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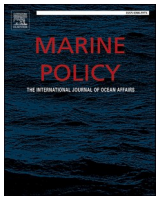

Full length article

Identifying future steps to allow an efficient fisheries management advice among scientific committees in regional fisheries management organizations

Maria Grazia Pennino [a,*], Santiago Cerviño [b], Marta Cousido-Rocha [b], Ruth Fernandez [c], Diana Gonzalez-Troncoso [b], Fernando Gonzalez [b], Beatriz Guijarro [d], José Luis Pérez Gil [e], Maria Soto [e]

[a] Instituto Español de Oceanografía (IEO, CSIC), Centro Oceanográfico de Madrid, C. del Corazón de María, 8, Madrid 28002, Spain
[b] Instituto Español de Oceanografía (IEO, CSIC), Centro Oceanográfico de Vigo, Subida a Radio Faro 50-52, Vigo, Pontevedra 36390, Spain
[c] International Council for the Exploration of the Sea (ICES), H. C. Andersens Boulevard 44-46, Copenhagen V DK 1553, Denmark
[d] Instituto Español de Oceanografía (IEO, CSIC), Centro Oceanográfico de Baleares, Muelle de Poniente, s/n, Palma 07015, Spain
[e] Instituto Español de Oceanografía (IEO-CSIC), Centro Oceanográfico de Málaga, Puerto Pesquero s/n, Fuengirola, Málaga 29640, Spain

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ABSTRACT

Fish stocks around the world are managed by regional fisheries management organizations (RFMOs) with regulatory authority which usually have differences in the internal processes to provide scientific advice. To improve the cooperation between the different RFMOs, and contribute to the reinforcement of regional fisheries assessment bodies (RFABs), we compare the work procedures from the main organizations that evaluate most of the commercial stocks of interest European fleets. The comparison is made in terms of stock assessment methods, decision-making, biological reference points, transparency, stakeholder's involvement and implementation of ecosystem-based fisheries management (EBFM) and precautionary approach (PA). Key scientific experts from each RFMO and RFAB have been involved in this analysis, identifying crucial future steps to enhance collaboration for efficient fisheries management advice.

1. Introduction

The growing interest in the oceans is giving rise to new and renewed global governance efforts targeting ocean problems in the areas of food production, biodiversity conservation, climate change, pollution and marine stocks overexploitation [2]. In particular, marine fish stocks play an important role in the livelihood of millions of people and the economic income and social role from the fishing sector is essential for many countries. However, nowadays almost 35.4 % of worldwide fished stocks are already considered overfished [18].

Fish stocks exploited at international levels are primarily managed by Regional Fisheries Management Organizations (RFMOs), which are formed through agreements between governments and state parties. These organizations are tasked with collecting fisheries statistics, assessing resources, making management decisions and monitoring activities, playing a critical role in facilitating intergovernmental cooperation in fisheries management [16]. RFMOs can be viewed as institutions that exist as the interface between the goals of global agreements, fisheries and the diverse interests of different countries [28]. Each RFMO manages stocks distributed over a specific geographical area or a particular type of species, such as the highly migratory species like tuna and tuna-like species [7]. RFMOs usually have a Commission, a Scientific Committee and various subsidiary bodies such as technical compliance committee and secretariat body. The Commission, composed of member states, has the main task of deliberate decisions to manage fish stocks [26,46]. These decisions are supported by the scientific advice provided by the Scientific Committee, which addresses various pertinent issues relevant to the RFMO's objectives.

Different structures exist for the RFMOs Scientific Committees [58]. Some have a committee composed of experts from member countries, who normally meeting multiple times during a year and draw up an assessment of the stocks and, based on that, provide scientific advice. Other RFMOs have scientists who work permanently or rely on independent organizations (e.g., International Council for the Exploration of

* Corresponding author.
E-mail address: grazia.pennino@ieo.csic.es (M.G. Pennino).

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the Sea, ICES) that provide scientific advice to different RFMOs (e.g. NEAFC). Although the structure of all RFMOs is similar, there are differences in the internal processes that make each RFMO unique [26]. Consequently, the cooperation between experts that work for the different RFMOs is sometimes difficult due to the specificities of these institutions in several aspects of the stocks' assessment and management processes [46].

Moreover, in 2001, the United Nations Agreement on Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UNFSA; [56]) entered into force; among their general principles, UNFSA includes to adopt measures to ensure long-term sustainability of fish stocks and ensure that such measures are based on the best scientific evidence available strengthening the role of RFMOs (Articles 9 and 10) with the suggestion to cooperate with each other [26]. The Code of Conduct for Responsible Fishing [12] is expressed in similar terms regarding the role of RFMOs.

Nevertheless, it is important to note that not all the stocks are managed under the umbrella of the RFMOs. Additionally, other regional fisheries bodies, lacking regulatory authority but sharing certain similarities to RFMOs in terms of stock assessment, act as advisory bodies and facilitate information exchanges between managers. These bodies are known as regional fisheries advisory bodies (RFABs). To scientifically advance and enhance the RFABs credibility, it is essential to focus efforts in improving stock assessments based on the principles of the traditionally consolidated RFMOs.

In this context, our goal is to improve collaboration between experts from different RFMOs and contribute to the strengthening of other RFABs. While the initial step in this work was inspired by discussions from the thematic session 'The evaluation process in the Scientific Councils of Regional Fisheries Organizations' held during the Iberian Symposium on Modeling and Evaluation of Fisheries Resources [51], this manuscript presents an independent and comprehensive analysis. The focus of this study is not on the outcomes of SIMERPE but on a dedicated comparative evaluation of the stock assessment processes and management advice structures of key RFMOs. To reflect this, we have reduced references to SIMERPE throughout the manuscript to clarify the study's standalone nature. Building upon discussions from the thematic session, this study focuses on comparing the General Fisheries Commission for the Mediterranean (GFCM), the Northwest Atlantic Fisheries Organization (NAFO), and the North East Atlantic Fisheries Commission (NEAFC) with a focus on the International Council for the Exploration of the Sea (ICES), which provides NEAFC with scientific advice. These RFMOs were specifically selected due to their direct relevance to the European Union's fisheries, as they manage key straddling stocks exploited by EU fleets. While these RFMOs target different species and have distinct structures, they share fundamental processes in scientific assessment and advice formulation, which makes their comparison meaningful. Furthermore, to emphasize collaboration with advisory bodies, we include the Fishery Committee for the Eastern Central Atlantic (CECAF), an RFAB supported by FAO, highlighting its role in providing advice for fisheries of EU interest in the Eastern Central Atlantic. The comparison was developed in terms of the stock assessment procedures, biological reference points, transparency, stakeholder's involvement and implementation of the ecosystem-based fisheries management (EBFM) and precautionary approach (PA).

