

Ecosystem-based harvest strategies in regional fisheries management

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Abstract

Fisheries have complex effects on the dynamics and structure of marine ecosystems. Single-stock management in isolation can cause ecosystems to deviate from desired states and fail to achieve both single-stock and ecosystem-wide objectives. This can be addressed through ecosystem-based fisheries management (EBFM), including ecosystem harvest strategies. We benchmarked the state of development of core components of ecosystem harvest strategies. We assessed the development and implementation of ecosystem state indicators, their application in defining limit and target reference points for ecosystem overfishing, the assessment of the predicted performance and tradeoffs of alternative ecosystem management procedures such as through management strategy evaluation, and the use of ecosystem thresholds to guide or trigger ecosystem management procedures. Across 22 intergovernmental bodies with mandates to adopt binding fisheries management measures, implementation of these components is limited. Two are at relatively more advanced stages involving the exploration or adoption of ecosystem thresholds and management procedures, while seven are at incipient stages focused primarily on the development or exploratory use of ecosystem indicators. The latter group includes all tropical tuna regional fisheries management organizations, which have coordinated activities to integrate ecosystem considerations into fisheries management processes but have not progressed to operational ecosystem harvest strategies. Approaches by the few intergovernmental bodies that have progressed the most serve as a model for organizations at incipient stages. Our findings benchmark the state of progress in transitioning to ecosystem harvest strategies, one key component of EBFM, and highlight priorities for mainstreaming ecosystem considerations in regional fisheries management.

Keywords: ecosystem-based fisheries management (EBFM); ecosystem indicator; ecosystem overfishing; fisheries management procedures; regional fisheries management organization (RFMO)

1. INTRODUCTION

The need to embed biodiversity conservation in fisheries management and to manage fisheries via an ecosystem approach has received increasing attention and has been prescribed in major

international fisheries agreements for over four decades (Friedman et al. 2018; FAO 2023). Capture fisheries and human-induced climate change are currently the main drivers of change and loss in marine biodiversity (Leadley et al. 2010; Jaureguiberry et al. 2022). Pressures from marine capture fisheries include relatively evident direct effects such as from physical impacts on habitat structure and capture mortality of commercial and bycatch species (Goñi 1998; Gray and Kennelly 2018; Juan-Jorda et al. 2022; Froese and Pauly 2024). Fisheries also have indirect, collateral effects ranging from changes to ecosystem structure and functioning manifested through complex food web links, including trophic cascades and regime shifts, sublethal effects on target and bycatch species such as from reduced school sizes, the spread of invasive alien species (e.g., from rafting on floating derelict fishing gear), and in some cases fisheries-induced evolution from selective removals based on heritable traits (Goñi 1998; Folke et al. 2004; Kuparinen and Merila 2007; Dakos et al. 2014; Heino et al. 2015; Estes et al. 2011, 2016; Hollins et al. 2018; Wang et al. 2021; Gilman et al. 2013, 2023a, 2026).

Intergovernmental bodies with mandates to adopt fisheries conservation and management measures that are binding on their members includes regional fisheries management organizations and arrangements (RFMO/As) and bodies with wider mandates than managing fisheries that also adopt binding measures for marine fisheries, collectively referred to as intergovernmental organizations (IGOs) for convenience. The scope of mandates of IGOs has substantially expanded since the first was established in 1923 and since legal instruments establishing international responsibility to conserve associated and dependent species first became an obligation under the 1982 Law of the Sea Convention (United Nations 1982; FAO 2001). This includes having a pivotal role in mainstreaming biodiversity in the global fisheries sector, as recognized by the UN Committee on Fisheries (FAO 2023, 2024), and a role in implementing an agreement on the conservation and sustainable use of biodiversity beyond national jurisdiction (Article 8.1, United Nations 2023; FAO 2025a). International measures encourage States to participate in regional fisheries conservation and management in both areas within and beyond national jurisdiction (FAO 1995; Warner et al. 2014). Previous performance assessments concluded that IGOs have been underperforming and require substantial reforms in many areas, including in implementing an ecosystem approach to fisheries management (Lodge et al. 2007; Cullis-Suzuki and Pauly 2010; Gilman et al. 2014; Juan-Jordá et al. 2017; Karim et al. 2020).

Single-stock management in isolation can fail to achieve both single-stock and ecosystem-wide objectives (Walters et al. 2005; Lindegren et al. 2009; Patrick and Link 2015; Fulton et al. 2019; Ye and Link 2023). Single stock management can be extended through holistic ecosystem-based fisheries management (EBFM), including ecosystem harvest strategies (Pikitch et al. 2004; Link and Browman 2014; Ye and Link 2023; Morrison et al. 2024). Harvest strategies, typically employed for stocks of target species, can also be employed at an ecosystem-level (Sainsbury et al. 2000; Butterworth 2007; Rayns 2007; Punt 2010; Kaplan et al. 2021; Gilman et al. 2017). One core element of a comprehensive fisheries ecosystem-based harvest strategy is to select and monitor a suite of indicators that track changes in manageable pressures, the state of components of ecosystem structure and dynamics, and management procedure responses intended to reduce pressures to return the ecosystem back near a target state (Pikitch et al. 2004; Jennings 2005; Link 2005; Shin et al. 2010; Gilman et al. 2017; Ye and Link 2023; Morrison et al. 2024). There is an extremely broad range of marine ecosystem state indicators, including on trophodynamics, structure of population assemblages (e.g., functional groups, trophic levels), structure of abiotic habitat components, and ecosystem overfishing (Murawski 2000; Brodziak and Link 2002; Cury et al. 2005; Jennings 2005; Link 2005; Shin et al. 2010; Link and Watson 2019; Link et al. 2020; Pauly et al. 2000; Ye and Link 2023). Ecosystem harvest strategies also include ecosystem-level target and limit reference points that when exceeded guide or trigger predefined management responses by applying a management procedure (also referred to as a harvest control rule or decision rule). Management strategy

evaluation (MSE) simulates the likely performance and tradeoffs of alternative management procedures against management objectives and accounts for the effects of uncertainty (Sainsbury et al. 2000; Punt et al. 2016; Perryman et al. 2025). Ecosystem-level harvest strategies are designed to maintain systems near ecosystem-level target thresholds and to reduce pressures, including fisheries exploitation rates, when a system approaches an ecological ecosystem-level limit threshold where management procedures incorporate a precautionary approach to address uncertainty (Pauly et al. 2000; Sainsbury et al. 2000; Butterworth 2007; Punt 2010; Libralato et al. 2019; Link and Watson 2019; Link et al 2020; Morrison et al. 2024). An ecosystem limit reference point is when an ecosystem becomes overfished by exceeding a tipping point by moving beyond critical key conditions that cause a protracted or permanent regime shift (Dakos et al. 2014; Selkoe et al. 2015). Indices have been developed and thresholds defined and applied to detect ecosystem overfishing (Link and Watson 2019; Link et al. 2020). Defining an ecosystem-level target reference point for a marine ecosystem's state typically aims to create a buffer to stay safely above an ecosystem-level ecological limit threshold, and to achieve an agreed, desirable balance of ecological and socioeconomic objectives, where there are necessary tradeoffs to balance goals for the persistence of the components of biodiversity and for selected ecosystems services and products (Link 2002; Rayns 2007; Selkoe et al. 2015; Gilman et al. 2017; Skirtun et al. 2019; Hunsicker et al. 2022; Morrison et al. 2024).

We benchmarked the state of development, adoption and implementation of ecosystem state indicators and their application in defining ecosystem-level limit and target reference point thresholds, the employment of MSE to simulate the likely performance and tradeoffs of alternative ecosystem-level management procedures, and the use of ecosystem thresholds to guide or trigger ecosystem management procedures in regional marine fisheries management. The study scope was on ecosystem-level harvest strategies, which are a subset of EBFM elements. The scope excluded other EBFM components such as single stock assessments and harvest strategies for target and other commercial species and for bycatch species of conservation concern (Pikitch et al. 2004; Rice 2000; Sainsbury et al. 2000; Link 2005). Approaches by IGOs that have made the most progress can serve as a model for replication by organizations at incipient stages. Our findings identify the state of progress by IGOs in employing these core components of comprehensive ecosystem-level harvest strategies, which supports identifying priorities for mainstreaming broad ecosystem-level and biodiversity considerations in regional fisheries management.

2. METHODS

The study scope includes intergovernmental organizations and arrangements with the competence to establish binding measures for marine capture fisheries and whaling, excluding those with no active fisheries or that have been dissolved. This includes 17 regional fisheries management organizations and arrangements (RFMO/As) and 5 intergovernmental bodies with wider mandates than managing fisheries that also adopt binding measures for marine fisheries. The study scope therefore excludes regional fisheries advisory bodies. These 22 IGOs were discovered and screened for inclusion in the study by reviewing the Regional Fishery Bodies database of the Food and Agriculture Organization of the United Nations (FAO 2025b) and determining the current status of each body (Table 1).

IGOs provide a formal mechanism for fishing States and States in whose jurisdiction common-property fishery resources managed by an IGO occur to meet their international obligation to cooperate to sustainably govern shared living marine resources throughout their distributions to provide for compatible measures in areas within and beyond national jurisdictions (United Nations 1982, 1995; FAO 1995). RFMO/As are a type of regional fishery body that have a mandate to adopt measures that are binding on their members. Unlike

RFMOs, RFMAs have a form of arrangement through which States adopt binding CMMs that do not provide for the establishment of a Secretariat under a governing body of member States (FAO 2025b).

