each convention area. Governance of the high seas is at a crossroads; this research brings novel information needed for effective management and long-term conservation of high seas fisheries and biodiversity.

2. Methods

Developing the RFMO performance questions builds on previous research, including recommended best practices for RFMOs from the OECD and published by Chatham House (Lodge *et al* 2007, Cullis-Suzuki and Pauly 2010). We evaluated 16 active RFMOs (table 1) against 100 questions divided evenly into ten categories. These methods expand on previous studies with new categories for spatial management with an emphasis on closures and protected areas, the adaptation of the developing states categories to contemporary access and equity goals, half point qualifications for certain criteria, new questions on transshipment, and the condensing of (Cullis-Suzuki and Pauly 2009 and Cullis-Suzuki and Pauly 2010)'s 26 sections to 10 categories by merging questions and criteria together to reflect current RFMO best practices. This should be considered when we compare each section to the closest related section in the results and explain the reasoning further in the supplemental results. The questions were reviewed internally in this project and externally through discussions with academic researchers and NGO representatives for advice on question content (table S3). The ten categories with ten questions each and structured the review were as follows:

1. Access and equity
2. Bycatch reduction
3. Flags and ownership
4. Illegal, IUU fishing prevention
5. Incorporation of scientific knowledge
6. Management, compliance, and enforcement
7. Set catch targets
8. Spatial management with an emphasis on closures and protected areas
9. Stakeholder involvement and voting rights
10. Transparency

The 100 questions were scored by the authors of this manuscript and those answers reviewed within this co-authorship list. If the RFMO fulfilled the criteria in a performance review question, it was assigned a score of 1, otherwise 0. A half point was given when the full criteria was not met (SI). Additionally, the supplemental material section includes documentation of how questions were scored and the 1600 scores themselves. A link to the CMM or publicly available RFMO information and an explanation were provided to explain the rationale for each response (of 0, 0.5, or 1). The maximum score was 100 points, which was considered the highest possible performance. The points breakdown for each of the 1600 questions across the 10 categories and 16 RFMOs can be found in supplemental material. Following previous work we did not weigh management scores (Pitcher *et al* 2009, Cullis-Suzuki and Pauly 2010). However, we did include two key reference points for discerning a given RFMO's score to control for any bias introduced to the performance questions. An absolute benchmark of performance was a score of 100/100 with 10/10 for each category since each of the 100 questions was considered for an RFMO's absolute ideal score of their management performance. We also created comparative reference points as benchmarks, with the hypothetical *best possible* score for an RFMO at 90 and the hypothetical *best case* RFMO score at 76.5. 90/100 questions indicated at least one RFMO was given full credit, and the *best case* was the composite total for the highest-scoring RFMOs from each of the 10 categories. When we compare our findings to previous analyses, we only compared 8/10 categories. Our study used a more rigorous evaluation criteria (more detailed questions, some new questions, and updated criteria with which to score questions) within eight category topics of evaluation compared to the 2010 assessment (Cullis-Suzuki and Pauly 2010).

The RFMOs were grouped into one of the three categories: tuna RFMO (tRFMOs), general/benthic RFMOs, or salmon/halibut RFMOs (table 1). RFMOs in this study that exclusively manage tuna and tuna-like species within their convention areas were labeled tRFMOs. Their convention areas are, on average, larger than those of non-tuna RFMOs. The RFMOs we refer to as 'general/benthic' RFMOs were designated based on a spatial area and are responsible for managing the identified fish species under their mandate in their convention area (mostly focused on small pelagic and demersal species). In addition to these RFMOs managing relevant pelagic, benthic, and demersal species, these RFMOs protect and monitor vulnerable marine ecosystems (VME) and flag when indicator species are caught. We recognize there is a distinction legally between a VME and a MPA, however given that both are considered spatial areas where

Table 1. RFMOs evaluated in this study along with their abbreviations and how they were categorized in this performance review.

RFMO	Abbreviation	Category
Commission for the Conservation of Southern Bluefin Tuna	CCSBT	tRFMO
Inter-American Tropical Tuna Commission	IATTC	tRFMO
International Commission for the Conservation of Atlantic Tunas	ICCAT	tRFMO
Indian Ocean Tuna Commission	IOTC	tRFMO
Western and Central Pacific Fisheries Commission	WCPFC	tRFMO
Commission for the Conservation of Antarctic Marine Living Resources	CCAMLR	General/benthic RFMO
General Fisheries Commission for the Mediterranean	GFCM	General/benthic RFMO
Northwest Atlantic Fisheries Organization	NAFO	General/benthic RFMO
North-East Atlantic Fisheries Commission	NEAFC	General/benthic RFMO
South-East Atlantic Fisheries Organization	SEAFO	General/benthic RFMO
Southern Indian Ocean Fisheries Agreement	SIOFA	General/benthic RFMO
South Pacific Regional Fisheries Management Organization	SPRFMO	General/benthic RFMO
International Pacific Halibut Commission	IPHC	Salmon/halibut
Pacific Salmon Commission	PSC	Salmon/halibut
North Pacific Anadromous Fish Commission	NPAFC	Salmon/halibut
North Atlantic Salmon Conservation Organization	NASCO	Salmon/halibut

fishing is restricted or prohibited, both designations were included in certain scenarios in the protected area category further explained in the supplemental material. The third group we focused on were non-tuna, species-specific organizations managing salmon and halibut fisheries. We also recognize RFMOs are not homogenous with variations to the broad RFMO high seas mandate. For example, there are newer RFMOs such as the South Pacific Regional fisheries Management Organization (SPRFMO), which was created in 2012, and there are more specific or enhanced RFMOs such as the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), which was formed as an integral part of the Antarctic Treaty System of 1959. Still, the impact of new treaties such as BBNJ may have implications for all RFMOs; therefore, we examined all RFMOs (Barrett 2020).

For the spatial component of the performance review, where RFMO convention areas overlapped, the average scores for the convention areas were used in the overlapping spatial areas only. Data collection for each of the 10 questions within each of the 10 categories (totaling 100 questions) took place between 2021 and 2023 and relied on public-facing information provided by RFMOs, primarily through their websites. This information included meeting documents, CMMs texts, Convention texts, and information pages for civil society. CMMs and other decisions adopted at annual convention meetings beyond December 2021 were not included in this study. Additional information was obtained from the scientific literature in order to answer specific questions on transshipment, fisheries observers, corporations involved with RFMOs, and VME closures (Ewell *et al* 2017, 2020, Bergstad *et al* 2019, Carmine *et al* 2020, Dellmuth *et al* 2020).