The study also suggests improvements towards intergovernmental cooperation in fisheries management. The overview of the selected fisheries bodies is intended to communicate to a wide range of scientists and managers about the functions and roles of various RFMOs/RFABs in the context of the stock assessment of species of commercial interest for the European Union.

2. Materials and methods

To provide a general overview of the assessment context of RFMOs/RFABs, key scientific experts from each RFMO/RFAB (hereafter just RFMO) have been involved in this analysis identifying crucial future steps to enhance a better integration for fisheries management advice. This study brings together the knowledge of stock assessment experts within these bodies to provide a useful picture of the current state of play of the European Union's stock assessment decisions.

Initial discussions held during the SIMERPE symposium (2021) helped inform this study, although the analysis presented here is an independent and comprehensive evaluation of the selected RFMOs' stock assessment procedures. During the event, specific thematic sessions were arranged, including one titled "*The evaluation process in the Scientific Councils of Regional Fisheries Organisations*". The format of this session involved concise presentations by four researchers representing different RFMOs. They provided insights into the general functioning of their respective institutions. Subsequently, an interactive discussion took place with the aim of identifying commonalities, differences, potential areas of synergy, avenues for improvement and opportunities for collaboration among the different RFMOs. This deliberation was attended by an audience of over 150 scientists who specialize in Fisheries Resources Assessment and Modeling. Their involvement added value to the discussion, contributing to its productivity and aligning with the primary aim: to enhance comprehension of each organization's operations and uncover avenues for improvement through collaboration.

Here, an exhaustive review of each RFMO was also conducted by each expert, enhancing and completing the knowledge acquired during the symposium. The RFMOs analysed in this study correspond to the FAO zones 21, 27, 37 and 34 from North Atlantic Ocean and Mediterranean Sea (Fig. 1).

The specificities of each RFMOs are influenced by various elements, including geographical factors, historical context, the composition of contracting parties or member states, the involvement of developing countries, the economic value of targeted species and political considerations. All these aspects condition to a greater or lesser degree the scientific procedure for the assessments and could determine the effectiveness of the scientific advice. The analysis of the above issues is beyond the scope of this work and, for the purpose of this study, we focus our interest in the criteria that constitute the basis for the stock assessment, such as: the stock assessment procedure, the biological reference points, the transparency, the stakeholder's involvement and the implementation of the ecosystem-based fisheries management (EBFM) and the precautionary approach (PA). Additionally, we have chosen case studies of stocks targeted by European fleets to illustrate how advice is generated among the different RFMOs with respect to these criteria: European hake (*Merluccius merluccius*) of ICES and GFCM, Atlantic cod (*Gadus morua*) of Division 3 M of NAFO and North-west African hakes (black hakes, *M. senegalensis* and *M. Polli*) of CECAF.

3. Overview of the selected RFMOs

The GFCM is composed by 22 contracting parties, 6 cooperating non-contracting parties and the European Union (EU), and was created in 1949 with the main objective to ensure the conservation and the sustainable use of living marine resources, as well as the sustainable development of aquaculture, in the Mediterranean and in the Black Sea (https://www.fao.org/gfcm/about/en/).

NAFO was founded in 1979, as a successor to the International Commission for the Northwest Atlantic Fisheries (ICNAF) in 1949–1978. NAFO is responsible for managing most of the fishery resources of the Northwest Atlantic except salmon, tunas/marlins, and sedentary species (e.g. shellfish). Currently NAFO has 13 Contracting Parties (https://www.nafo.int/).

NEAFC is an organisation of six Contracting Parties which have signed up to the Convention on Multilateral Cooperation in North-East Atlantic Fisheries, which entered into force in November 1982. The ICES is an intergovernmental marine science organization, which provides science-based advice to NEAFC (and other advice requesters such as the EU). It advises the Commission on measures related to fishing

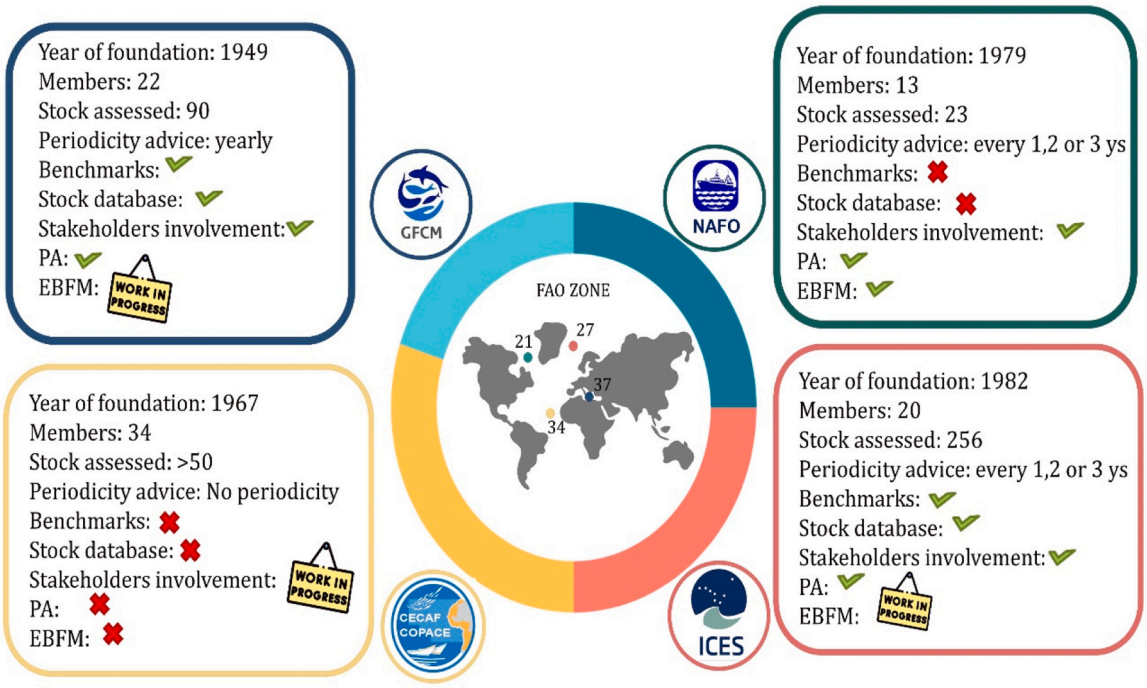

Fig. 1. Schematic summary of the criteria evaluated in the different RFMOs and map of the FAO areas in which the RFMOs operate.