One of the RFMOs, the Inter-American Tropical Tuna Commission (IATTC), serves as the secretariat for both the *Convention for the Strengthening of the Inter-American Tropical Tuna Commission Established by the 1949 Convention Between the United States of America and the Republic of Costa Rica* (the Antigua Convention) and the *Agreement on the International Dolphin Conservation Program* (AIDCP). Convention texts and in-effect binding conservation and management measures of both IATTC and AIDCP were assessed.

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), International Whaling Commission (IWC), Joint Technical Commission of the Maritime Front (Comision Tecnica Mixta del Frente Maritimo) (CTMFM), North Atlantic Salmon Conservation Organization (NASCO) and North Pacific Anadromous Fish Commission (NPAFC), which have wider mandates than managing fisheries, were included as these bodies adopt binding CMMs for marine fisheries. We excluded the Convention on the Conservation and Management of Pollock Resources in the Central Bering Sea (CCBSP) and the International Baltic Sea Fishery Commission (IBFC). There are currently no active CCBSP-managed fisheries and IBSFC was dissolved in 2005 (Gilman et al. 2014; CCBSP 2021; FAO 2025b).

Conservation and management measures (CMMs, also referred to by some IGOs as Resolutions, Recommendations or Decisions), and Scientific Committee reports were compiled between 21 October 2025 and 7 January 2026 for the 17 marine RFMO/As and 5 other IGOs with remits that include but are broader than managing fishery marine resources but are also mandated to adopt binding fisheries management measures. We then submitted inquiries to the 22 IGO secretariats to request their review of a draft of the extracted information from the review of the CMMs and recent scientific committee reports to identify any incorrect or missing information. We received responses from 17 (non-response: NASCO, NPAFC, RECOFI, SEAFO and WCPFC).

We systematically reviewed each IGO's in-force and binding CMMs, reports from each IGO's most recent scientific committee meeting, and other materials available from the IGO's website to identify whether IGOs are exploring or have adopted ecosystem harvest strategy components according to the following six stages of development (which do not require sequential implementation):

- (1) A process is underway to explore candidate ecosystem state indicators that are affected by fishing pressures or that affect fisheries for potential future adoption to define ecosystem-level limit or target thresholds (i.e., reference points for ecosystem-level fisheries overexploitation) or to conduct ecosystem assessments,
- (2) Adopted ecosystem state indicators to be used in the future or are currently being used to define ecosystem-level thresholds,
- (3) A process is underway to define and potentially adopt ecosystem-level limit and/or target reference points that would be used to guide or trigger a management procedure,
- (4) Adopted ecosystem-based limit and/or target reference points for ecosystem structure and dynamics (which can but does not have to be used to guide or trigger a pre-agreed management response defined in an ecosystem-level management procedure),
- (5) A process is underway to analytically explore, such as but not limited to simulation-based MSE modelling, the likely performance and tradeoffs of alternative ecosystem-level management procedures against management objectives (even if a binding management procedure has not yet been adopted), and
- (6) Adopted and are implementing ecosystem-level management procedures, which are responses that are either guided or otherwise are pre-agreed and triggered when ecosystem thresholds are exceeded. Ecosystem management procedures are intended

to reduce fishing pressures to stay safely above an ecosystem limit threshold and return the ecosystem back to near a target state.

We categorized IGOs as being in Stage 1 if they are exploring candidate ecosystem indicators to support the development of publication series that communicate information on the status and trends in components of the state of ecosystems to inform fisheries management, and/or if the IGO is exploring ecosystems indicators to inform ecosystem-level limit or target thresholds or other ecosystem-level harvest strategy components. We only include IGOs in Stage 2 if they have selected ecosystem state indicators for use in defining ecosystem-level thresholds. The intent was to use stage definitions that allow for flexibility in approaches, including for data-limited fisheries that lack data quality for robust quantitative ecosystem and simulation modelling and to allow for accounting for various forms of qualitative information.

We used a supervised machine learning-based decision tree approach (Strobl et al 2009) with ordinal response (Buri and Hothorn 2020; Tutz 2022) to explore potential predictors of IGO stage of development of ecosystem-level harvest strategies. The ordinal response variable comprised 7 levels: stages 1-6 defined above, and stage 0, has not conducted activities of stages 1-6. Details on this conditional inference tree regression modelling approach are provided in Gilman et al. (2023b). The explored model-specific predictors were: year the treaty or agreement was adopted; year entered into force; number of members; category of IGO; focus on fisheries that target salmon, tunas or other species; region of the area of competence; whether the area of competence includes one or both of exclusive economic zones and the high seas; members' mean gross domestic product per capita; and the mean of members' Worldwide Governance Indicators and UN Human Development Index values (further described in Supplemental Material Section S2 and Table S2). The conditional inference tree regressions models were fitted to this dataset using the `partykit` package for R (Hothorn and Zeileis 2015) with a minimum binary split criterion of 0.95, where predictors were included in the best-fit model only if they met this minimum split criterion.

3. RESULTS

Table 2 summarizes the state of development or otherwise adoption of: indicators of ecosystem structure and dynamics used to define ecosystem thresholds, ecosystem-level target and limit reference points, ecosystem-level MSE, and ecosystem-level management procedures. Supplemental Material Table S1 provides additional details. Tables 2 and S1 identify all stages of ecosystem harvest strategy component that IGOs have met, as opposed to identifying only the highest achieved stage.

Two of the 22 assessed IGOs are at relatively more advanced stages of ecosystem-level harvest strategy implementation of exploring and adopting ecosystem thresholds and management procedures. These two IGOs have not sequentially implemented the theoretical order of the stages of development of a comprehensive ecosystem harvest strategy. Seven IGOs are at an incipient stage of exploring ecosystem indicators to be used to communicate information on ecosystem assessments or to define ecosystem reference points (Table 2). The latter includes all tropical tuna RFMOs. While the remaining 13 IGOs have not been exploring or implementing components of ecosystem-level fisheries harvest strategies, most account for various environmental variables and climate indices in individual stock assessment models (Table S1).

NAFO's *Roadmap for an Ecosystem Approach to Fisheries* employs an ecosystem state indicator, the Total Catch Index (TCI), that is also the basis for an adopted ecosystem-level reference point and is used to inform single-stock harvest rate decisions (Supplemental Material Table S1). TCI indicates the total catch of a given functional guild that is sustained by the ecosystem production potential of a NAFO-defined Ecosystem Production Unit (Koen-Alonso et

al. 2019, 2022; NAFO 2024a,b). NAFO estimates TCI using a food web network Ecosystem Production Potential modelling framework with functional guilds as the model nodes to estimate fisheries production potential (Koen-Alonso et al. 2019, 2022). NAFO has adopted the '2TCI Ecosystem Reference Point', defined as double the estimated Total Catch Index or 2TCI, as an ecological ecosystem-level threshold above which there is estimated to be a high risk of ecosystem overfishing. While NAFO has not formally adopted 2TCI as a limit reference point (i.e., it is up to managers' discretion to keep catch levels above it or not), it conceptually represents the maximum level of catch that could be considered sustainable from an ecosystem productivity perspective. The framework currently in place calls for managers to consider it in their harvest decisions if catches exceed 2TCI. As part of the Roadmap, NAFO documents the status and trends of ecosystems through Ecosystem Summary Sheets by monitoring and reporting on several additional ecosystem indicators: (1) trends in ocean climate and oceanographic features, (2) trends and structure of the fish community, and (3) trends in trophic relationships (e.g. diet composition, stomach content weights). If 'significant ecological change' is detected in a system, this triggers discussions for potential scientific advice and fisheries management responses (NAFO 2025).

CCAMLR has adopted and monitors Southern Ocean ecosystem indicators of the effects of fishing mortality of target krill and fish species on life history characteristics of dependent indicator species, and indicators of environmental variables and non-fishery pressures that affect target and dependent species (Table S1) (CCAMLR 2013, 2014, 2022). These indicators are used to guide krill fishery management procedures (such as catch limits, gear restrictions, and temporal and spatial management measures) that account for predicted requirements of dependent predators (but no thresholds for fishery effects on dependent predator populations have been adopted), and the Krill Fishery Management Approach, which employs some elements commonly used in formal MSE processes, accounts for the effects of krill fishing on dependent predator populations (Zhao 2024; CCAMLR 2025a,b).

Of the IGOs that are exploring ecosystem indicators but have not formally adopted indicators for use in defining an ecosystem-level threshold or other component of an ecosystem-level harvest strategy, and/or for use ecosystem status assessments, some have been monitoring a suite of indicators over several years (Table S1). For example, IATTC monitors mean trophic level of the catch, mean trophic level of the modelled community across trophic-level ranges, the Marine Trophic Index, the Fishing-in-Balance index, and Shannon's diversity index, derived from an Ecopath model of the tropical eastern Pacific (IATTC, 2023, 2024, 2025b). WCPFC has been developing and testing candidate indicators of the effects of ecosystem changes on WCPFC fisheries and ecosystems since 2015, and is currently considering five ecosystem indicators: mean condition of catch (using metrics of percent fat content and whole weight and fork length of bigeye, skipjack, and yellowfin tunas), trends in estimated bycatch levels (by gear type, and by set type for tuna purse seine fisheries), redistribution of species, ecosystem traits index, and impacts on food webs (SPC 2022, 2023, 2025). Others are at incipient stages in exploring alternative indicators to potentially be used to inform ecosystem-level thresholds, and several of the IGOs account for variability in various environmental conditions, including due to human-induced climate change, in stock assessments (Supplemental Material Table S1).

Using the conditional inference tree regression modelling approach with four-level ordinal response, we found no informative predictors of the IGO stage of development of ecosystem-level harvest strategies. None of the IGOs were in some of the stages, so we collapsed the 7-level response into a 4-level ordinal response shown in Figure S1. The six continuous predictors are summarized in Figure S2, which shows that many of those predictors are highly correlated with each other, noting that one reason for using a conditional inference tree modelling approach is to account for potential predictor multi-collinearity.