Additional data was used to inform two sections of the performance review: stock status plots and fishing effort. RFMO fish population data from the Sea Around Us Project (www.seaaroundus.org/) was downloaded in April 2022 for analysis. Stock status plots by RFMO were downloaded and the 'percentage of stocks of a given status' was used in this analysis for the year 2018. For the global scale, we used stock status plots to determine abundance, because it is the only consistent dataset available for all target species caught in the waters of an RFMOs convention area (Pauly *et al* 2013). Many RFMOs did not have consistent stock assessments for all target species, making stock status plots the best indicator for relative abundance at scale and a comparative tool for fish population health across RFMO convention areas. While landing data must be used with consideration, they are often the only datasets available and are considered sufficient for determining the health of fish stocks in a given area, particularly for large marine ecosystems (Pauly *et al* 2008, Kleisner *et al* 2013). Stock status plots are based on the modernization of previous Sea Around Us algorithms and incorporate a rebuilding category (for stocks that drop into the 'collapsed' status and in later years recover) (Kleisner *et al* 2013). A species is categorized as 'target' for an RFMO if catch records show the taxon is caught for at least five consecutive years over at least ten years and the total catch over that time is at least 1000 tons (Kleisner and Pauly 2015). A stock is considered 'collapsed' when the year of catch is greater than the year of the highest recorded catch and the catch that year is less than 10% of the maximum catch recorded for that taxa (Grainger and Garcia 1996, Froese and Kesner-Reyes 2002, Kleisner *et al* 2013). It should be noted this is for all stocks in the waters of an RFMO's convention area. If portions of RFMO convention areas overlap, the stock was assigned to both relevant RFMOs. All Sea Around Us data was used from the publicly available website (Grainger and Garcia 1996, Froese and Kesner-Reyes 2002, Kleisner *et al* 2013, Kleisner and Pauly 2015, Pauly *et al* 2020).

Information derived from automatic identification system (AIS) technology was leveraged to obtain estimates of fishing effort intensity using

Global Fishing Watch (GFW, https://globalfishingwatch.org/) fishing effort 2.0 data for the year 2019 downloaded in March 2022 (see supplemental). To control for RFMOs with larger convention areas and to understand concentration of fishing hours in each convention area, we examined fishing effort per 10 km^2 in addition to total fishing. RFMO convention area polygons were downloaded from the FAO in March of 2022 for this analysis. Spatial data were analyzed using ArcGIS Pro 2.6.1. Additional analysis for fishing effort by area of RFMO convention area was conducted in python 3 using JupyterLab V 3.5.1 on the Pangeo Cloud operated by 2i2c. We tested for relationships between RFMO management performance and fishing effort or stock status using Pearson correlation coefficients and linear regressions with R Studio Version 2023.12.0 + 369.

Twenty-three of our questions were directly outcome related and selected as a subset of the 100 questions to determine if there was a correlation between RFMO performance metrics that incorporated outcomes of RFMO actions as opposed to policies on paper. We identified 23 outcome-related performance questions from the overall 100 performance questions and created a subset of values from this group of 23 questions' values (0, 0.5, or 1) for each of the 16 RFMOs. To be considered outcome-related, the question must examine a metric of performance towards conservation or sustainable management that shows enacted change beyond policy adoption. For example, 'Is at least 1% of the RFMOs convention area fully protected?' required a spatial analysis to see how much of the RFMOs convention area had been declared closed to fishing. These questions differ from governance performance questions, such as 'Does the RFMO allude to flag state duties?', etc The identified 23 performance questions as outcome-related values for all 16 RFMOs were found in questions from the topic categories (number of questions from section in parenthesis): Incorporation of scientific knowledge (2), Set catch targets (2), bycatch reduction (6), Spatial management/MPAs (8), IUU fishing prevention (2), Stakeholder Engagement & Voting rights (2) and management compliance enforcement (1) (supplemental). While the 23 outcome-oriented subset questions were not evenly spread across the 10 categories, that was acceptable because we were not looking for evenness of outcome-oriented questions spread across the 10 categories, we were looking for outcome-oriented questions and anomalies, which is different from some entirely *governance* focused sections. Further information can be found in the supplemental material and results. We analyzed this subset by creating a correlation matrix for each of the 23 outcome-related question scores for each RFMO, the aggregate score of the 23 outcome-related questions for each RFMO, with all other variables in this study including overall performance (out of 100), target stock status values for each RFMO, and fishing effort values for each RFMO. This correlation matrix also used a Pearson correlation and displayed coefficient values as (r) and was conducted using R Studio Version 2023.12.0 + 369.

3. Results

3.1. Variables of all RFMOs

1. 100 performance questions for all 16 RFMOs

The average score for all RFMOs across all 10 assessment categories was 45.53/100 (SD 9.8). The median score for the 16 RFMOs was 46 (figure 1). There was a considerable range in total scores with the highest score of 61.5 for the Western and Central Pacific tuna RFMO (WCPFC), and the lowest score of 29.5 for the North Atlantic salmon RFMO (NASCO) (figure 1). An absolute benchmark of performance was a score of 100/100 with 10/10 for each category. However, we identified two relative benchmarks for comparative purposes: 90/100 (90 questions where at least one RFMO was given 1 point, making the *best possible* RFMO score at 90), and 76.5/100 (the aggregate score for each category's highest RFMO score, making the *best case* score at 76.5).

The assessment category with the lowest relative score was *stakeholder involvement and voting rights*, with an average of 2.3/10 (figure 1). The highest-scoring category average was *set catch targets* at 5.7/10. Other categories below the 45.53/100 average score were *access and equity* (3.3/10) and *spatial management/MPAs* (4.2/10). The categories above or at the average were *management, compliance, and enforcement* (4.6/10), *incorporation of scientific knowledge* (4.6/10), *bycatch reduction* (4.9/10), *flags and ownership* (5.2/10), *IUU prevention* (5.2/10), and *transparency* (5.6/10) (figure 2). No RFMO received 10/10 for any category (figure 2).

All 16 RFMOs received the same scores for nine questions in this review which indicated equivalent management for these metrics (i.e. all RFMOs received identical scores of either 1 or 0) (figure 2). All RFMOs alluded to flag state duties and published their convention meeting reports and approved CMMs. However, we found that no RFMOs coordinated on joint closures, had binding quantitative performance standards for non-target species bycatch reduction plans, had high-resolution satellite or electronic monitoring data publicly available, and none had accurate beneficial owners for registered vessels.

Considering overlapping RFMO convention areas, the ocean areas with lower performance question scores were the North Atlantic, Indian Ocean, and the Mediterranean Sea (figure 3). Areas close to the Southern Ocean were also less protected, given CCSBT's low overall score (figure 3).