opportunities, vulnerable habitats, and fisheries closures. ICES was established in 1902 by exchange of letters between participating countries. In 1964, through an agreed Convention, ICES received a legal foundation and full international status. There are 20 ICES member countries (https://www.ices.dk/Pages/default.aspx).

CECAF was established in 1967, by Resolution 1/48 adopted by the FAO Council at its Forty-eighth Session held in Rome under Article VI (2) of the FAO Constitution (https://www.fao.org/cecaf/overview/ru/). The Committee is composed of 34 members whose territory borders the Atlantic Ocean from Cape Spartel (Morocco) to the mouth of the Congo River, or that carry out fishing or research activities in the sea area concerned (FAO major fishing area 34) or having some other interest in the regional fisheries. Differently from the other analysed RFMOs, CECAF has a purely advisory status.

4. Stock assessment procedure

The implementation of scientific advice is a complex process that usually depends on the institutional and operational framework of the RFMOs [58]. The quality of the scientific advice relies mainly on the availability and the quality of the data submitted by the member states, which often depend on resources in the respective country [50]. In fact, some countries may lack the necessary scientific expertise that prevents them from participating effectively in the process [40].

4.1. Stock assessment specificity

In the GFCM, the stock assessment process is carried out in the framework of three technical groups, under the umbrella of the Scientific Advisory Committee (SAC): the Working Group on the Stock Assessment on Demersal Species (WGSAD), the Working Group on Stock Assessment on Small Pelagic Species (WGSASP) and the Subregional Group on Stock Assessment in the Black Sea (SGSABS). These groups meet annually and the number of stocks assessed can vary among years, but are generally around 90 stocks: 60 stocks in the WGSAD, 20 stocks in the WGSASP and 10 in the SGSABS assessed on a yearly basis. The stocks are classified as priority or non-priority stocks at regional level, in accordance with the best scientific information available.

The GFCM collects data in support of the decision-making mechanism and to inform all its activities in the Mediterranean and the Black Sea through existing recommendations, national reports, stock assessment forms and ad-hoc data calls. The GFCM Data Collection Reference Framework (DCRF) supports the formulation of sound scientific advice by GFCM subsidiary bodies. It provides indications for the collection of fisheries data (DCRF manual, [22]) as well as tools for their transmission to the GFCM in a standardized way (online platform).

Input data for the stock assessment is submitted by contracting parties to the GFCM before the working groups (WG). However, experts participating in the groups may provide new data duly justified. During these technical groups, all the assessments are reviewed and new analyses are carried out if it is considered necessary by the group experts. The assessments validated will be later on presented and reviewed at the respective sub-regional committee: Western Mediterranean (SRC-WM), Central Mediterranean (SRC-CM), Adriatic Sea (SRC-AS) and Eastern Mediterranean (SRC-EM), through which the SAC operates.

Since 2018, a benchmark process has been launched to cover the priority stocks with the objective of improving the quality of advice. The SAC has recognized the benchmark process as an important tool to review and evaluate input data and, when needed, identify strategies for improving data collection, underlining the crucial role of data quality.

Although the role of GFCM is crucial in the assessment of stocks in the Mediterranean and Black Sea, currently advice on the status of the main stocks in the Mediterranean and Black Sea has been provided both by GFCM-SAC and EU-Scientific, Technical and Economic Committee for Fisheries (STECF), often without a clear coordination and lack of transparent shared rules and practices. This situation has led in the past to: i) duplications of the advice on the status of the stocks thus adding confusion in the management process and, ii) a continuous managers' interference in the scientific process by the Directorate-General for Maritime Affairs and Fisheries (DG MARE) officials hindering its transparency and independence. This situation was reported by a group of Mediterranean experts [3] and, although they considered that it was imperative that this stalemate was rapidly resolved, the situation currently remains the same.

In NAFO the assessment process is the following: the member states send the commercial fishery activity information and scientific data

(surveys, biological studies, etc.) to the expert in charge of each stock designated by the NAFO Scientific Council (SC). This expert is responsible for compiling all the data of the stock and making the draft assessments with the available data. These assessments are discussed and approved in the NAFO Standing Committee on Fisheries Science (STACFIS) of the Scientific Council. On the other hand, NAFO has different sources of catch data and the NAFO Joint Commission-Scientific Council Catch Estimation Strategy Advisory Group (CESAG) is in charge of deciding annually which are the most appropriate commercial catches to carry out the assessments.

The SC produces the scientific advice based on the approved assessment and the results of different stock projection scenarios required by the Commission following the principles and objectives of the NAFO Precautionary Approach Framework. Finally, the NAFO Commission approves the management actions for each of the stocks based on the scientific advice produced by the SC.

At the moment there are 23 stocks evaluated by the NAFO Scientific Council and the periodicity of the full assessment of each stock varies between one and three years depending on the biology and status of each stock. Every year, commercial and scientific data are analysed for all stocks, whether or not they are fully assessed.

In NAFO no benchmarks are usually performed although part of their objectives are reached in several Management Strategy Evaluation (MSE) processes carried/have been carried out. It is foreseen that in the future, more benchmarks will be carried out for the species assessed by NAFO. In this line, in 2022 the first joint benchmark between ICES and NAFO took place for the Northern shrimp (*Pandalus borealis*) [32].

Part of NAFO stocks are managed by MSE and not by annual assessments. In these cases, the Commission establishes the management objectives it desires for a specific stock and the SC is in charge of developing and testing a Harvest Control Rule (HCR) to produce advice annually that meets the management objectives, considering the main sources of uncertainty that exist in the stock evaluation.