4. DISCUSSION

Seven assessed IGOs are exploring ecosystem indicators to be used to communicate information on ecosystem assessments or to define ecosystem reference points. The tropical tuna RFMOs (IATTC/AIDCP, ICCAT, IOTC, and WCPFC) have been coordinating and working towards harmonizing approaches for integrating ecosystem considerations into fisheries management processes (Fuller et al. 2024), explaining why they are all in stage 1. Three of the four bilateral IGOs have not been conducting components of ecosystem harvest strategies (CTMFM, JNRF, PSC). Bilateral IGOs might defer to national management authorities to conduct scientific activities related to EBFM, including the development of ecosystem harvest strategy components (Gilman et al. 2014). Using conditional inference tree regression modelling, we found no informative institutional, economic, governance, or regional predictors of the stage of ecosystem harvest strategy development among IGOs. This is consistent with an assessment of predictors of IGO adoption of individual vessel and fleetwide bycatch limits (Gilman et al. 2023b). Three of the IGOs at Stage 0 might not be in need of ecosystem harvest strategies: aboriginal subsistence whaling is currently the only whaling operation occurring under IWC jurisdiction; a small West Greenland internal-use fishery is currently the only at-sea fishery for salmon in the North Atlantic conducted by NASCO's Contracting Parties; and up to five vessels have participated in SEAFO fisheries with an annual catch of less than 300t (see footnotes of Table 2).

Two IGOs are at relatively more advanced stages of ecosystem-level harvest strategy implementation of exploring and adopting ecosystem thresholds and management procedures. NAFO uses an indicator for ecosystem overfishing to guide management decisions on catch limits (Koen-Alonso et al. 2019, 2022; NAFO 2024a,b). CCAMLR uses ecosystem indicators of the effects of fisheries to guide krill fisheries management procedures (such as catch limits, gear restrictions, and temporal and spatial management measures), with a management objective that includes sustaining the prey biomass requirements of dependent predators of fishery target species and employs an advisory evaluation framework (the Krill Fishery Management Approach) that accounts for the effects of krill fishing on dependent predator populations (Zhao 2024; CCAMLR 2025a,b).

There are numerous environmental non-governmental organizations and intergovernmental bodies without the competence to establish binding measures for marine capture fisheries (and thus were outside the scope of this study) that are working to mainstream ecosystem considerations in fisheries management (Friedman et al. 2018). This includes, for example, regional fishery advisory bodies (see FAO 2025b for a comprehensive list, and the NEAFC record in Table S1 for an example of ICES' EBFM advice). Target 10 of the Kunming-Montreal Global Biodiversity Framework relate to assimilating biodiversity considerations into fisheries management (CBD 2022). Large Marine Ecosystem commissions such as the Benguela Current Commission apply an ecosystem approach to regional ocean governance (Hamukuaya 2020; Degger et al. 2021). Furthermore, several nations have now adopted broad EBFM policy statements, however, as with IGOs (Lodge et al. 2007; Cullis-Suzuki and Pauly 2010; Gilman et al. 2014; Juan-Jordá et al. 2017; Karim et al. 2020) most nation's transition to ecosystem harvest strategies has been limited (e.g., Pitcher, et al., 2008; Skern-Mauritzen et al., 2016; Hunsicker et al. 2022). For example, Hunsicker et al. (2022) concluded that "ELRPs [ecosystem-level reference points] are not yet commonly required across member countries [of the North Pacific Marine Science Organization, PICES: Canada, China, Japan, Korea, Russia, and U.S.A.]." Skern-Mauritzen et al. (2016) found that ecosystem drivers of fish stock productivity were implemented in tactical management for only 2% of 1,200 assessed marine fish stocks. Fisheries management systems at both national and IGO levels are still predominantly single-stock based. But a few nations have made progress with transitioning to some components of ecosystem harvest strategies. We briefly review examples from Australia,

Thailand and the US of national-level progress in operationalizing components of ecosystem harvest strategies in order to put the IGO results into context. For the southern and eastern scalefish and shark fishery, Australia employs MSE frameworks that account for ecosystem effects and uses performance measures that account for ecosystem considerations (Fulton et al. 2014, 2019). Thailand manages a multispecies, multi-gear fishery in the Gulf of Thailand and Andaman Sea by employing an ecosystem cap on total fishery yield. The total allowable catch limit is defined as 95% of the maximum sustainable yield of aggregated categories of fisheries marine resources (Kulanujaree et al. 2020; Fulton et al. 2022). Through implementation of an EBFM Policy and Road Map, the U.S. has conducted MSE of ecosystem-scale scenarios that informs multispecies and ecosystem-level management (Kaplan et al. 2021; Gove et al. 2023; Harvey et al. 2025). There are also several examples of US fisheries management decision-making processes being informed by ecosystem models (Townsend et al. 2019; Craig and Link 2023). For example, the US Atlantic States Marine Fisheries Commission develops catch advice for Atlantic menhaden (*Brevoortia tyrannus*), which is the target species of a U.S. industrial fishery, by incorporating into a single-species stock assessment model the estimate derived from an ecosystem model of the menhaden fishing mortality rate that sustains biomass of striped bass (*Morone saxatilis*), and other piscivores targeted by U.S. recreational fisheries for which menhaden is an important prey species (Craig and Link 2023).

Several IGOs have adopted criteria used to identify benthic “vulnerable marine ecosystems” (VMEs) and have adopted thresholds that trigger spatial fisheries management responses such as move-on rules and local-scale area closures (FAO 2009; Walmsley et al. 2021; Watling and Auster 2021; Gilman et al. 2023b). These VMEs are sites within communities at seamounts, hydrothermal vents, cold water corals, and sponge fields that are a part of benthic marine ecosystems. Benthic VME indicators, thresholds and management procedures were not categorized as ecosystem harvest strategy components because these IGO VME management systems, which typically identify sites within vulnerable benthic habitat and restrict fishing in those sites, do not account for or manage how demersal fisheries broadly affect the dynamics and structure of entire benthic ecosystems. Given the dynamics of vulnerable benthic marine ecosystems and the life histories of the constituent taxa of their biogenic structural habitat (e.g., long-lived, slow-growing) (Clarke et al. 2016; Cordes et al. 2023), managing bottom fishery impacts on these systems through ecosystem harvest strategy frameworks may not be feasible or optimal. Current frameworks that employ spatial fishery closures and account for network and connectivity considerations among VMEs might be more effective and practical.

Previous assessments concluded that IGOs have been underperforming and require substantial reforms in many areas, including in their implementing an ecosystem approach to fisheries management (Lodge et al. 2007; Cullis-Suzuki and Pauly 2010; Gilman et al. 2014; Juan-Jordá et al. 2017; Karim et al. 2020). Juan-Jordá et al. (2017) found that two of the five tuna RFMOs (WCPFC and IATTC) had made “slight progress” in developing and monitoring ecosystem indicators, and none had progress with other assessed ecosystem harvest strategy components (ecosystem-level reference points and ecosystem management procedures). A decade later, two additional tropical tuna RFMOs are also at stage 1. Other previous assessments focused on EBFM principles, governance structures, precautionary approaches, bycatch management and compliance rather than on operational EBFM frameworks, including the development of ecosystem harvest strategy components. Their shared conclusion was that, although many IGOs articulated commitments to EBFM, implementation was uneven and often failed to deliver effective, enforceable management outcomes. Since those assessments (several of which are now dated), progress has occurred in specific domains, particularly bycatch management, ecological risk assessment, and ecosystem monitoring, partially addressing some previously identified shortcomings. These four previous assessments did not explicitly evaluate progress toward operational ecosystem harvest strategies that link ecosystem indicators to ecosystem-level reference points and management procedures (Lodge et al. 2007;

Cullis-Suzuki and Pauly 2010; Gilman et al. 2014; Karim et al. 2020). Our assessment of global IGOs helps fill this gap, showing that while ecosystem-level harvest strategies remain rare, a small number of IGOs have made tangible progress, expanding upon and hence complementing previous evaluations.

IGOs' mandates are increasingly demanding that they contribute to mainstreaming broad ecosystem-level and biodiversity considerations in regional fisheries management (FAO 2023, 2024, 2025a). Fisheries, as well as historical industrial whaling, have caused broad changes to the structure and functioning of some marine ecosystems, including prey release, trophic cascades and regime shifts, underscoring the need for management that addresses cumulative and indirect effects across food webs and ecosystem components (Springer et al. 2003, Daskalov et al. 2007; Surma et al. 2014; Estes et al. 2016; Gilman et al. 2026). Single-stock management in isolation can fail to achieve both single-stock and ecosystem-wide objectives (Walters et al. 2005; Lindegren et al. 2009). A solution is to extend single stock management through ecosystem harvest strategies – the focus of this study, as well as through other EBFM components, and more broadly through marine ecosystem-based management with cross-sectoral management of marine pressures (Pikitch et al. 2004; Link and Browman 2014).

Similar to stock-specific harvest strategies, ecosystem-wide harvest strategies attempt to maintain ecosystems near target thresholds and to reduce pressures, including from fishing, when a system approaches an ecological limit reference point such as when the entire ecosystem is considered to be overfished (Sainsbury et al. 2000; Butterworth 2007; Punt 2010; Libralato et al. 2019; Link and Watson 2019; Link et al. 2020; Ye and Link 2023; Morrison et al. 2024; Gilman et al. 2026). Ecosystem harvest strategies formally link ecosystem indicators to ecosystem reference points and pre-agreed management responses, analogous to stock-specific harvest strategies but applied at broader ecological scales (Ye and Link 2023; Morrison et al. 2024). This logic aligns with work arguing for harvest strategies that incorporate broader ecosystem dynamics to achieve ecosystem objectives alongside single-species goals (Sainsbury et al. 2000; Butterworth 2007; Punt 2010) and is consistent with more recent syntheses showing how ecosystem approaches can be integrated into conventional fisheries management frameworks (e.g., Kaplan et al. 2021).