1a. *Change in performance over time*

As with a previous RFMO performance review (Cullis-Suzuki and Pauly 2010), WCPFC again

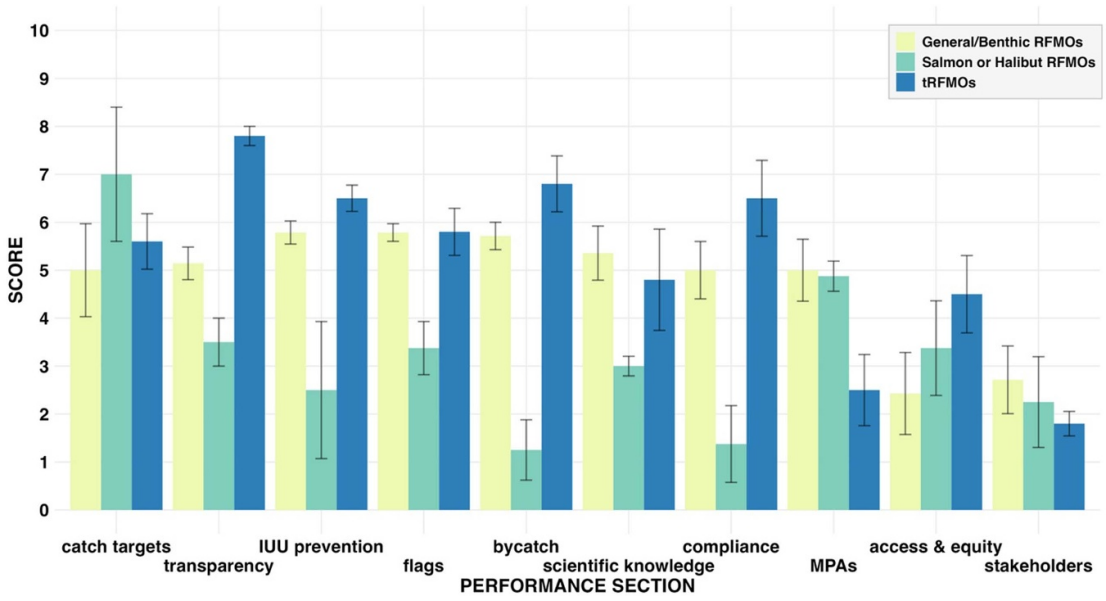

Figure 1. Average scores by category of RFMO performance across RFMOs. RFMOs are categorized under the following groups: general and/or benthic RFMOs (yellow), salmon or halibut RFMOs (green), and tuna RFMOs (blue). A perfect possible score for each of the ten sections was 10, and the standard error of the mean is denoted with error bars. The grouped bars were ordered left to right by their descending overall average score. There are 10 questions for each of the 10 categories (100 total questions) examined for all 16 RFMOs (N) using publicly available data (see methods).

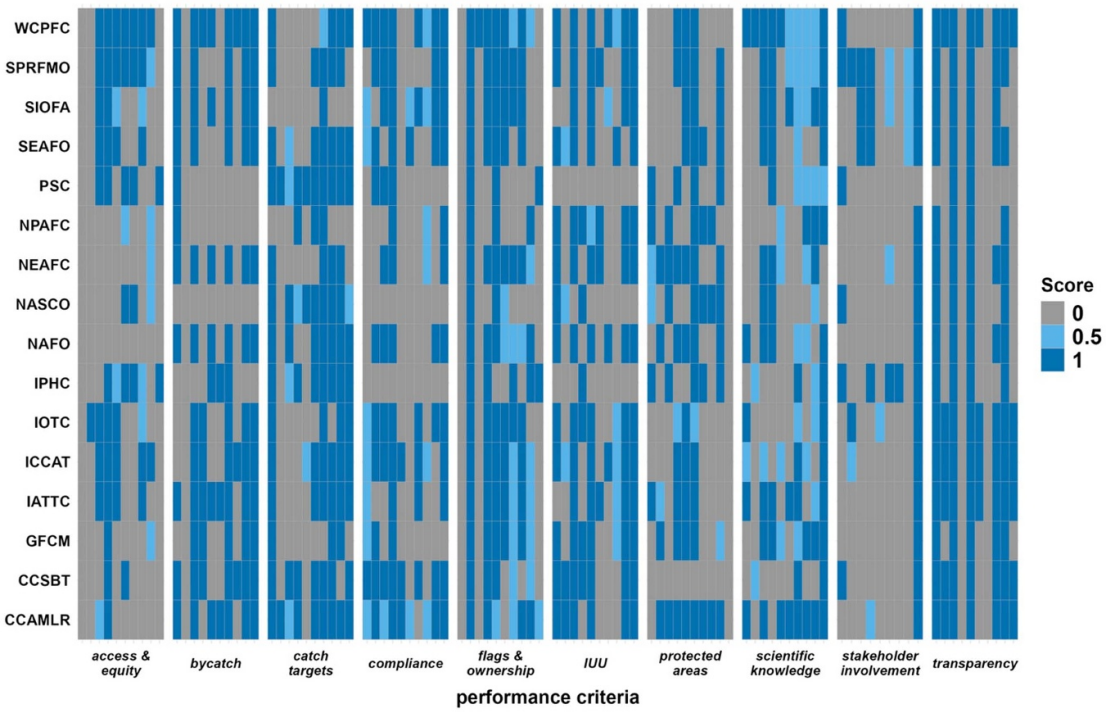

Figure 2. Chart displaying the results from all 1,600 questions across the 10 categories and 16 RFMOs. All criteria scores for the RFMO performance review ranged from 0 to 1, with partial completion (0.5) being assigned in certain instances.

achieved the highest of all RFMOs (figure 2). CCAMLR increased its overall RFMO rank to 2nd (previously 8th), and GFCM decreased from 2nd in 2010 to 12th in our review (excluding the International Whaling Commission). When we compared eight of our ten categories to the 2010 performance review counterpart that it most resembled, average scores decreased for six categories (set catch targets, IUU prevention, flags and ownership, bycatch, incorporation of scientific knowledge, and access and equity/provisions for developing states), and increased for two categories (transparency, and management compliance & enforcement) (see supplemental).