CECAF stocks are managed by Fisheries Partnership Agreements (FPAs) between the EU and third countries [9,10]. In the FPAs the number of EU licences are determined based on the "surplus" likely available to EU fleets on stocks and in waters covered by FPAs. However, no agreed method has been yet made available to allow calculations of surplus, especially in the case of stocks shared at sub-regional level among several coastal States and in absence of a mandatory management framework initiated and supported by CECAF. In these circumstances, the role of CECAF as a Regional Fishery Organization is in the background of the sovereignty in management of coastal States [11].

Nevertheless, the CECAF Committee regularly assesses the status of 85 (in 2022) fish stocks and provides management advice for between 20 and 30 fisheries. The CECAF Committee relies on the Scientific Sub-Committee that provides science-based advice for fisheries management decisions. Assessment groups are divided in three WGs: small pelagic species, demersal species and artisanal fisheries, whose results on stock assessments are presented to the Scientific Sub-Committee. The WGs are subsequently reorganized as follows: Small Pelagic North and Demersal North (covering areas from Morocco to Senegal) and Small Pelagic South and Demersal South (from Guinea-Bissau to Angola, including the island states of Cape Verde and Sao Tome and Principe). The WGs meet as required and on an intersessional basis and collate data and information from Member States about the fisheries resources. They conduct stock assessments using a central reference model for the communication of results based on a spreadsheet version of the Schaefer dynamic production surplus model with observation errors, Biodyn [1], to provide maximum sustainable yield (MSY) reference points and make short term projections of the status quo scenarios and a reduction in catches scenario. Recently, some other assessment models have been presented in the WGs (e.g., surplus production models in continuous-time - SPiCT, Just another Bayesian biomass assessment - JABBA, Life Cycle Assessment - LCA, Length-Based Bayesian Biomass - LBB, catch-maximum sustainable yield - CMSY), but transition from Biodyn to alternative improved assessments is not yet implemented [52]. The determination of stock status is based on MSY estimates used to classify status categories, as defined by FAO [13]

- "Not fully exploited" - the current stock is greater than 60 % of the unexploited stock, representing a stock biomass that is greater than that which supports MSY
- "Fully exploited" - the current stock is 40–60 % of the unexploited stock, which is about the size of the stock that can produce MSY
- "Overexploited" - the current stock is less than 40 % of the unexploited stock, a stock that is less than that which supports an MSY

Based on CECAF estimates on stock status and projections, recommended measures for TAC are provided for each stock. Nevertheless, each member state conducts its own assessments and determines a TAC for each stock in their own waters. The way how this TAC is determined is not clearly expressed, although ideally it should follow the United Nations Convention for the Law of the Sea [57]. In CECAF no benchmarks are usually performed and, unfortunately, if the stock is overexploited, the surplus should be zero automatically, which, in practice, is ignored in the FPAs.

ICES provides advice on catch opportunities for 256 stocks of fish and shellfish. The periodicity of this advice depends on requirements by relevant management bodies and usually includes annual, biennial, triennial or quadrennial advice. The latest advice for these stocks was based on MSY (82 stocks), Precautionary Approach (150 stocks), and Management Plans (25 stocks). For six stocks catch advice was not possible due to lack of reliable data.

ICES has developed a Stock Information Database (https://sid.ices.dk/Default.aspx) and a Standard Graph Database (https://standardgraphs.ices.dk/stockList.aspx) to access relevant information, including assessment type and ICES stock data category and stock assessment outputs.

ICES issues annual data calls to member countries and collaborative bodies (https://www.ices.dk/data/tools/Pages/Data-calls.aspx) to gather the input data from commercial catches necessary to perform the stock assessments. The data are preferably submitted through dedicated databases such as InterCatch and the Regional DataBase, that can ease data standardization and documentation. Data from surveys at sea are also preferably submitted to specific databases such as DATRAS (Database of Trawl Surveys).

Each stock is evaluated by a team of experts with the roles of stock coordinator (compilation and standardization of input data) and stock assessor (conducting the stock assessment model). The stock coordinator and assessor can be supported by various other experts responsible for particular pieces of the stock assessment model (e.g. standardization of survey data, estimation of recreational fisheries catches, splitting of the catches in different stock components).

Stock coordinators, assessors and their teams attend annual WG meetings where the input data and assessment for their particular stock is presented, discussed and reviewed (for the first time) among peers. Importantly, assessment WGs produce a first draft of the scientific advice for their relevant stocks. The draft advice and related stock assessments are reviewed (for a second time) at dedicated Advice Drafting Groups, attended by representatives of the Advisory Council (ACOM), the WG, ICES Secretariat and, if appropriate, Observers. The draft advice proposed by Advice Drafting Groups is then posted for review (for the third time) by ACOM, including representatives of ICES 20-member countries. A dedicated online meeting is scheduled to resolve any comments by ACOM to the assessments and advice, after such meeting the scientific advice is considered approved by ACOM and it is published. The WG reports including all the background information are also published on the same day the advice for fishing opportunities is released.

If an assessment is not accepted by the WG, by the Advice Drafting Group or by ACOM, a dedicated benchmark or review process is set up to agree on new input data or model settings that would improve model

performance and diagnostics and hence be accepted by both the WG and ACOM. In these cases, the publication of scientific catch advice and stock status may be delayed until results from the new benchmark or review process become available. If a delay is not possible, ICES may provide scientific advice based on a different ICES stock data category [33].

From 2008 onwards, ICES uses a benchmark process as a means to peer-review and incorporate new science for use in provision of all types of recurrent advice. The benchmark process is a critical element in ICES advice to ensure a sound scientific basis. There are three types of benchmark process: 1) Expert Group level, in which small changes to the method that are mainly technical in nature are performed; 2) Review, in which one or two larger issues (i.e., changing/correcting an entire data series, or for more substantive revisions to model setting) are addressed; and 3) Full benchmark, in which a full review of methods, underlying conceptual assumptions, and data is applied [36].

4.2. Decision making procedure

Generally, the Commission of the RFMO makes decisions either based on a consensus, voting or a mixture of mandatory consensus and voting. GFCM, NEAFC and NAFO apply majority voting with the right to object. The right to object and opt-out, which relieves members of the obligation to implement the agreed action, is an important aspect of the decision-making process. NAFO enhanced the opt-out procedure and established a review panel which resolves the dispute in a transparent manner [39].