Comprehensive ecosystem harvest strategies require an element that assesses and compares the predicted performance of alternative ecosystem management procedures. This can be achieved by applying robust operating models that accurately simulate ecosystem dynamics and structure and account for multiple sources of uncertainty. This can require complex models because they must account for multiple species, trophic interactions, environmental drivers, and attribution of impacts (e.g., Nicholson and Jennings 2004; Bundy et al. 2010; Trenkel et al. 2015). Even single-species MSE has a substantial resource commitment (e.g., Taylor et al. 2025). The development and conditioning of such models is time-intensive, dependent on high-quality data, and computationally demanding. This is why a broad range of alternative approaches for evaluating candidate ecosystem management procedures is needed, including for data-limited fisheries. Beyond data and technical hurdles, factors such as conflicting management objectives, limited capacity for cross-disciplinary modelling, and the need to reconcile ecological precaution with socioeconomic and cultural objectives can be constraints for IGOs to operationalize ecosystem harvest strategies, despite increasing policy mandates (FAO 2023, 2024, 2025a). In this context, operationalizing ecosystem-level harvest strategies requires pragmatic rather than dogmatic approaches, where implementation approaches are aligned with both the data available to conduct analyses and the capacity of the IGO to carry-out and sustain over time the work required to keep these harvest strategies operational.

The two IGOs that have implemented multiple components of ecosystem-level harvest strategies have done so through non-linear and adaptive processes, with indicators, thresholds,

and management responses often developed in parallel or out of sequence. This departure from a model sequential development process might partly reflect the difficulty of inferring causation and interpreting spatiotemporal trends in ecosystem state indicators (Nicholson and Jennings, 2004; Bundy et al. 2010; Trenkel et al. 2015). This suggests that precautionary approaches might be a pragmatic and defensible means of operationalizing ecosystem harvest strategies under uncertainty in practice.

Our findings provide a benchmark of the state of progress by IGOs in transitioning to employing core components of ecosystem harvest strategies, a key part of EBFM. This provides evidence to inform the focus of future efforts to mainstream broad ecosystem-level and biodiversity considerations in regional fisheries management. Approaches by IGOs that have made the most progress developing and implementing ecosystem harvest strategies serve as a model for replication by organizations at incipient stages.

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Table 1. Intergovernmental organizations and arrangements with the competence to establish binding measures for marine capture fisheries and whaling, excluding those with no active fisheries or that have been dissolved.

Intergovernmental organizations and agreements	Acronym
Mandate broader than managing fisheries and fishery resources	
Commission for the Conservation of Antarctic Marine Living Resources	CCAMLR
Joint Technical Commission of the Maritime Front (Comision Tecnica Mixta del Frente Maritimo)	CTMFM
International Whaling Commission	IWC
North Atlantic Salmon Conservation Organization	NASCO
North Pacific Anadromous Fish Commission	NPAFC
Tuna RFMOs	
Commission for the Conservation of Southern Bluefin Tuna	CCSBT
Indian Ocean Tuna Commission	IOTC
Inter-American Tropical Tuna Commission, including the Agreement on the International Dolphin Conservation Program ¹	IATTC and AIDCP
International Commission for the Conservation of Atlantic Tunas	ICCAT
Western and Central Pacific Fisheries Commission	WCPFC
Other RFMO/As	
General Fisheries Commission for the Mediterranean	GFCM
International Pacific Halibut Commission	IPHC
Joint Norwegian-Russian Fisheries Commission	JNRFC
North-East Atlantic Fisheries Commission	NEAFC
Northwest Atlantic Fisheries Organization	NAFO
North Pacific Fisheries Commission	NPFC
Pacific Salmon Commission	PSC
Regional Commission for Fisheries	RECOFI
South East Atlantic Fisheries Organisation	SEAFO
Southern Indian Ocean Fisheries Agreement	SIOFA
South Pacific Regional Fisheries Management Organisation	SPRFMO

¹ The assessment of IATTC included both the *Convention for the Strengthening of the Inter-American Tropical Tuna Commission Established by the 1949 Convention Between the United States of American and the Republic of Costa Rica* (the Antigua Convention) and the *Agreement on the International Dolphin Conservation Program* (AIDCP), as IATTC serves as the secretariat for both.

Table 2. Status of the development and adoption of elements of ecosystem-based harvest strategies for marine fisheries and whaling by intergovernmental bodies. Intergovernmental body acronyms are defined in Table 1.

Ecosystem harvest strategy stages:

- 0 Has not conducted activities of stages 1-6
- 1 Exploring candidate ecosystem state indicators to inform ecosystem-level thresholds or to conduct ecosystem assessments
- 2 Adopted ecosystem state indicators to inform ecosystem-level thresholds
- 3 Exploring ecosystem limit or target thresholds
- 4 Adopted ecosystem limit or target thresholds
- 5 Exploring alternative ecosystem management procedures
- 6 Adopted ecosystem management procedure

Intergovernmental body	Ecosystem harvest strategy stage	Citations
Mandate broader than managing fisheries and fishery resources		
CCAMLR	2, 6	Zhao 2024; CCAMLR 2013, 2014, 2022, 2025a,b
CTMFM	0	Gilardoni 2019; Gilardoni and Sanchez 2021; CTMFM 2025a,b,c,d
IWC ¹	0	IWC 2016, 2022a,b, 2024a,b,c,d
NASCO ²	0	NASCO 2020, 2025a,b,c,d,e
NPAFC	0	NPAFC 2012a,b, 2023, 2024, 2025a,b,c
Tuna RFMOs		
CCSBT	0	CCSBT 2022, 2024, 2025a
IATTC, AIDCP ³	1	Fuller et al. 2025; IATTC 2025a
ICCAT	1	ICCAT 2016, 2025a,b
IOTC	1	Juan-Jorda et al. 2019; IOTC 2019, 2025
WCPFC	1	SPC 2023, 2025; WCPFC 2020, 2025
Other RFMO/As		
GFCM	0	GFCM 2021, 2024, 2025a,b,c
IPHC	1	Hicks et al. 2024; IPHC 2023,2025a,b
JNRFC	0	Howell et al. 2025; JNRFC 2025a,b; Bogstad et al. 2026
NAFO	2, 4	Koen-Alonso et al. 2019, 2022; NAFO 2024a,b

NEAFC	0	ICES 2024; NEAFC 2022, 2024
NPFC	0	NPFC 2020, 2025a,b,c
PSC	0	PSC 2025a,b
RECOFI	0	RECOFI 2025a,b,c,d,e
SEAFO ⁴	0	Voges 2020; SEAFO 2024, 2025a,b, 2026
SIOFA	0	SIOFA 2025a,b,c
SPRFMO	1	SPRFMO 2025a,b,c,d,e

¹ Aboriginal subsistence whaling is currently the only whaling operation occurring under IWC jurisdiction (IWC 2024a,e).

² A small West Greenland internal-use fishery is currently the only at-sea fishery for salmon in the North Atlantic conducted by NASCO's Contracting Parties (NASCO 2022, 2024).

³ The assessment of IATTC included both the Antigua Convention and the Agreement on the International Dolphin Conservation Program (AIDCP).

⁴ Up to five vessels have participated in SEAFO fisheries with an annual catch of less than 300t (Voges 2020).

Supplemental Material

Ecosystem-based harvest strategies in regional fisheries management

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S1. Status of the Development and Adoption of Elements of Ecosystem-based Harvest Strategies for Marine Fisheries and Whaling by Intergovernmental Bodies

Table S1. Status of the development and adoption of elements of ecosystem-based harvest strategies for marine fisheries and whaling by global intergovernmental bodies with a mandate to adopt binding fisheries management measures.

Ecosystem harvest strategy stages:

- 0 Has not conducted activities of stages 1-6
- 1 Exploring candidate ecosystem state indicators to inform ecosystem-level thresholds or to conduct ecosystem assessments
- 2 Adopted ecosystem state indicators to inform ecosystem-level thresholds
- 3 Exploring ecosystem limit or target thresholds
- 4 Adopted ecosystem thresholds
- 5 Exploring candidate ecosystem management procedures
- 6 Adopted ecosystem management procedure

Intergovernmental body	Ecosystem-based harvest strategy stage	Summary
Mandate broader than managing fisheries and fishery resources		
CCAMLR	2, 6	Article II of the Convention on the Conservation of Antarctic Marine Living Resources states the objectives of the Convention, that harvesting and associated activities are to follow three principles of: preventing harvested populations from declining to levels that exceed a point of recruitment impairment; maintaining the ecological relationships between harvested, dependent and related populations; and preventing changes or minimizing the risk of changes in the marine ecosystem that are not reversible over two to three decades (CCAMLR, 1980). CCAMLR monitors various Southern Ocean ecosystem indicators of the effects of krill and finfish fisheries that are then used to guide fishery management measures, including to support predicted requirements of predators that are dependent on fishery target species, within a time frame of preventing irreversible changes (over 20-30 years) to the state of the ecosystem. This is in addition to meeting an objective of maintaining maximum recruitment of individual harvested stocks (Constable et al., 2000; Rayfuse, 2018; CCAMLR, 2014, 2025a). CCAMLR's Ecosystem Monitoring Program was established in 1984 to assess the effects of fishing mortality of target krill and fish species on dependent species (CCAMLR, 2013, 2014, 2025a). The Ecosystem Monitoring Program monitors key life history characteristics of krill- as well as fish-dependent 'indicator' species of seals, penguins, albatrosses and petrels; environmental parameters such as local weather, sea-ice and snow cover; as well as non-fishery pressures such as marine debris, toxins and high pathogenicity avian influenza (CCAMLR, 2013, 2014, 2025a). The selection of indicator dependent predator species was based on the following criteria: have diets that are mainly made up of the identified critical prey species; have broad geographical distributions; represent key ecosystem components; and the understanding of their biology and availability of data were adequate (Constable et al., 2000; CCAMLR, 2013). CCAMLR's Scientific Committee is developing a regular CCAMLR State of Antarctic