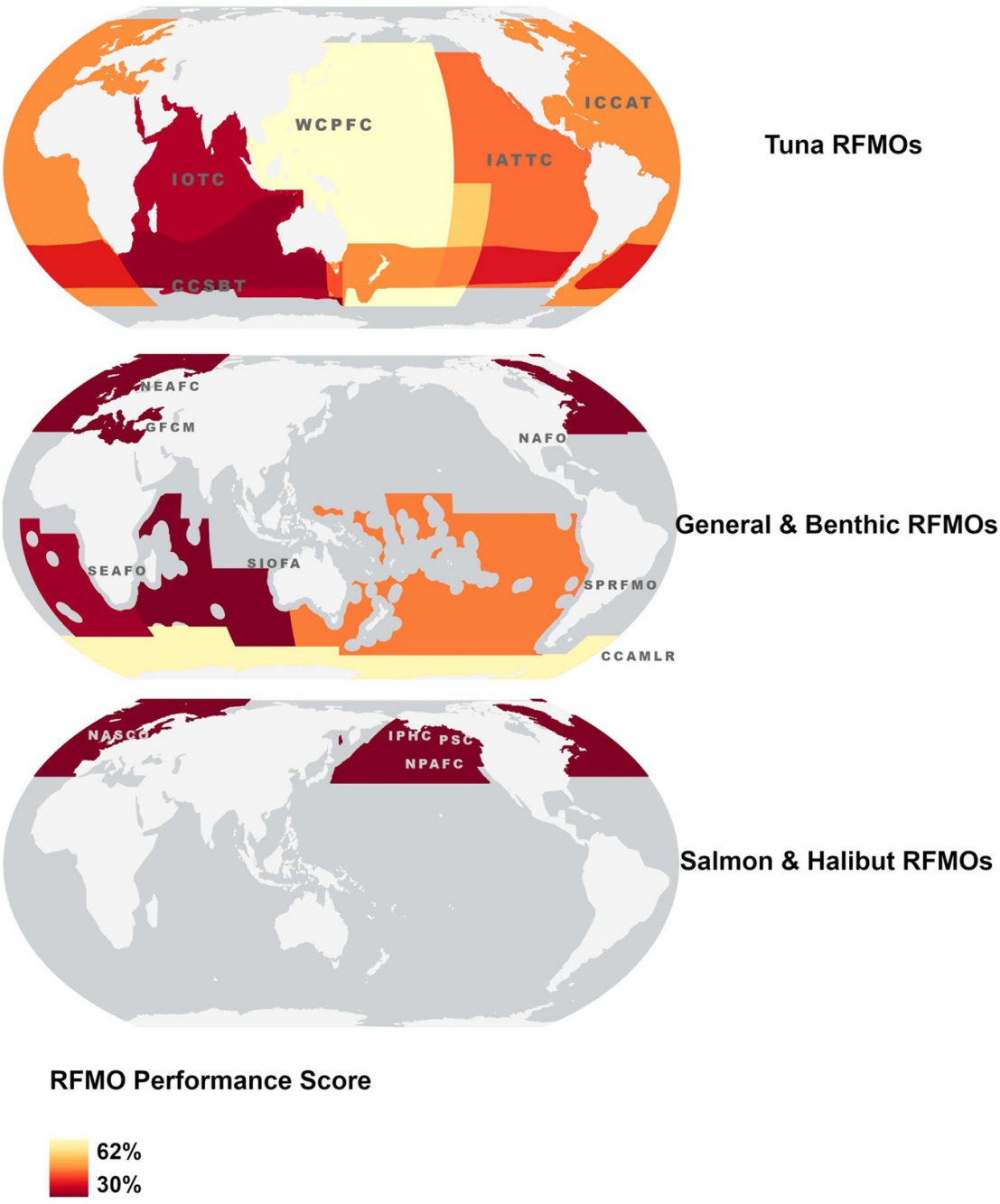

Figure 3. Performance of RFMOs based on RFMO websites, measures, mandates, and convention texts. The performance score is the average value of the 10 measured categories of the RFMO mandate. Color scale is bound by the minimum and maximum values of performance.

1b. The dual-mandate cases: set catch targets & spatial protection

Five RFMOs had no-take MPAs in place: CCAMLR, IPHC, NASCO, NEAFC, and NPAFC. Additionally, 5% or more of the convention areas of CCAMLR, NASCO, and NPAFC were protected by no-take MPAs. Benthic RFMOs skewed the average of MPA performance higher, given their requirement to protect VMEs.

The majority of RFMOs set catch targets for most species each year except for SIOFA and NPAFC. However, we found tRFMOs did not enact rebuilding plans for all declining target species and did not consistently (5 consecutive years) set catch limits based on the best scientific evidence available (SI). Apart from CCAMLR, general/benthic RFMOs managed more species on average and scored the lowest on average of the RFMO sub-groups for this category.

2. Targeted stock status in the waters of RFMOs

On average, 56% of stocks targeted in an RFMO's convention area were considered collapsed or

overexploited (2018) (table 2). According to the Sea Around Us data utilized, all 16 RFMO convention areas had a proportion of overexploited or collapsed target species, and that proportion of collapsed or overexploited stocks targeted in their convention area increased from 1996 to 2018 (i.e. since the UNFSA was agreed to) (table 2). The convention areas of CCSBT (67%), NAFO (67%), IPHC (65%), CCAMLR (65%), and PSC (61%) had the highest proportion of targeted fish collapsed or overexploited in 2018 (table 2). The largest percent change increases from 1996–2018 in the proportion of fish stocks overexploited or collapsed were found in the convention areas of SIOFA (271%), CCSBT (196%), GFCM (189%), IOTC (163%), and WCPFC (120%) (table 2). The rate of percent change increase is lower in some RFMO waters when examining more recent years (2002–2010). The collapsed/overexploited proportion in the convention areas of CCAMLR, NPAFC, and SEAFO improved from 2010–2018; still, in 2018 the proportion found was 65%, 44%, and 57%, respectively (table 2).

By ocean area, the highest percentage of targeted species considered collapsed/overexploited was found in the Southern Ocean, the North Atlantic, Northern Pacific, and the southwestern Pacific Ocean (figure 4). However, the areas where the rate of RFMO-jurisdictional targeted species collapses were increasing fastest were in the Indian Ocean (SIOFA and IOTC at 271 and 163% change, respectively), the Southern Ocean (CCSBT and CCAMLR at 196 and 68% change, respectively), the Mediterranean (GFCM at 189% change), and the Western and Central Pacific Ocean (WCPFC and SPRFMO at 120 and 51% change, respectively) (table 2).

3. Fishing Effort by RFMO

Vessels fishing in the convention area of WCPFC demonstrated the greatest fishing effort, with ∼26 million hours fished in 2019 (figure 5(a)). For general/benthic RFMOs, the total highest fishing effort and fishing density (hours/10 km^2) was in NEAFC with ∼9 million hours (figure 5(a)). For halibut and salmon RFMOs, the highest fishing effort and effort per 10 km^2 occurred in NASCO with ∼10 million hours (figure 5(a)). For reference, the total global fishing effort for the previous year was ∼36 million hours (Carmine *et al* 2020). While accounting for area resulted in some overall ranking changes, the five RFMO convention areas with the highest number of total hours, (WCPFC, ICCAT, NASCO, NEAFC, GFCM), were consistent as the five RFMOs with the densest fishing effort (hours/10 km^2) (figure 5(b)). The RFMOs with the most fishing intensity and density can be found in the Western and Central Pacific, Mediterranean, and Atlantic Ocean.

3.2. Correlation of variables

100 performance questions and targeted stocks

The proportion of target stocks considered collapsed or overexploited in 2018 were not correlated with the 100 questions score ($r = -0.02$). The percent increase of targeted species considered collapsed or overexploited (from 1996–2018) in an RFMO convention area and the RFMO's management performance score was weakly positively correlated ($r = 0.37$). In other words, RFMOs with a higher percent increase in their proportion of collapsed and overexploited stocks weakly exhibited higher management performance scores, but the correlation weakened when we examined shorter time scales or one year (table S5). Using a linear regression, we did not find a significant effect of an RFMO's average management performance score on the proportion of stocks considered collapsed/overexploited ($p = 0.93$, $R^2 = 0.0005$) or on their percent increase between 1996–2018 ($p = 0.17$, $R^2 = 0.13$). Given these results, we conclude that there was no strong relationship between the 100 aggregated performance questions and targeted fish stock status.