The GFCM is governed by the decisions of its 22 contracting parties, 6 cooperating non-contracting parties, and the European Union (EU). It holds statutory sessions on an annual basis to review the implementation of its yearly work plan, adopt recommendations and resolutions, endorse its autonomous budget and agree on its future priorities and direction. It can convene special or extraordinary sessions at the request or with the approval of the majority of its members. The sessions of the Commission are attended by member delegates, experts, advisers and observers. Each member has the right to one vote, except in the case of a regional economic integration organization, such as the European Union, which is entitled to the number of votes equal to the number of its member states that are also members of the GFCM. Regional economic integration organizations cannot exercise their votes when their member states exercise theirs and vice versa. The GFCM also sees the participation of select cooperating non-contracting parties, and allows relevant partner organizations to contribute as observers. As regulated in the GFCM Agreement, the Commission is coordinated by a Bureau.

In CECAF, decisions of the Committee are taken by a majority of the votes casted, unless otherwise provided. Each member has one vote. The final decisions in CECAF are not mandatory for Member States as they are sovereign to implement their own management decisions.

ICES' decision making in relation to advisory products is based on consensus by the members of ACOM. Consensus allows for disagreement but all participants accept the general decision at the end of the process (i.e. general agreement).

5. Reference points implemented

Following UNFSA [56] a reference point is an estimated value derived through an agreed scientific procedure, which corresponds to the state of the resource and of the fishery, and which can be used as a guide for fisheries management. Reference points can be classified as (1) Limit reference points, that set boundaries which are intended to constrain harvesting within safe biological limits and (2) Target reference points, that are intended to meet management objectives. Reference points are stock-specific accounting for the reproductive capacity, the resilience of each stock and the characteristics of fisheries exploiting the stock, as well as other sources of mortality and uncertainty. Following UNFSA [56] different RFMOs have implemented reference points in different ways.

In the GFCM the provision of advice is based on a framework for describing stock status and providing management advice in relation to reference points [14]. In order to further standardize and simplify the definitions of stock status as well as management advice provided by the expert groups, the thirty-seventh session of the Commission (2013) agreed to organize a workshop on the definition and use of reference points to provide advice on stock status and management measures. The main conclusions of this workshop were revised by both working groups on stock assessment (WGSAD and WGSASP) and the (at that moment active) Sub-Committee on Stock Assessment, and then endorsed by the SAC at its sixteenth session (2014). This document contains a framework on how to describe the status of stocks and provide management advice for those stocks for which reference points are adopted by the SAC.

The document provides definitions for stock status and management advice on stocks for which reference points related to indicators of biomass and/or exploitation are available and defines three categories of reference points: target, threshold and limit reference points. The document includes 15 tables in which the stock status and proposed management advice for different combinations of indicators (only fishing mortality (F), only biomass (B) or both) and reference points (an unique reference point, two precautionary reference points – limit and threshold –, or a full set of three reference points – target, threshold and limit–) available for a given stock. For a large number of Mediterranean stocks (most demersal stocks), only reference points for exploitation (F) are usually available; this is closely linked to the impossibility to obtain good sensible parameterisation for any stock using Beverton-Holt or Ricker stock-recruitment models due to the short time series available and the range of biomass levels observed. $F_{0.1}$ is considered as a proxy of $F_{msy.}$ $F_{0.1}$ is defined as proposed by Gulland and Boerema [25]: the fishing mortality rate at which the marginal yield-per-recruit (i.e. the increase in yield-per-recruit in weight for an increase in one unit of fishing mortality) is only 10 percent of the marginal yield-per-recruit on the unexploited stock.

NAFO's current PA [42] is based on avoiding exceeding the limit reference points. The approach does not define target reference points. In the NAFO PA framework, F_{lim} is defined as the fishing mortality rate that should only have a low probability (5 %) of being exceeded. F_{lim} cannot be greater than F_{msy}. If F_{msy} cannot be estimated, then an appropriate proxy may be used instead. B_{lim} is defined as the biomass level below which stock productivity is likely to be seriously impaired, and stocks should have a very low probability (<5 %) of being below B. To estimate biomass limits, stock/recruitment relationship information or different proxies based on different biological reference points are usually used. The most common B_{lim} proxy used is the 30 % B_{msy}.

NAFO is currently revising its PA framework [45] to try to adapt it to the new NAFO Convention Objectives established in 2017.

CECAF uses target and limit reference points based on Biodyn estimates of MSY (or alternative methods as LCA or the length-based yield-per-recruit analysis - LBYPR). Target reference points are stipulated as $B_{0.1}= 1.1 \cdot B_{msy}$, $F_{0.1}= 0.9 \cdot F_{msy}$ for Biodyn assessment model and $F_{0.1}$ for yield-per-recruit in LCA and LBYPR. The B_{cur}/B_{msy} and F_{cur}/F_{msy} are used as limit reference points while the $B_{cur}/B_{0.1}$ and $F_{cur}/F_{0.1}$ are used as target reference points. CECAF recognizes that for fisheries with a large proportion of juveniles in the catch, it would be relevant to explore alternative reference points (e.g. 30–40 % maximum spawning potential) [19].

ICES has agreed and published guidelines for the estimation of PA and MSY reference points [29,31], that are used to assess the state of the stocks and exploitation. B_{lim} is defined as a deterministic biomass limit reference point below which a stock is considered to have reduced reproductive capacity and it is the key PA reference point since other PA points are estimated from it. F_{msy} is initially calculated as a constant F which should provide maximum yield without biomass constraints. $MSY_{Btrigger}$ should be selected to safeguard against undesirable or unexpected low SSB when fishing at F_{msy} and to fulfil the precautionary

criterion of having less than 5 % annual probability of the spawning stock biomass (SSB) being lower than B_{lim} in the long term. For stocks without full analytical assessments, several methods are proposed to derive proxies to MSY reference points [29] including Length Based Indicators (LBI), Mean Length Z (MLZ), Length Based Spawner Potential Ratio (LBSPR) and Surplus Production model in Continuous Time (SPiCT) [5,6].