Intergovernmental body	Ecosystem-based harvest strategy stage	Summary
		Environment report that will summarize environmental conditions and data relevant to the marine living resources of the convention area (CCAMLR, 2025b). CCAMLR's current Krill Fishery Management Approach to determine the spatial and seasonal allocation of krill catch limits, which was adopted in 2019, is based on three components: regularly updated krill biomass estimates assessed at various scales, harvest rates using CCAMLR decision rules based on biological parameters and projections for krill stock biomass, and a risk assessment framework that accounts for the spatial overlap between krill and predators (Zhao et al., 2024; CCAMLR, 2025a,b,c). In 1991, CCAMLR established a precautionary 'trigger' level limit for krill catch in the southwest Atlantic, which was based on the maximum catch level in this zone prior to 1991 – the trigger limit is not based on evidence of ecosystem-level predicted effects of exceeding the threshold (CCAMLR, 1991). To prevent the fishery from becoming spatially concentrated, in 2009, CCAMLR divided the trigger level into subareas, however, this measure was not renewed in 2024 (CCAMLR, 2023; Zhao et al., 2024; CCAMLR, 2025a,b,c). In summary, CCAMLR has adopted and monitors indicators of the state of the Southern Ocean ecosystem that are sensitive to fishing pressures as well as environmental indicators and non-fishery pressure indicators that affect target and dependent species (CCAMLR, 2013, 2014, 2022). These indicators are used to guide krill fishery management procedures (such as catch limits, gear restrictions, and temporal and spatial management measures) that account for predicted requirements of dependent predators (but no thresholds for fishery effects on dependent predators have been adopted), and the Krill Fishery Management Approach accounts for the effects of krill fishing on dependent predator populations (Zhao, 2024; CCAMLR, 2025a,b).
CTMFM	0	CTMFM has not been exploring or adopted ecosystem state indicators that are affected by fishing pressures or affect fisheries to be used to define ecosystem-level fisheries thresholds, exploring or adopted ecosystem-level thresholds, conducting ecosystem-level fisheries MSE, nor exploring or adopted fisheries ecosystem-level management procedures (Gilardoni, 2019; Gilardoni and Sanchez, 2021; CTMFM, 2025a,b,c,d). CTMFM conducts joint oceanographic research and environmental monitoring within the Treaty area, including research on variability in plankton communities of the Rio de la Plata and its Maritime Front, which could be used to improve the understanding of the effects of this variability on fisheries (CTMFM, 2025a,b,c).
IWC	0	IWC has not been exploring or adopted ecosystem state indicators that are affected by pressures from whaling operations or that affect whaling operations to be used to define ecosystem-level thresholds for whaling operation mortalities, exploring or adopted ecosystem-level thresholds for whaling, conducted ecosystem-level MSE of candidate whaling strategies, nor exploring or adopted ecosystem management procedures for whaling operations (Hunter et al., 2024; IWC, 2016, 2022a,b, 2024a,b,c,d,e). However, aboriginal subsistence whaling is currently the only whaling operation occurring under IWC jurisdiction (IWC, 2024a,e), making the development of ecosystem-based whaling harvest strategies a relatively low priority for IWC. IWC conducts regular 'implementation reviews' of the biology, removals, and status of whale species subject to aboriginal subsistence whaling (e.g., Scordino et al., 2024). An in-progress update of the implementation review for gray whales will account for the effects of variability in ecosystem conditions from heatwaves on gray whale population abundance. The IWC Working Group on Cetaceans and Ecosystem Functioning also considers the "contribution of cetacean to the functioning of healthy ecosystems" and the socioeconomic value of cetaceans (Hunter et al., 2024; IWC 2024d). This includes IWC evaluation of findings of ecosystem modelling, including modeled simulations in the western north Pacific Ocean of predicted ecosystem effects of alternative whale take levels (Tamura et al. 2023).
NASCO	0	NASCO has not been exploring or adopted ecosystem state indicators that are affected by pressures from North Atlantic salmon fisheries or that affect salmon fisheries to be used to define ecosystem-level thresholds, exploring or adopted ecosystem-level

Intergovernmental body	Ecosystem-based harvest strategy stage	Summary
		thresholds, conducting ecosystem-level MSE, nor exploring or adopted fisheries ecosystem management procedures (NASCO, 2020, 2025a,b,c,d). A small West Greenland internal-use fishery is the only at-sea fishery for salmon in the North Atlantic conducted by NASCO's Contracting Parties (NASCO, 2022, 2024a). Scientific advice to NASCO is that north Atlantic salmon fisheries likely have minor or no effects on marine ecosystems (NASCO, 2024b).
NPAFC	0	NPAFC has not been exploring candidate ecosystem state indicators that are affected by pressures from fisheries that capture anadromous species nor ecosystem state indicators of the effects of changes in ecosystem state that affect anadromous fish (and salmon-targeted fisheries outside of the convention area) to be used to define ecosystem-level thresholds for potential employment in ecosystem-level harvest strategies. NPAFC has not been exploring ecosystem-level thresholds for fisheries that target or with incidental catch of anadromous species, has not conducted ecosystem-level fisheries MSE, and has not adopted fisheries ecosystem management procedures (NPAFC 2012a,b, 2023, 2024, 2025a,b,c). The <i>Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean</i> prohibits directed high-seas fishing for North Pacific salmon. The Convention further prohibits the retention of incidentally-caught anadromous north Pacific salmon and steelhead trout, and requires fisheries for non-anadromous fish to minimize the incidental catch of anadromous fish (NPAFC, 1992). NPAFC supports cooperative research to identify ecosystem-level mechanisms that affect anadromous populations of north Pacific salmon and steelhead trout and affect salmon-targeted fisheries (outside of the convention area) (NPAFC, 2022; 2023). This includes assessing impacts of changes in ocean conditions, including from climate change, on anadromous populations (e.g., McKinnell et al., 2024; NPAFC, 2010, 2024; Stanbury 2025). This enables NPAFC to forecast the abundance and distributions of north Pacific salmon and steelhead trout populations (NPAFC, 2022; 2023), information needed to inform fisheries management decisions.
Tuna RFMOs		
CCSBT	0	CCSBT has not been exploring or adopted ecosystem state indicators that are affected by fishing pressures or affect fisheries to be used to define ecosystem-level thresholds, exploring or adopted ecosystem-level thresholds, conducting ecosystem-level fisheries MSE, nor exploring or adopted fisheries ecosystem-level management procedures (CCSBT, 2022, 2025a). CCSBT's Ecologically Related Species Working Group and Technical Ecologically Related Species Working Group are the primary bodies that discuss species associated and dependent on southern bluefin tuna (CCSBT, 2024a). CCSBT has adopted a Multi-Year Seabird Strategy, which includes an action plan, developed by the technical working group (CCSBT, 2024b) and a Spatially Explicit Fisheries Risk Assessment has been conducted for albatross and petrel bycatch in surface longline fisheries by CCSBT's participating members (CCSBT, 2025b). CCSBT's Ecologically Related Bycatch Strategy addresses impacts of southern bluefin tuna fisheries on ecologically related species other than seabirds, and includes an action to explore addressing ecosystem impacts of fisheries (CCSBT, 2025c).
IATTC, AIDCP ¹	1	The <i>IATTC Strategic Science Plan 2026–2030</i> includes a workplan to support the operationalization of an ecosystem approach to fisheries management by developing ecosystem-advice products, including an EcoCard for the eastern Pacific Ocean, and a complementary Ecosystem Status Assessment (see details in Fuller et al. 2024). The workplan outlines activities to identify screening criteria for: defining ecoregions, developing candidate ecosystem indicators, defining draft ecoregions and pilot projects to assess candidate ecosystem indicators at an ecoregion scale, and, where appropriate, developing and recommending decision rules for consideration by the Commission (Fuller et al., 2025; IATTC, 2025a). IATTC is currently at a stage of the workplan of exploring the delineation of potential ecoregions and developing preliminary criteria for defining ecoregions and candidate indicators for use in the EcoCard. While IATTC is not yet at the stage of developing