100 performance questions with fishing effort

Total fishing effort in hours within an RFMO's convention area had a weak positive correlation with the 100-question scores ($r = 0.37$). The number of vessels found fishing in an RFMO convention area was moderately correlated ($r = 0.40$) to the 100-question scores. This correlation is parallel to the stock status finding where a higher management/question score is weakly associated with more fishing vessels or fishing hours. However, fishing density in an RFMO had a weaker negative correlation ($r = -0.26$), meaning a weak correlation between dense detected fishing effort in an RFMO and lower scores on the 100-performance questions. Using a linear regression, we did not find a significant effect of performance scores on fishing effort by RFMO Convention Area ($p = 0.15$, $R^2 = 0.14$). These trends should be considered as emergent, but were not significant and explained a portion of the variance.

Outcome-related performance questions with stock status

Consistent with our other results, the aggregate of the values of the 23 outcome-oriented subset of the total 100-questions had exhibited weak positive correlations with the proportion of stocks collapsed or overexploited in 2018 ($r = 0.15$), effort fished ($r = 0.1$), and effort density ($r = 0.1$). There was no correlation with the percent difference increased in collapsed stocks during the study period ($r = 0.06$).

However, we also created a Pearson correlation matrix of all target stock status and fishing effort variables with each of the 23 outcome-oriented questions

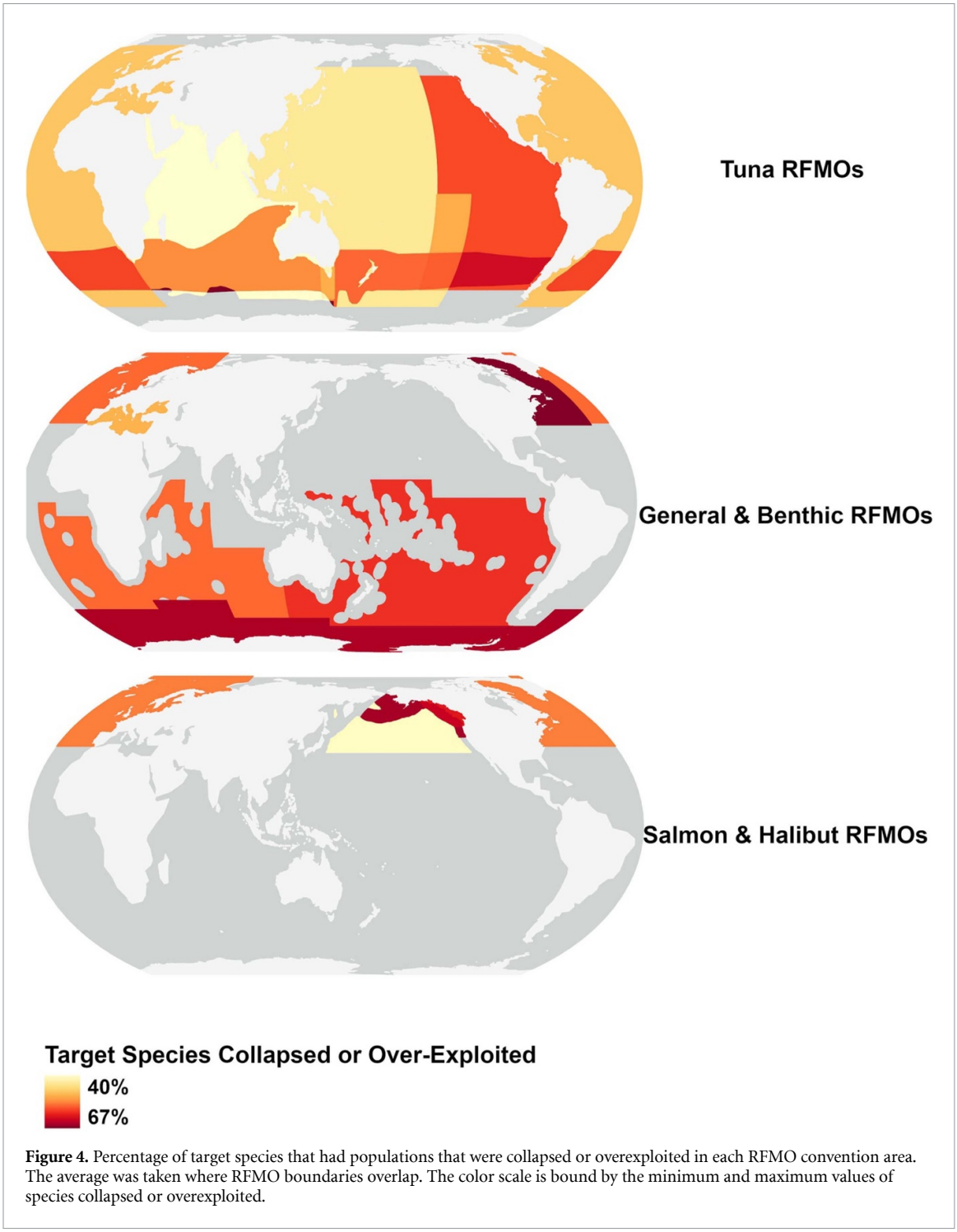

Figure 4. Percentage of target species that had populations that were collapsed or overexploited in each RFMO convention area. The average was taken where RFMO boundaries overlap. The color scale is bound by the minimum and maximum values of species collapsed or overexploited.

to identify potential anomalies. Unique from other findings, we found that scores for five outcome-oriented questions (variables) were negatively correlated ($r \geqslant -0.5$) with the variables related to the proportion of RFMO target stocks collapsed or overexploited status. Variables that were correlated with either a lower proportion of target stocks collapsed or overexploited or a lower increase in this proportion of target stocks in an RFMO's convention area over the study period included:

1. closures *or* catch reductions in response to declared overfishing ($r = -0.5$). A total of 13 RFMOs received a full point
2. fisheries closures, MPA, or VME closure adoption ($r = -0.6$). A total of 14 RFMOs received a full point; one RFMO received half a point.
3. static fisheries closures for specific geographic areas (static meaning permanent no-entry/no-take protected areas for all species) ($r = -0.5$). A total of five RFMOs received a full point.

Table 2. Percent collapsed, overexploited by year of stocks caught in waters of the RFMO were courtesy of Sea Around Us. Determining increased % from 1996–2018 was part of this study.