For few stocks ICES has defined F_{eco}, a rescaled target F according to ecosystem indicators and in line with pre-calculated single stock precautionary limits (e.g. [34]).

In Fig. 2, a summarized schematic representation of the crucial information regarding RFMOs reference points discussed here can be found.

6. Transparency

Transparency in processes of RFMOs (e.g., accessibility to documentation, participation of independent experts in assessments, participation of non-governmental stakeholders, etc.) is an essential factor in marine resource management. In this regard the different organizations have taken in place different initiatives.

GFCM maintains a large amount of fisheries-related data collected through submissions from its contracting parties. A subset of this information is made publicly available in line with the existing GFCM data confidentiality policies. Among this information, reports of all the meetings are public and available at the GFCM website (www.fao.org/gfcm), as well as the Stock Assessment Forms (SAFs) and the Stock Assessment Results (STAR) of the validated assessments. The SAFs include all the information for each stock assessed, including data, type of model and final results and conclusions and the STARs summarize all the metadata and results of the assessments. The sessions of the Commission are attended not only by member delegates, experts and advisers but also by observers.

NAFO has conducted two Performance Review Panels in the last decade in which members of the organization together with external experts analyse the performance of the organization and its different bodies to make recommendations for improvement. All NAFO Scientific Council reports and stock assessment documents are publicly available on the NAFO website (https://www.nafo.int/). Assessment data or programs are not publicly available and can be obtained by contacting the NAFO Secretariat. Non-governmental or fishery-related organizations can participate as observers in the meetings of the Scientific Council (SC) with voice but no vote. Since 2018 the SC annually invites external experts to its meetings to act as reviewers of the assessments of some stocks.

The ICES advisory process is open and transparent and full details can be found in the guide to ICES advisory framework and principles [30]. The first of the ten principles relates to transparency: "the guidelines and procedures to produce ICES advice are documented, openly accessible, and up-to-date". Principle 6 relates to data accessibility: "data are findable, attributable, researchable, reusable, and conform to the ICES data policy. Data flows are documented". Guidelines for participation and conduct of observers of the advisory process are available in the ICES website (https://www.ices.dk/community/Documents/Observers/CM_2013_Del-11%203_Observer_rules.pdf).

In CECAF, there is no formal transparency guide to be applied. In fact, the main challenge in CECAF is to develop transparent data-collection protocols to implement a monitoring system to assess the application of CECAF recommendations [20]. FAO Fisheries Statistics Branch (FIAS) has an online resource, the Fishery and Resources Monitoring system (FIRMS), where CECAF partners can contribute to the global inventory of marine resources and fisheries. The most recent publications of CECAF can be found also online (https://www.fao.org/cecaf/publications/en/). Nevertheless, it is not always possible to obtain all the reports. Specific assessment data are constrained to the WGs participation. The WGs are frequently not able to obtain all catch and effort data nor the reports of coastal surveys.

7. Stakeholders involvement

The participation of governmental and non-governmental organizations is common in the SAC and GFCM meetings, as well as in some of the technical meetings. The GFCM usually conducts consultations with a wide array of stakeholders to gather their input and priorities on its strategy for the Mediterranean and Black Sea.

In NAFO, the stakeholder associations can participate in the meetings as observers with voice but without vote. It is not very usual for them to participate in the meetings of the Scientific Council but it is quite common that they participate in the meetings of the joint WGs of

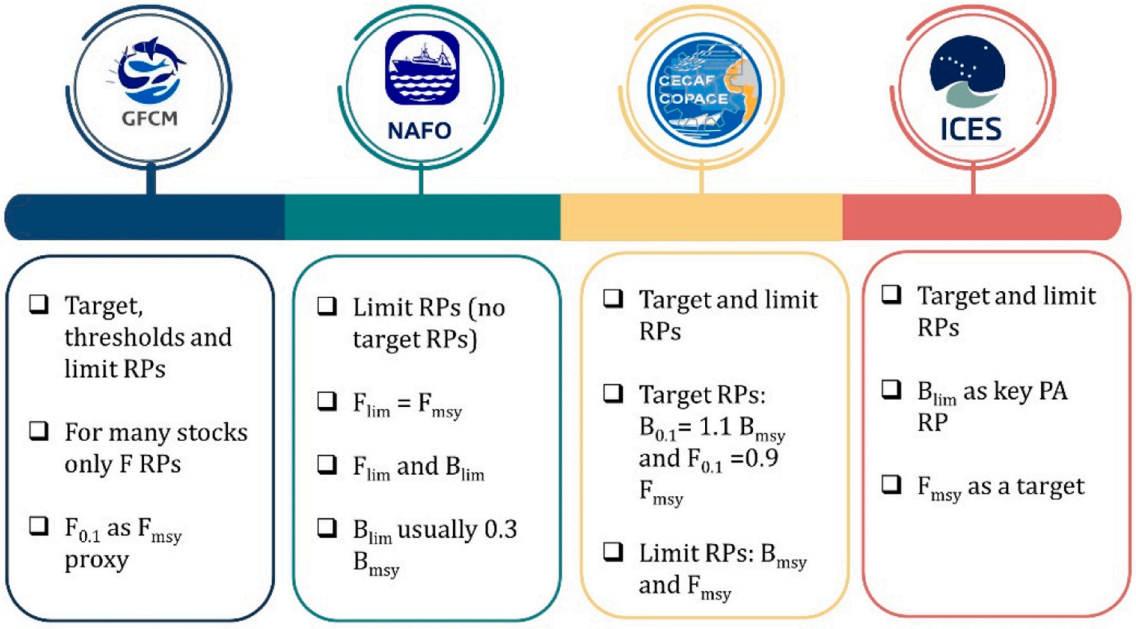

Fig. 2. Schematic representation of the different reference points used in the assessed RFMOs.

the Commission and the Scientific Council. Apart from this official role, the different national scientific delegations of the contracting parties have a constant communication with the stakeholders to transmit and explain the main conclusions of the NAFO Scientific Council.

ICES published its stakeholder involvement strategy in 2023 [35]. The strategy outlines the key principles of stakeholder engagement and defines the roles of both stakeholders and scientists in the engagement. The ICES strategic plan requires stakeholder engagement and cooperation. Currently, stakeholders can participate in ICES' advisory process as observers, can contribute to science and method development by participating in ICES workshops, and can participate in or scoping exercises when developing new advisory products.