Intergovernmental body	Ecosystem-based harvest strategy stage	Summary
		specific candidate ecosystem indicators that could potentially inform ecosystem-level thresholds, the process that is now underway at IATTC includes actions in the workplan to develop ecosystem indicators (planned to occur during Phase 3 of the workplan in 2026-2027, Fuller et al., 2024). Since 2003, IATTC has included a section on ecosystem considerations in its annual <i>Fishery Status Report</i>, which is presented to the Ecosystem and Bycatch Working Group or the Scientific Advisory Committee to inform management discussions by accounting for ecosystem effects of eastern Pacific Ocean tuna fisheries (Fuller et al., 2024; IATTC, 2024). IATTC also routinely reports a suite of ecosystem and environmental indicators. Ecosystem indicators include mean trophic level of the catch, mean trophic level of the modelled community across trophic-level ranges, the Marine Trophic Index, the Fishing-in-Balance index, and Shannon's diversity index, which are derived from an Ecopath ecosystem model of the tropical eastern Pacific. Environmental indicators include the Oceanic Niño Index, the Pacific Decadal Oscillation index, sea surface temperature, and chlorophyll-a concentration (IATTC, 2023, 2024, 2025b). In line with IATTC's workplan on operationalizing an ecosystem approach to fisheries management, these indicators may be re-evaluated in the future using defined screening criteria to assess their suitability for potential inclusion in an EcoCard.
ICCAT	1	ICCAT is actively exploring candidate ecosystem indicators and approaches to ecosystem thresholds. The ICCAT Sub-Committee on Ecosystems and Bycatch (SC-ECO) agreed in 2016 to develop an indicator-based ecosystem report card (EcoCard, ICCAT, 2016, 2022). SC-ECO has received and discussed numerous candidate environmental indicators (both ecosystem state indicators that are affected by fishing pressures and that affect fisheries) for the EcoCard as well as recommendations on the process to develop ecosystem-level reference points (Juan-Jorda et al., 2018b, 2019; Alvarez-Berastegui, 2020; Andonegi et al., 2020; Wolfaardt et al., 2020; Zudaire et al., 2020; Carruthers et al., 2024; Kell et al., 2024; Alvarez-Berastegui et al., 2025; Bell and Wade, 2025; Carruthers and Taylor, 2025; ICCAT, 2025a; Melendez-Artega et al., 2025). The SC-ECO has adopted a workplan to continue work on ecosystem approach tasks, including the EcoCard, and the Standing Committee on Research and Statistics is developing a SCRS Science Strategic Plan 2026-2031, which like the now expired 2015-2020 plan is likely to continue to plan for research to enable providing scientific advice on the ecosystem effects of ICCAT fisheries (ICCAT, 2025a,b).
IOTC	1	IOTC (2019) noted criteria for developing ecosystem indicators and numerous candidate indicators have been proposed to and considered by the Working Group on Ecosystems and Bycatch (e.g., IOTC, 2019, 2025). IOTC has delineated nine candidate ecoregions and is now assessing their suitability as a spatial framework for developing ecosystem-based advisory products. Ecosystem models have been developed for some of these ecoregions as well as for the regional tropical Indian Ocean, which will potentially guide the development of ecosystem indicators which in turn could inform ecosystem-level thresholds (Idarraga-Garcés et al., 2024; Juan-Jorda et al., 2024; Amate et al., 2025; IOTC, 2024, 2025). The WPEB Program of Work for 2026 to 2030 includes development and testing of ecosystem report cards and developing a plan for an Ecosystem Approach to Fisheries (Appendix XV in IOTC, 2025).
WCPFC	1	WCPFC has been developing and testing candidate indicators of the effects of ecosystem changes on WCPFC fisheries and ecosystems since 2015 (Allain et al., 2015; WCPFC, 2015, 2020). WCPFC is currently considering six ecosystem indicators for inclusion in an Ecosystems and Climate Change Indicator Report Card: mean condition of catch (using metrics of percent fat content and whole weight and fork length of bigeye, skipjack, and yellowfin tunas), trends in estimated bycatch levels (by gear type, and by set type for tuna purse seine fisheries), redistribution of species, ecosystem traits index, impacts on food webs, and median phytoplankton size, this in addition to several candidate climatological, oceanographic feature and fishery-related indicators (SPC, 2022, 2023, 2025; WCPFC, 2025). WCPFC's Scientific Committee and Science Service Provider (the Pacific Community, SPC) employ nine criteria for developing and evaluating candidate ecosystem indicators (SPC, 2025). Once adopted, these ecosystem state indicators could potentially be used to inform ecosystem-level thresholds.

Intergovernmental body	Ecosystem-based harvest strategy stage	Summary
Other RFMO/As		
GFCM	0	GFCM has not been exploring or adopted ecosystem state indicators that are affected by fishing pressures or that affect fisheries to be used to define ecosystem-level thresholds, exploring or adopted ecosystem-level thresholds, conducting ecosystem-level MSE, nor exploring or adopted fisheries ecosystem-level management procedures (GFCM, 2021, 2022, 2024, 2025a,b,c). The most current SAC meeting report and SAC programme of work for 2025-2027 do not identify planned activities to transition to components of ecosystem-level harvest strategies (GFCM, 2025a,b). However, the GFCM Scientific Advisory Committee on Fisheries is tasked with providing advice on “the sustainable management of fisheries and ecosystems...as well as on issues associated with the ecosystem approach to fisheries” and GFCM's 2030 Strategy includes employing multispecies and ecosystem-level assessments (GFCM, 2021, 2022). GFCM has also prioritized exploring the integration of the effects of climate change into stock-specific reference points and MSE (GFCM, 2025d). GFCM is currently focusing on exploring methods to incorporate environmental variables and climate indices into European sprat stock assessment models (GFCM, 2025d).
IPHC	1	IPHC plans to conduct research on how management measures for the Pacific halibut (<i>Hippoglossus stenolepis</i>) stock could respond to productivity regime shifts (paragraph 26d in IPHC 2025b) and is therefore exploring the potential use of ecosystem state indicators to define ecosystem-level thresholds (that in this case would be applied in a single-stock management procedure). IPHC adopted a harvest strategy policy for the Pacific halibut stock, which accounts for the effects of variability in various environmental conditions on stock productivity (IPHC, 2025a). IPHC does not currently define ecosystem state indicators or use ecosystem-level thresholds or ecosystem-level management procedure in the stock-specific harvest strategy (IPHC, 2025a). The IPHC Pacific halibut management strategy evaluation process similarly accounts for effects of variability in environmental conditions that affect stock productivity, including average recruitment and the spatial distribution of spawning biomass and recruitment (IPHC, 2023a, Hicks et al., 2024). These environmental indicators are included as inputs to MSE models to simulate the likely performance of alternative management procedures against IPHC's management objectives, as well as to define the Pacific halibut stock-specific reference points and management procedures defined in the harvest strategy policy. The IPHC <i>Biological and Ecosystem Science Research Program</i> objectives include understanding the effects of environmental conditions on Pacific halibut life-history characteristics and accounting for the effects of environmental conditions in stock assessment models (IPHC, 2025c). This is reiterated as a stock assessment research priority in the current <i>IPHC Five-Year Program of Integrated Research and Monitoring</i> (identifying explanatory environmental predictors of regional ocean productivity and Pacific halibut recruitment, IPHC, 2023b).
JNRFC	0	JNRFC has not been exploring or adopted candidate ecosystem state indicators that are affected by fishing pressures nor indicators of the effects of changes in ecosystem state that affect fisheries to be used to define ecosystem-level thresholds, exploring or adopted ecosystem-level thresholds, conducting ecosystem-level fisheries MSE, nor exploring or adopted fisheries ecosystem-level management procedures (Howell et al., 2025; JNRFC 2025a,b; Bogstad et al., 2026a). JNRFC conducts annual joint ecosystem surveys and through its Joint Russian-Norwegian Arctic Fisheries Working Group accounts for environmental and ecosystem conditions and species interactions on commercial fish stocks of the Barents and Norwegian Seas (Eriksen et al., 2024; Howell et al., 2025; JNRFC, 2025b). JNRFC restricts Barents Sea capelin fisheries to the period of spawning migration (from January to April) and has a minimum landing size in place, concentrating fishing mortality on mature, spawning age classes, in order to support stock management objectives (Bogstad et al., 2026b), which supports prey availability to predators of fishes, birds, and marine mammals (Hjermann et al., 2010; Bogstad et al., 2026a).

Intergovernmental body	Ecosystem-based harvest strategy stage	Summary
NAFO	2, 4	NAFO's <i>Roadmap for an Ecosystem Approach to Fisheries</i> employs an ecosystem state indicator, the Total Catch Index (TCI), that is also the basis for an adopted ecosystem-level reference point and is used to inform single-stock harvest rate decisions. TCI indicates the total catch of a given functional guild that is sustained by the ecosystem production potential of a NAFO-defined Ecosystem Production Unit (Koen-Alonso et al., 2019, 2022; NAFO, 2024a,b). NAFO estimates TCI by applying a food web network Ecosystem Production Potential modelling framework with functional guilds as the model nodes to estimate fisheries production potential (Koen-Alonso et al., 2019, 2022). NAFO has adopted the '2TCI Ecosystem Reference Point', defined as twice the estimated Total Catch Index or 2TCI, as an ecological ecosystem-level threshold above which there is estimated to be a high risk of ecosystem overfishing. While NAFO has not formally adopted 2TCI as a limit reference point (i.e., it is up to managers' discretion to keep catch levels above it or not), it conceptually represents the maximum level of catch that could be considered sustainable from an ecosystem productivity perspective. The framework currently in place calls for managers to consider it in their harvest decisions if catches exceed 2TCI. The NAFO Scientific Council defines total catch between 1 and 2 TCI as intermediate risk of ecosystem overfishing and <1 TCI as low risk (NAFO, 2024b). While the 2TCI introduces a concept akin to an ecosystem-level limit reference point, NAFO has yet to consider the concept of a target ecosystem-level reference point. The Roadmap currently does not explicitly account for socioeconomic or cultural considerations (Koen-Alonso et al., 2019, 2022; NAFO, 2022, 2024a,b), but these considerations are core to the internal discussions and positions taken by NAFO's Contracting Parties. As part of the Roadmap, NAFO documents the status and trends of ecosystems through Ecosystem Summary Sheets by monitoring and reporting on several additional ecosystem indicators: (1) trends in ocean climate and oceanographic features, (2) trends and structure of the fish community, and (3) trends in trophic relationships (e.g. diet composition, stomach content weights). The Ecosystem Summary Sheets are typically updated every 5 years unless changes in a system warrants an earlier update (NAFO, 2025). If 'significant ecological change' is detected in a system, this triggers discussions for potential scientific advice and fisheries management responses (NAFO, 2025).
NEAFC	0	NEAFC has not been exploring or adopted candidate ecosystem state indicators that are affected by fishing pressures nor indicators of the effects of changes in ecosystem state that affect fisheries to be used to define ecosystem-level thresholds, exploring or adopted ecosystem-level thresholds, conducting ecosystem-level fisheries MSE, nor exploring or adopted fisheries ecosystem-level management procedures (ICES, 2024; NEAFC, 2022, 2024). NEAFC obtains all scientific advice exclusively from the International Council for the Exploration of the Seas (ICES) (NEAFC, 2022). In response to a request from NEAFC on how best to monitor and assess ecosystem based objectives in the context of NEAFC's intentions to establish higher-level biodiversity and ecosystem objectives, ICES produced a report providing advice on alternative approaches to implement an Ecosystem Approach to Fisheries Management (EAFM), identifying the relative complexity and data needs of each alternative approach, and clarifying the benefits of interpreting NEAFC's higher-level objectives and developing operational objectives for an EAFM (ICES, 2024 and see paragraphs 9.91 to 9.98 in NEAFC 2024).
NPFC	0	The Commission and Scientific Committee have not been exploring or adopted ecosystem state indicators that are affected by fishing pressures or affect fisheries to be used to define ecosystem-level thresholds, exploring or adopted ecosystem-level thresholds, conducting ecosystem-level fisheries MSE, nor has the Commission been exploring or adopted fisheries ecosystem-level management procedures (NPFC, 2020, 2025a,b,c). While NPFC has not been exploring ecosystem state indicators with an explicit aim to inform defining ecosystem-level limit or target thresholds, NPFC has been exploring ecosystem indicators to provide "auxiliary information and ecosystem context" to inform fisheries management decisions (Rooper and Boldt, 2025). The NPFC Scientific Committee and subsidiary bodies have been exploring candidate ecosystem state and other indicators that affect NPFC bottom fishes, including physical environment, prey, predation, and dynamics (e.g., growth, condition, biomass) indicators (Rooper and Boldt, 2025). At the 2025 meeting of the