RFMO convention area boundaries	Stocks considered collapsed/overexploited in 2018 (%)	Increase of stocks considered collapsed/overexploited from 1996–2018 (% increase)	Stocks considered collapsed/overexploited from 1996–2018 (% change)	Absolute score for the 100-performancequestions	Year RFMO came into force or established
CCSBT	67	44	196	46.5	1994
NAFO	67	18	36	45.5	1979
IPHC	65	15	30	38.5	1923
CCAMLR	65	26	68	60.5	1982
PSC	61	10	20	31.5	1985
SPRFMO	59	20	51	53.5	2012
IATTC	58	23	66	53	1950
SIOFA	57	42	271	44	2006
SEAFO	57	11	25	47.5	2003
NASCO	56	14	33	29.5	1983
NEAFC	56	13	29	43.5	1982
GFCM	51	33	189	41	1949
ICCAT	49	20	67	54	1969
WCPFC	45	24	120	61.5	2004
NPAFC	44	8	23	30.5	1993
IOTC	41	25	163	48	1996

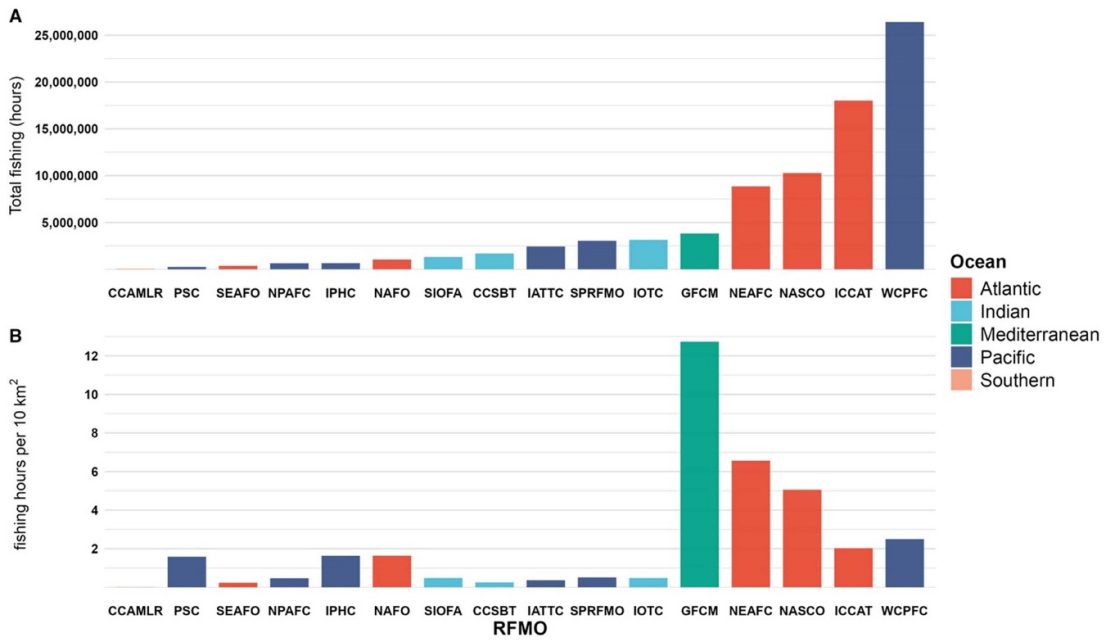

Figure 5. (A) Total fishing effort in hours by RFMO in 2019 from global fishing watch data (B) fishing density in hours per 10 km^2 in each RFMO convention area for 2019.

4. at least 1% of the RFMOs' convention area (by surface area) is a fully protected area (no-take) ($r = -0.5$). A total of five RFMOs received a full point.
5. a ban on transshipment (partial and full were scored respectively) ($r = -0.5$).

For transshipment, only one RFMO, SEAFO in the south-east Atlantic, has a full ban on transshipment at sea, with five other RFMOs maintaining what we called a 'partial ban' (GFCM, IATTC, ICCAT, IOTC, and WCPFC). We scored a partial ban with a score of 0.5 and a full ban with a score of 1 and built on findings for this question from Ewell *et al* (2017) and measures found during our study period. All five variables related to either reducing catches, creating MPAs in some form, or transshipment bans.

4. Discussion

This is the most recent comprehensive independent RFMO review since 2010. We evaluated 100 performance values evenly distributed across 10 categories, used updated Sea Around Us target stock status plots, and incorporated previously unevaluated satellite-derived fishing effort. RFMOs were scored against the 100 performance questions based on publicly available information regarding their adherence to their mandates, the strength and utility of CMMs passed, transparent and equitable participation at meetings, and regulatory compliance by country members, among other dimensions (Lodge *et al* 2007, Cullis-Suzuki and Pauly 2010). We found RFMO performance questions were not correlated with better management results (i.e. lower proportion of target stocks collapsed/overexploited, or less fishing intensity/density). Instead, we even found some weak correlations of an inverse relationship. However, in search of anomalies using the Pearson correlation matrix, our analysis found 5 questions correlated with better RFMO target stock status outcomes that were related to reduction of allowable catches, fisheries closures/MPA creation, and transshipment at-sea bans. Overall, with an average RFMO performance of 45.5/100, we highlight potential concern for sustainable use and long-term conservation of marine life on the high seas.

4.1. Benchmarks of RFMO performance

Each of the 100 questions measured an aspect of good governance principles, sustainability of RFMO use, transparency, and 'long-term conservation' of fish stocks. Therefore, each of the 100 questions was considered for an RFMO's absolute ideal score of their management performance. We also created comparative reference points as benchmarks, with the hypothetical *best possible* score for an RFMO at 90 and the hypothetical *best case* RFMO score at 76.5. 90/100 questions indicated at least one RFMO was given full credit, and the *best case* was the composite total for the highest-scoring RFMOs from each of the 10 categories. These are comparative metrics to help illuminate variation in RFMO ambition and action, which can identify RFMO *leaders* and *laggards*. These scores indicate, in theory, what is possible for any RFMO to achieve within the current governance structure under real-world conditions. Given that the best performing RFMO (WCPFC) had a score of 61.5/100 and

average RFMO performance was 45.5/100, RFMOs are falling behind what even the *best case* reference point indicates they are capable of achieving.

Comparison to previous reviews

For our review, we reevaluated components of the criteria used by a previous review (Cullis-Suzuki and Pauly 2010) related to equity, technological changes, more stringent protected area requirements (key aspects of the Convention on Biological Diversity Agreement (CBD)), and updated criteria for fishing vessel ownership transparency. We also added quantified vessel fishing hours within RFMO convention areas using publicly available satellite data (Kroodsma *et al* 2018). Global Fishing Watch data and their algorithm have been derived as a global dataset in order to work across different fisheries so all global fishing effort can be compared (de Souza *et al* 2016, Taconet *et al* 2019). However, as we were constrained by publicly available information and AIS-fishing effort compliance, it is not guaranteed that all fishing effort was included or that all fishing found in an RFMO was under the scope of the RFMO's mandate (Park *et al* 2023, Paolo *et al* 2024). For example, NASCO prohibits fishing for Atlantic salmon on the high seas, making it likely fishing occurring in this portion of NASCO's convention area targeted species not under NASCO's mandate, but fishing occurring within a nation's EEZ could include Atlantic salmon. The strengths of a global comparable fishing effort dataset come with the caveat that it cannot estimate the number of hauls for a specific fishery, but even its critics note 'No apparent differences in the geographical location of the midpoints of a fishing trip' between GFW fishing effort and vessel self-sampling data (Hintzen *et al* 2025). There have been documented discrepancies between AIS-derived fishing effort and official reported catch in the Indian Ocean with some countries potentially underreporting their official catches to various groups including the IOTC (Cappa *et al* 2024). All fishing activity that occurs in a convention area could foreseeably impact an RFMO's mandate to 'protect biodiversity in the marine environment;' thus, RFMOs would benefit from incorporating data that estimates all fishing occurring in their convention area for ecosystem-based fisheries management considerations.