Internal CECAF statutes indicate rules for participation of any external expert and stakeholder and shall be chosen by the Scientific Committee and be appointed by the Director General of CECAF. In the ninth session of the CECAF Scientific Sub-Committee [19] it was pointed out that a major challenge for CECAF is to integrate CECAF recommendations into national fisheries policy, as currently stakeholders dont implement the advice and scientific recommendations and there is no participation of fisheries ministers at the Committee meetings. Beyond CECAF, considering the FPAs signed between the EU and third countries, the EU Commission requests on a regular basis the review of the assessments, advice and management recommendations related to the "surplus" in the context of Western African fisheries. In the past, the STECF has been designated to develop this difficult task [53].

8. Ecosystem-based fisheries management and precautionary approach

The ecosystem-based fisheries management (EBFM) and the PA are important components of modern fisheries management.

EBFM is a new direction for fishery management, essentially reversing the order of management priorities to start with the ecosystem rather than the target species. The overall objective of EBFM is to sustain healthy marine ecosystems and the fisheries they support [48].

PA involves the application of prudent foresight. Taking account of the uncertainties in fisheries systems and the need to act with incomplete knowledge, it requires consideration of the needs of future generations and avoidance of changes that are potentially not reversible ([27]).

The two most important instruments in defining the role of the EBFM and PA in the RFMO's management are the UNFSA (a binding agreement) and the FAO Code of Conduct (a voluntary instrument), which task RFMOs to manage fisheries in a sustainable way and to take PA and EBFM into account. RFMOs which have entered into force after the negotiation of UNFSA often include the EBFM and PA in their convention texts. The conventions of older RFMOs may lack important features such as the EBFM and PA considerations. However, these RFMOs can incorporate new environmental norms, such as long-term sustainability of fisheries and ecosystems, and re-establish their convention to prioritize marine ecosystems.

Although the stock assessment process is based on monospecific assessment in the GFCM, the ecosystem approach to fisheries is an important aspect in the GFCM's management approach as reflected in Article 8(b)(iii) of the GFCM Agreement [15] according to which the GFCM shall formulate and recommend "to adopt multiannual management plans applied in the totality of the relevant subregions based on an ecosystem approach to fisheries to guarantee the maintenance of stocks above levels which can produce maximum sustainable yield, and consistent with actions already taken at the national level."

Additionally, the central GFCM fisheries management subsidiary body features the ecosystem approach to fisheries in its mandate to direct its work [15]. In particular, the Scientific Advisory Committee on Fisheries shall *inter alia* "Provide independent advice on a technical and scientific basis to facilitate the adoption of recommendations concerning the sustainable management of fisheries and ecosystems at the regional and subregional levels, including on relevant biological, environmental, social and economic aspects, as well as on issues associated with the ecosystem approach to fisheries, the impact of Illegal Unreported and Unregulated fishing on populations and ecosystems, and the assessment of biological and ecological implications under different management scenarios". In fact, there are 45 GFCM instruments (Recommendations, Resolutions, and Decisions) that are explicitly referring to the ecosystem approach to fisheries management adopted over the years. A big number of these instruments relate to management plans or otherwise management measures of certain species across different sub-regions within the GFCM area of application.

Finally, GFCM is also in the process of developing two mirror projects which will centre on the ecosystem approach to fisheries: The Fisheries and Ecosystem Based Management for the Black Sea (FishEBM BS) project and the Fisheries and Ecosystem Based Management for the Blue Economy of the Mediterranean (FishEBM MED) project, both with a focus on promoting blue economy.

In 2005, NAFO Contracting Parties agreed on the need to update the 1979 NAFO Convention in order to modernize the Organization and ensure its statutes meet the requirements of the relevant international instruments, between them UNFSA and the FAO Code of Conduct. An amended Convention text was agreed by the Contracting Parties in 2007 and it entered into force on 18 May 2017. NAFO began the implementation of an Ecosystem Approach to Fisheries Management (EAFM) in the years following the publication of the FAO Guidelines on Deep Sea Fisheries. In addition to the traditional stock assessment of commercial fish species, NAFO also required advice regarding vulnerable species and habitats. In response, the Scientific Council established a new WG on the Ecosystem Approach to Fisheries Management (WG-EAFM), which began meeting 2008, to identify and delineate marine benthic habitats subject to significant adverse impacts and in need of protection. This WG aided in changing the NAFO Conservation and Enforcement Measures to prohibit bottom fishing in a number of areas where Vulnerable Marine Ecosystem (VME) indicator species were known to occur in high densities, and placing stocks of forage fishes, such as capelin (*Mallotus villosus*) in the Grand Bank (NAFO division 3NO), under long-term fishing moratoria, recognizing the important role they play in the food-web. In 2013 the WG changed its name to the Ecosystem Science and Assessment (WG-ESA) and in recent years, importance has been placed on encounter biomass thresholds for sponges and corals, ecological interactions between cod (*Gadus morhua*), redfish (Sebastes spp.) and shrimp (*Pandalus borealis*), and comprehensive lists of VME indicator species and VME elements.

In addition, a joint Commission and Scientific Council Working Group on the Ecosystem Approach Framework to Fisheries Management (WG-EAFFM) was established to report on ecosystem developments and the work of WG-ESA to both the Commission and the Scientific Council, to consider the advice of Scientific Council, and to provide recommendations to the Commission.

NAFO Commission has approved a Roadmap for the development and implementation of an Ecosystem Approach to Fisheries. The NAFO Roadmap core principles are: a) the approach has to be objective-driven, b) it should consider long-term ecosystem sustainability, c) it must be place-based, and d) the consequences of trade-offs in managing human activities have to be explicitly defined. The Roadmap is not a fixed plan; it evolves as different components are developed, refined and implemented. Core elements of the Roadmap include the identification of ecosystem-based management units, a hierarchical approach to define exploitation rates by considering ecosystem, multispecies and stock level sustainability, and the integration of impacts on benthic communities. The modular design of the plan has allowed NAFO to start implementing some components (e.g. closures to bottom fishing for the protection of Vulnerable Marine Ecosystems), while work on others is still ongoing (e.g. multi-species modelling). Even though the Roadmap is not fully implemented, NAFO has made important progress towards EAFM over the last decade. More information about the NAFO Roadmap

can be found in Koen-Alonso et al. [38].