Intergovernmental body	Ecosystem-based harvest strategy stage	Summary
		NPFC Small Scientific Committee on Bottom Fish and Marine Ecosystems, an information paper presented candidate indicators that affect the productivity of NPFC bottom fish stocks (Rooper and Boldt, 2025). A literature review was also submitted to the NPFC Scientific Committee that identified potential ecosystem and environmental indicators for Japanese sardine (<i>Sardinops melanisticta</i>), including temperature, climate variables and currents (Rooper et al., 2025). Some ecosystem considerations, including indices of environmental conditions and climate cycles, were included in simulations conducted by the Small Scientific Committee on Pacific Saury for the development of a harvest control rule for Pacific saury (<i>Cololabis saira</i>) (Dai and Rooper, 2023; NPFC, 2024a). NPFC recognizes the importance of an ecosystem approach to fisheries management through its Convention and Scientific Committee discussions (NPFC, 2012, 2020, 2025a). The NPFC Research Plan and the current Work Plan, both for the period 2024-2028, include several activities related to an ecosystem approach to fisheries management (NPFC, 2024b,c) and the 2025-2029 Five-Year Work Plan of the Small Scientific Committee on Bottom Fish and Marine Ecosystems includes an activity to assess the ecosystem impacts of fisheries (NPFC 2025d).
PSC	0	PSC has not been exploring nor adopted ecosystem state indicators that affect salmon populations or that are affected by fishing pressures to be used to define ecosystem-level thresholds, exploring or adopted ecosystem-level thresholds, conducting ecosystem-level fisheries MSE, nor exploring or adopted fisheries ecosystem-level management procedures (PSC, 2025a,b). PSC works to account for the effects of variability in environmental conditions, including from climate change, in PSC's Pacific salmon assessments and management frameworks (see Tables 6 and 7 in PSC, 2023).
RECOFI	0	RECOFI has not been exploring or adopted candidate ecosystem state indicators that are affected by fishing pressures nor indicators of the effects of changes in ecosystem state that affect fisheries to be used to define ecosystem-level thresholds, exploring or adopted ecosystem-level thresholds, conducting ecosystem-level fisheries MSE, nor exploring or adopted fisheries ecosystem-level management procedures (RECOFI, 2023a,b, 2024, 2025a,b,c,d). RECOFI's Working Group on Fisheries has been prioritizing stock assessments of priorities species, minimum data reporting, IUU fishing and the impacts of marine pollution and ecosystem changes, and climate change on fisheries, aquaculture and the marine environment of the RECOFI area (RECOFI, 2023, 2024, 2025a,b,c,d). RECOFI is contributing to the management and implementation of a FAO/GEF project in the Red Sea Large Marine Ecosystem that includes an objective of improving ecosystem-based fisheries management by developing regional fisheries management plans to support regional-level stock management and regional coordination of fisheries monitoring, control and surveillance frameworks (RECOFI, 2025e).
SEAFO	0	SEAFO has not been exploring or adopted candidate ecosystem state indicators that are affected by fishing pressures nor indicators of the effects of changes in ecosystem state that affect fisheries to be used to define ecosystem-level thresholds, exploring or adopted ecosystem-level thresholds, conducting ecosystem-level fisheries MSE, nor exploring or adopted fisheries ecosystem-level management procedures (Voges, 2020; SEAFO, 2024, 2025a,b, 2026). The SEAFO convention calls for "ensuring the long-term conservation and sustainable use of all living marine resources in the South East Atlantic Ocean, and to safeguarding the environment and marine ecosystems in which the resources occur" (SEAFO, 2001). Fishing effort under SEAFO has been minimal: Since 2013 longline and pot fisheries have been conducted in the SEAFO convention area, with total annual catches of less than 300 tonnes (Voges 2020).
SIOFA	0	Based on the most recent Scientific Committee meeting report and the current Scientific Committee Workplan, SIOFA has not been exploring or adopted ecosystem state indicators that are affected by fishing pressures or affect fisheries to be used to define ecosystem-level thresholds, exploring or adopted ecosystem-level thresholds, conducting ecosystem-level fisheries MSE, nor exploring or adopted fisheries ecosystem-level management procedures (SIOFA, 2025a,b). SIOFA published the first SIOFA Ecosystem Summary annual report in 2023. These reports are intended to describe known effects of SIOFA fisheries on ecosystems in the SIOFA Area. The most recent <i>SIOFA Ecosystem Summary 2025</i> explains that,

Intergovernmental body	Ecosystem-based harvest strategy stage	Summary
		"no information is currently available on the trophic interactions or other larger ecosystem effects of SIOFA fisheries" (SIOFA Secretariat, 2025).
SPRFMO	1	In 2025, SPRFMO's Scientific Committee endorsed the development of an Ecosystem Status Profile that would describe indicators of ecosystem status as well as indicators for "drivers of change, and interactions among species, fisheries, and the environment" for the SPRFMO Area and adjacent EEZs (SPRFMO, 2025a,c,d). The Ecosystem Status Profile is under development and will be considered for endorsement by the Commission in 2026. An ecosystem status overview is included in the Scientific Committee's Multiannual Workplan, tasked to the Ecosystem Working Group (SPRFMO, 2025a). Several indicators are being considered under eight high-level categories of environmental and oceanographic pressures, lower trophic levels, status of key species, fisheries and human uses, ecological and trophic dynamics, vulnerability and risk assessment, ecosystem services, and management responses (SPRFMO, 2025d). SPRFMO has not adopted ecosystem state indicators that are affected by fishing pressures or affect fisheries to be used to define ecosystem-level thresholds, exploring or adopted ecosystem-level thresholds, conducting ecosystem-level fisheries MSE, nor exploring or adopted fisheries ecosystem-level management procedures (SPRFMO, 2025a,c,d,e). The SPRFMO Scientific Committee includes a Climate Change Task Team, which provides guidelines on accounting for climate change in stock assessments and management advice (SPRFMO, 2025a,b,f). The Climate Change Task Team fills an advisory and methodological role, providing guidance and identifying research needs, which are incorporated into the Scientific Committee's multiannual workplan.

¹ The assessment of IATTC included both the *Convention for the Strengthening of the Inter-American Tropical Tuna Commission Established by the 1949 Convention Between the United States of American and the Republic of Costa Rica* (the Antigua Convention) and the *Agreement on the International Dolphin Conservation Program* (AIDCP), as IATTC serves as the secretariat for both.

S2. PREDICTORS OF STAGE OF ECOSYSTEM HARVEST STRATEGY DEVELOPMENT

We used a supervised machine learning-based decision tree approach with ordinal response to explore potential predictors of the stage of intergovernmental bodies' development of ecosystem harvest strategies. The following predictors were explored:

- Category of: tuna-RFMO, non-tuna RFMO, RFMA, remit broader than an RFMO/A;
- Focus on fisheries that target salmon, tunas or other species;
- Zones of area of competence of: national waters, areas beyond national jurisdiction, or both
- Region of area of competence of: Atlantic Ocean (including Mediterranean and Black Seas), Pacific Ocean, Indian Ocean, Southern Ocean, Global;
- Number of current members;
- Members' mean gross domestic product (GDP) per capita in 2025 or otherwise most recent year available (from United Nations 2025, except European Union and Taiwan from IMF 2025, and Faroe Islands, Greenland, and French overseas territories from World Bank 2025a);
- Members' mean of absolute values (0 to 100 scale) of six Worldwide Governance Indicators in 2024 (World Bank 2025b,c);
- Members' mean United Nations Human Development Index value in 2023 (UNDP, 2025).
- Year the treaty or agreement that established the IGO first entered into force (not of a predecessor treaty or agreement, if relevant); and
- Year of adoption of the treaty or agreement (of predecessor, if relevant).