Some of the category scores that have declined since the 2010 performance review were due to changes in the RFMO *best practices* for example, targeting IUU fishing prevention (targeting transshipment behaviors and the presence of concurrent human rights violations), or the incorporation of scientific knowledge requiring new concepts such as harvest control rules or ecosystem-based approach to fisheries management, which were all previously unassessed. Still our findings, including the lack of correlation between the aggregate performance question scores and stock status indicators, were consistent with the last independent RFMO performance review (Cullis-Suzuki and Pauly 2010).

4.2. Three possibilities behind the correlation results

We hypothesized that effective and precautionary RFMO management would be demonstrated in our results through their correlation with management outcomes. This would mean that each RFMOs 100 responses to the review questions would be negatively correlated with their target stock status collapsed or overexploited or total fishing effort in their convention area. If true, this would indicate that the better an RFMO was at fulfilling their expected *best practices* through policies and decision-making, the lower the proportion of stocks overexploited and collapsed would be. Instead, our review generally found no or weak positive correlation between RFMO management (100 performance questions) and our outcome variables (table S5). However, we also found one weak negative correlation between RFMO management and fishing activity density, suggesting that these overall trends may be indicative of stochasticity across RFMOs rather than the results of management. Taken together, these relationships did not provide evidence for a measurable positive impact of RFMO management score on fishery or fish outcomes, except for the five potential anomalies found. We believe there are three main reasons that may drive the lack of impact that we, and the previous 2010 study found.

1. Reactionary policymaking

One potential driver behind the weak positive correlations found between the performance questions and target stocks collapsed/overexploited could be due to a prolonged reactionary response to committee advice, as opposed to the mandated precautionary approach. Generally, if an RFMO's scientific advisory body recognizes the collapse or decline of a stock, they recommend catch limits, quotas, or other management measures with the aim of halting or reversing declines. This institutional reaction can cause delays in results for fish populations which may lead to some of our findings. For example, IOTC where their convention area exhibited one the sharpest increases in the target stocks in its convention area that were considered collapsed or over-exploited (163% change from 1996–2018), but had an absolute performance score of 48/100, which was slightly above the average. However, IOTC might reflect both the recent availability of better stock assessment data and accelerating overexploitation, but still highlights a key disconnect between these variables in our results (table 2) (Juan-Jordá *et al* 2011, Sinan and Bailey 2020, Heidrich *et al* 2023). We also found reactionary policymaking demonstrated with shortfin mako sharks in ICCAT where a rebuilding plan was created four years after the population was already declared overfished (ICCAT 2021). Similarly, the mackerel

population in the North Atlantic was considered overfished for over a decade before rebuilding plans were implemented (Østhagen *et al* 2020). However, this lack of a precautionary approach to fisheries management and quota allocation can fail to anticipate or prevent declines (de Bruyn *et al* 2013, Pentz and Klenk 2022). As a result, RFMOs may not be able to keep pace with a fast-changing ocean (Pentz and Klenk 2017).

2. 'Signals' vs 'noise'

In this project we measured RFMO performance through 100 questions that have been updated versions of the *best practices*, and species stock statuses for only the fish targeted in each RFMO. This study does not include the many exogenous environmental factors impacting the open Ocean and high seas, including climate change, large-scale species decline in the open ocean, deep-sea habitat impacts, and cascading biodiversity loss. When attempting to measure RFMO performance policies and management, and their impact on target stocks in the open ocean, the confounding exogenous environmental factors of wide-spread and large scale change, might overwhelm any effects from the management policy (McCauley *et al* 2018, Carmine *et al* 2020, Dulvy *et al* 2021, Palacios-Abrantes *et al* 2022, Pentz and Klenk 2023). It is possible that longstanding metrics of widely recognized best practices for RFMOs are not aligned with what truly benefits high seas, straddling, and migratory species. However, based on our results for RFMOs, the 'signals' of both good and bad management decisions might not be able to rise above the 'noise' of the high seas for detectable long-term management outcomes.

3. Policies created obfuscate ineffective RFMO action

The stated objectives and commitments of institutions in policies or otherwise are heavily scrutinized because they hold important insight into the values and goals of those institutions and are important to study in sustainability science across industries (Ewell *et al* 2020, Roelfsema *et al* 2020, Cronin *et al* 2022, Diana *et al* 2022, Elliott *et al* 2023, Kaikkonen *et al* 2024, Hidalgo *et al* 2025). However, an institution's stated policies can obfuscate ineffective monitoring, compliance, and enforcement, and paint an inaccurate picture of reality by ineffectively enforcing their own measures. The lack of a strong correlation between our RFMO management (measured by our 100 questions) and target stock statuses may be due to the quality of the measures themselves as well as their enforcement in practice. The creation of RFMO policies that meet *best practices* on paper may not be an indicator of an RFMO's ability to limit overexploitation. Some measures may be written with substantial opportunities for circumvention. For example, we examined if any of the bycatch-related CMMs contained binding quantitative performance standards, and none did. We found only three RFMOs (CCAMLR, IATTC, and IPHC) showed improvement for bycatch rates for non-target vulnerable species. This is not a new finding, but a reinforced finding from previous studies that show the lack of correlation between RFMO management policies and fish stock status (Cullis-Suzuki and Pauly 2010).

4.3. RFMO recommendations

Specific recommendations

Our findings revealed five questions as anomalies with strong correlations to the proportion of RFMO convention area target stocks collapsed or overexploited ($r \geqslant -0.5$) that may deserve potential recommendation for future RFMO or high seas policy after further investigation. First, when an RFMO detects a high likelihood of overfishing occurring in its convention area, it should immediately either reduce allowable catches or, if necessary, close the fishery for a duration that is aligned with the best available science. To wait to respond after overfishing has already occurred is to prolong reactionary policymaking and contradicts the RFMO mandate to approach sustainable use utilizing a precautionary approach.

Second, RFMOs might consider MPA adoption in high seas areas that are permanent, no-take, and total >1% of RFMO convention area. MPA adoption was associated with three of the five anomaly variables including: (1) any MPA, VME, or fisheries closure adoption, (2) that the MPA was permanent and 'no-take', and (3) the no-take/no-entry MPAs compose more than 1% of the RFMO. No-take MPAs have been shown to be more effective than MPAs that allow fishing for conservation goals, with no-take MPAs hosting 323% more fish biodiversity on average compared to multi-use protected areas (Sala and Giakoumi 2018). No-take MPAs in the high seas also do not have the often associated negative impacts on small-scale fisheries and instead can drive positive spillover effects into nearby EEZs that reduce the current inequality of fisheries benefits (Sumaila *et al* 2015). However, no tRFMOs have a no-take MPA in place and there were no clear plans for one. This may be due to the false assumption that pelagic MPAs can have limited conservation benefits compared to benthic-focused MPAs in the high seas due to the migratory behavior of pelagic species (Boerder *et al* 2019). In fact, high seas biodiversity hotspots like the Costa Rica Thermal Dome, high seas ridges, and seamounts have functional importance that extends to pelagic predators such as tunas and billfishes (Wagner *et al* 2020). Closures of these areas to fishing activity may benefit large, highly migratory species by protecting migratory corridors and aggregating locations as input control measures as a complement to output control measures (i.e. bycatch and catch reductions) (Boerder *et al* 2019). However, we showed all RFMOs underperformed the overall average for

the spatial management and MPAs section, with an average score of 4.19/10, indicating room for growth.