The latter two predictors are correlated with national compliance with aspects of the FAO (1995) Code of Conduct for Responsible Fisheries (Pitcher et al., 2009).

Table S2 identifies the predictors that were explored in a supervised machine learning-based decision tree model with ordinal response to explore which of the predictors explain IGO stage of development of ecosystem-level harvest strategies. The World Bank Worldwide Governance Indicators were not reported for Curaçao or Faroe Islands (World Bank, 2025b,c) and the United Nations Human Development Index did not report values for Cook Islands, Curaçao, Faroe Islands, Greenland, Monaco, Niue, or Taiwan (UNDP. 2025).

Table S2. Predictors of IGO stage of development of ecosystem-based harvest strategies that were explored through a supervised machine learning-based decision tree.

IGO	IGO Category	Focus	Zones of area of application	Region ^a	Region detailed ^b	No. members	Mean GDP per capita	Mean Worldwide Governance Indicators value	Mean UN Human Development Index value	Year entered into force ^d	Year adopted ^e
AIDCP	non-tuna RFMO	Tuna	Both	PO	EPO	14	16,275	50	0.77	1999	1992
CCAMLR	broader remit	Other	High seas	SO	SO	27	34,453	68	0.88	1982	1980
CCSBT	tuna RFMO	Tuna	Both	SO	SO	8	35,088	73	0.88	1994	1993
CTMFM	non-tuna RFMO	Other	EEZ	AO	SWAO	2	18,492	65	0.86	1973	1973
GFCM	non-tuna RFMO	Other	Both	AO	MBS	24	30,489	56	0.83	1952	1949
IATTC	tuna RFMO	Tuna	Both	PO	EPO	21	21,378	58	0.80	2010	1949
ICCAT	tuna RFMO	Tuna	Both	AO	AO	55	15,662	53	0.74	1969	1966
IOTC	tuna RFMO	Tuna	Both	IO	IO	29	13,999	52	0.73	1996	1993
IPHC	non-tuna RFMO	Other	Both	PO	NEPO	2	67,612	77	0.94	1924	1923
IWC	broader remit	Other	Both	global	global	88	27,206	61	0.79	1948	1935
JNRFC	RFMA	Other	Both	AO	BNS	2	50,871	63	0.90	1975	1975
NAFO	non-tuna RFMO	Other	Both ^c	AO	NWAO	13	47,133	70	0.90	1979	1949
NASCO	broader remit	Salmon	Both	AO	NAO	8	58,111	74	0.93	1983	1982
NEAFC	non-tuna RFMO	Other	Both	AO	NEAO	6	55,397	73	0.93	1982	1959
NPAFC	broader remit	Salmon	High seas	PO	NPO	5	43,675	69	0.91	1993	1952
NPFC	non-tuna RFMO	Other	High seas	PO	NEPO	9	35,445	67	0.86	2015	1952
PSC	non-tuna RFMO	Salmon	Both	PO	NEPO	2	67,612	77	0.94	1985	1930
RECOFI	non-tuna RFMO	Other	Both	IO	PGGO	8	30,593	54	0.85	2001	1999
SEAFO	non-tuna RFMO	Other	High seas	AO	SEAO	6	21,459	64	0.80	2003	2001
SIOFA	non-tuna RFMO	Other	High seas	IO	SIO	11	30,821	70	0.88	2012	2006
SPRFMO	non-tuna RFMO	Other	High seas	PO	SPO	17	30,403	64	0.84	2012	2009
WCPFC	tuna RFMO	Tuna	Both	PO	WCPO	26	22,602	66	0.78	2004	2000

^a AO=Atlantic Ocean, Mediterranean Sea and Black Sea; PO=Pacific Ocean, IO=Indian Ocean

^b Region: AO=Atlantic Ocean; BNS=Barents and Norwegian Seas; EPO=eastern Pacific Ocean; IO=Indian Ocean; MBS=Mediterranean and Black Seas; NAO=north Atlantic Ocean; NEAO=northeast Atlantic Ocean; NEPO=northeast Pacific Ocean; NPO=north Pacific Ocean; NWAO=northwest Atlantic Ocean; PGGO=Persian Gulf and Gulf of Oman; SEAO=southeast Atlantic Ocean; SIO=southern Indian Ocean; SO=Southern Ocean; SPO=south Pacific Ocean; SWAO=southwest Atlantic Ocean; WCPO=western and central Pacific Ocean.

^c The NAFO Regulatory Area applies only to areas beyond national jurisdiction (ABNJ, i.e., the high seas), however, the convention area includes both EEZs and ABNJ

^d Year the convention or agreement that established the IGO first entered into force (not of a predecessor treaty or agreement, if relevant)

^e Of predecessor treaty or agreement, if relevant

Figure S1 shows a summary of the 4-level ordinal response variable used as the ordinal response in the conditional inference tree regression modelling approach to explore potential predictors of IGO stage of development of ecosystem-level harvest strategies. For IGOs that have achieved more than 1 ecosystem harvest strategy stage, we used the highest stage. The six continuous predictors are summarized in Figure S2, which shows that many of those predictors are highly correlated with each other and one reason for using a conditional inference tree modelling approach to account for potential predictor multi-collinearity.

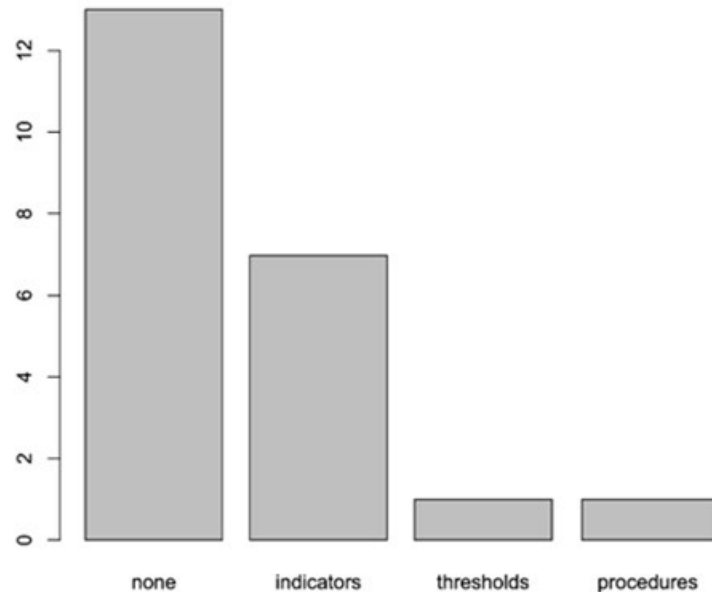


Figure S1. Summary of the 4-level ordinal response variable frequencies after collapsing the original 7-level response for IGO stage of development of ecosystem-level harvest strategies.

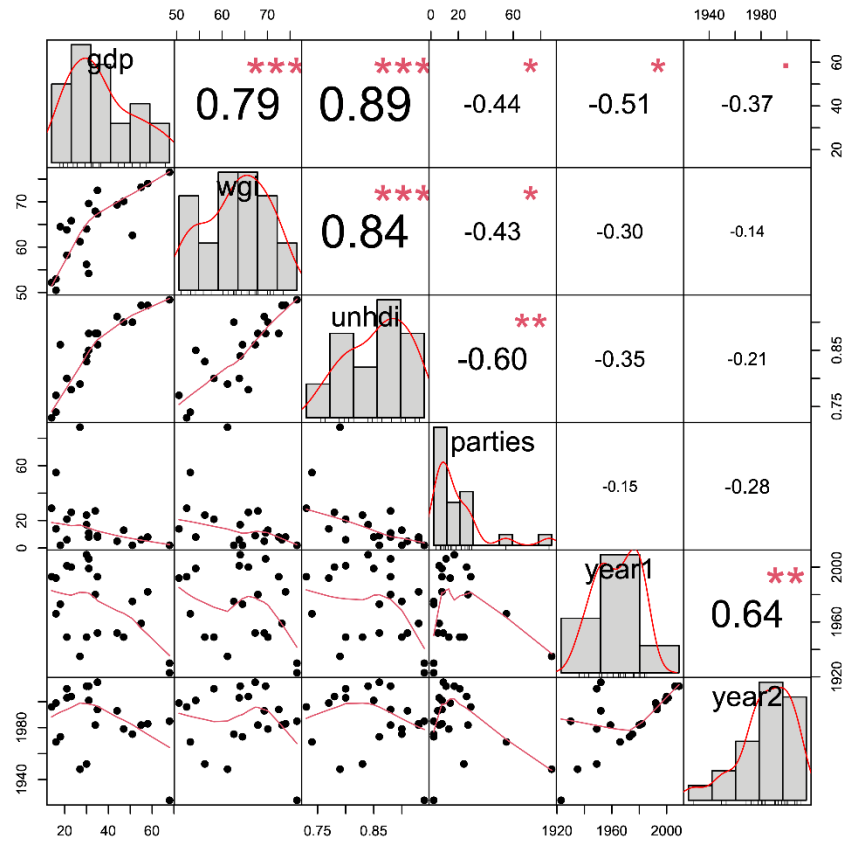


Figure S2. Pearson correlation matrix plot of the continuous predictors included in the ordinal regression tree model visualized using the PerformanceAnalytics package for R (Peterson and Carl 2024). Panels above the diagonal show the (absolute) value of the correlation plus the significant correlation coefficients shown by the stars. Panels below the diagonal show the bivariate scatterplots with a fitted loess-smoothed line. gdp = mean Gross Domestic Product per capita, wgi = mean of Worldwide Governance Indicator absolute values, unhdi = mean United Nations Human Development Index value, parties = Number of contracting parties, year1 = year adopted (of predecessor treaty or agreement, if relevant), year2 = year entered into force.

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