Somewhat distinct from the other four anomaly variables from the outcome-oriented subset, the fifth evaluating each RFMOs transshipment at-sea ban (partial, full, or none). This practice has been linked to an increased risk of illegal, unreported and unregulated (IUU) fisheries catches, as these activities take place far from shore, where they are more difficult to monitor (e.g. one case study showed at least 68% of Pacific tuna transshipments were unsubstantiated with data from RFMOs) (Boerder *et al* 2018, Seto *et al* 2022). Previous studies have demonstrated the ecological and social benefits of a full moratorium on transshipment at-sea for all RFMOs and that a small number of States and corporations benefit from the majority of transshipment (Ewell *et al* 2017, Bengtsson *et al* 2024). Since only one RFMO, SEAFO in the south-east Atlantic, has a full ban on transshipment at sea, with five other RFMOs maintaining what we called a 'partial ban', transshipment remains a common practice on the high seas. Given that transshipment at-sea poses a threat to human rights, legal fishing, and high seas biodiversity protection, decision-makers at RFMOs should consider a full moratorium of at-sea transshipment. This could help avoid overfishing while achieving additional identified ecological and social benefits (Ewell *et al* 2017).

Avoiding corruption through good governance

Good governance ensures that actors with financial motivations regarding a decision are generally restricted in the decision-making process to prevent financial conflicts of interest. For RFMOs, this would refer to all state delegates for contracting parties at RFMOs according to the United Nations Convention against Corruption (UNCAC) and the OECD guide on 'preventing policy capture' (UNCAC 2003, OECD 2017). Corporations benefiting from fishing the high seas are attending RFMO meetings as part of state delegations through their employees and/or hired advocacy group representatives, presenting a potential conflict of interest (table S3). While Environmental NGOs (ENGO) also have participated at RFMO meetings (∼25% of non-state actor participants), they have been described as a counter to industry involvement (Petersson *et al* 2019, Dellmuth *et al* 2020). We found that while scientific meetings at five RFMOs (CCAMLR, IATTC, IOTC, NAFO, and WCPFC) had more than 25% ENGO participation, the remaining 11 RFMOs had far less than 25% of participants (table S3). Corporations, on the other hand, have participated in as many as five different national delegations for one RFMO, with the largest company by fishing effort in the high seas, Sajo Group, sending a representative to all five tRFMO convention meetings (table S3) (Petersson *et al* 2019, Carmine *et al* 2020, Sinan *et al* 2021, Schiller *et al* 2023).

Based on OECD guidelines, there is concern for potential regulatory capture, because RFMOs are a 'regulatory agency where private actors seeking to reduce the cost of compliance persuade regulators to create, avoid, or alter rules, or to show leniency in enforcing them' (Thomas *et al* 2010, OECD 2017). Given documented instances of collusion with the tuna industry by ICCAT delegates over catch documentation, guardrails to avoid regulatory capture are necessary (Guevara *et al* 2012). We identified unique and notable legal language aimed to limit industry influence with the RFMO IPHC, which includes ∼700 words in its official rules of procedure on identifying, notifying and managing conflicts of interest (actual or perceived) (IPHC 2020). While IPHC is unique for its method for member state voting commission appointees, all RFMOs have the potential and capacity to enact a regulatory ruling that models this language, which can attempt to reduce conflicts of interest or potential regulatory capture.

Evaluating governance

While target stock status is an important tool for assessing fishery management, it should not be considered a perfect indicator of fish population health or management effectiveness. Stock assessment models have been shown to 'overstate the sustainability of the world's fisheries' and if used alone, they can risk delivering a misleading interpretation of management success (Edgar *et al* 2024). As such, a comprehensive analysis of RFMO performance should also assess their governance. Good governance principles, including fair, defined, and equitable procedures of an institution, serve as a critical backstop when all else fails in decision-making (Pentz *et al* 2018). Evaluating governance overall can assess the 'futureproofing' abilities of an RFMO, or the processes that may minimize the impact of an unknown future event (e.g. climate change) (Pentz *et al* 2018). Without robust governance tools in place (e.g. permitting, limited entry, TAC, voting procedures, etc) it would be unlikely for that RFMO to respond quickly enough to evade overexploitation while under emergency management conditions.

Reviewing RFMO governance also evaluates basic RFMO data collection, analysis, and synthesis, which is required for understanding the status of their fish stocks. Our approach, including the diverse questions addressed in this study, was necessary to fully evaluate RFMOs' current and future abilities to manage high seas fisheries. Our findings of an absolute average RFMO performance review at 46% (45.5/100) indicate that RFMOs may not be 'futureproofing' in practice.

4.4. Future with the BBNJ treaty

RFMOs are mandated with the dual task of managing the *sustainable use* of high seas and straddling fisheries and ensuring the *long-term conservation* of

fish species and the species within the same ecosystem (UNFSA 1995). However, we found generally low overall performance across the 10 management categories, increasing overexploited and collapsed target stocks, industrial fishing intensity, and absence of a strong effect of management intent on outcomes. We did, however, find anomalies of strong correlations between better target stock status and protected area adoption, banning transshipment at-sea, and reducing allowable catches in response to overfishing. Given our findings, there might be a need to prioritize the *long-term conservation* of fish stocks to ensure the *use* of the high seas is, in fact, *sustainable*. The BBNJ agreement's goals of protection of marine biodiversity would have the authority to create high seas protected areas which have been argued as a way to implement the precautionary principle for fisheries management (Lauck *et al* 1998). BBNJ requires the legal collaboration with RFMOs. This future collaboration of BBNJ and RFMOs could aim to fill the long-term conservation mandate gaps in current RFMO performance.

Data availability statement

The data used is publicly available and attached in the supplemental materials. Code and other data can be found at https://github.com/gcarmine/RFMOPerformance.

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Conflict of interest

H Ö provide scientific support to companies in the seafood sector through the Seafood Business for Ocean Stewardship (SeaBOS) initiative, and is chairman of the SeaBOS Fundraising Foundation. These engagements are voluntary and unpaid.

Author contributions

Conceptualization: G C, G O C, H Ö, J J, P N H Methodology: G C, M R C, C B, C L T, G O C Data collection & analysis: G C, M R C (bycatch), C B (compliance), C L T (protected areas) Writing: G C, M R C, G O C, C L T, H Ö, J J, P N H.

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