During the September 2022 Annual meeting, NAFO made significant progress in further developing its ground-breaking Ecosystem Approach Framework to fisheries management by adopting an ecosystem reference point ("total catch index" or "TCI") to complement stock assessments and to help inform management decisions regarding the potential risk of ecosystem overfishing [44]. This TCI is estimated by Ecosystem Production Unit (EPU) and functional group, and it's intended to be an ecosystem limit reference point, establishing a total catch that cannot be exceeded in that EPU and that functional group in order to protect the ecosystem. The TCI is calculated based on the primary production of each EPU.

In CECAF there are no guidelines for provision of advice based on EBFM and PA considerations. Recommendations for fisheries management are mainly based on single stock status and vary depending on the WG and expert knowledge. Nevertheless, some projects have been conducted to support national fisheries management and research institutions in sustainable management according to EBFM principles, such that FAO EAF-NANSEN Programme (https://www.fao.org/in-action/eaf-nansen/background/history-of-the-nansen-programme/ru/), DEMERSTEM project (http://pescao-demerstem.org/indexuk.php) and CECAF-PESCAO project [17].

The ICES approach to advice on fishing opportunities integrates the precautionary approach with the objective of achieving MSY [33] so that fish populations should be maintained within safe biological limits. When the spawning biomass of a stock falls below MSY $B_{trigger}$, fishing mortality needs to be reduced to allow the stock to rebuild its biomass to levels capable of producing MSY.

In several instances ICES incorporates ecosystem trends and variability into fishing opportunities advice. Between 2019 and 2022 a questionnaire was used to audit the incorporation of ecosystem trends and variability into ICES stock assessments (e.g. changes in length distribution or natural mortality), forecasts (e.g. environmentally driven recruitment), mixed fisheries (e.g. bycatch of non-targeted species) or management plan evaluations (e.g. environmentally driven recruitment, environment or density driven weight-at-age) [8,55]. Just under 50 % of all ICES stock assessments had some implicit consideration of ecosystem factors. For a small number of stocks (e.g. cod, *Gadus morhua*, in Division 7.a, Irish Sea), a new fishing reference point was defined (F_{eco}). F_{eco} is adjusted based on the status of an environmental indicator (e.g. Sea Surface Temperature for Irish Sea cod) and provides long term yield at a lower risk for the stock. In addition to single-stock advice, ICES provides mixed-fisheries advice, fisheries overviews and ecosystem overviews, that address biological interactions between fish stocks by ecoregion.

9. Case study

To illustrate the difference in the advisory process among RFMOs we have chosen case studies of stocks targeted by European fleets, such as stocks of European hake for ICES and GFCM, one stock of Atlantic cod for NAFO and one stock of North-west African black hakes for CECAF (Table 1).

In Mediterranean waters European hake is one of the most valuable species economically and the demersal species suffering from the highest fishing mortality, with all the stocks under overexploitation. The GFCM assesses this stock each year during the WGSAD, using different models depending on the stock unit (Table 1). It's worth to mention that in the Mediterranean stock units are defined by Geographical Sub-Areas (GSAs). Although this species is assessed by separate stock units and with different models, the final advice is based on a unique unit (GSA 1–5–6–7), with the advice provided for each GSA considered as "complementary advice" [17].

The main BRPs used is $F_{0.1}$ which is considered as a proxy of F_{MSY}, although in the last advice carried out for the joint assessment of GSAs

Table 1
Summary of the different criteria assessed in the stock case study for the different RFMOs.

	Species	Stock	Assessment model	BRP	Benchmark	Advice	Management measures
GFCM	European hake *Merluccius merluccius* 	4 stock units	GSA1: XSA GSA5: a4a GSA6: a4a GSA7: ra4a	$F_{0.1}$ is a proxy of F_{MSY} B_{pa} and B_{lim} for GSA 1–5-6–7	Not routinely performed but one it was done in 2019.	Reduce F Recovery plan	Species currently subject to a multiannual management plan (EU-MAP) in the western Mediterranean, which includes a fishing effort regime (maximum number of days at sea for bottom trawlers), spatio-temporal closures (for protecting juveniles and spawners) and the possibility of applying technical measures (improvement of selectivity) as compensation mechanisms for the fishing effort regime
NAFO	Atlantic cod *Gadus morhua* 	1 stock unit	Bayesian SCAA	B_{lim} F_{lim}	Not routinely performed but one it was done in 2018.	F no more than Fsq	Spatial-temporal closures Technical measures (restriction in trawl mesh size)
CECAF	Black hake *Merluccius* spp. (*M. senegalensis & M. polli*) 	1 stock unit	Surplus production, YPR, LCA	$F_{0.1}$, $B_{0.1}$	Never performed	Reduce effort and bycatch Spatio-temporal closures	TAC
ICES	European hake *Merluccius merluccius* 	2 stock units	Southern stock (ICES division 8.c and 9.a): SS3 Northern stock (ICES in subareas 4, 6, and 7, and in divisions 3.a, 8.a–b, and 8.d): SS3	$MSY_{Btrigger}$, F_{lim}, B_{lim}, Bpa, Fpa	Routinely performed when necessary.	Catches corresponding to F_{msy} (Northern stock) or F_{msy} with ranges (Southern stock)	TAC and technical measures (spatial and temporal closures, mesh regulations, landing obligation with some exemptions)

1–5–6–7, Bpa and B_{lim} values were also provided. All data and models used as basis for the advice are available in the WGSAD report [21]. Stakeholders usually participate in the WGSAD and are involved in the process. The latest scientific advice suggested to reduce F and, depending on the GSAs, to implement a recovery plan. This species is also under the multiannual plan for the fisheries exploiting demersal stocks in the western Mediterranean (EU-MAP, Regulation (EU) 2019/1022 of the European Parliament and of the Council of 20 June 2019), which includes GSAs 1, 5, 6, 7, 9, 10 and 11. This multiannual plan applies a fishing effort regime for bottom trawlers which contemplates a maximum reduction of 40 % of days at sea between 2020 and 2024; currently, this reduction has reached 35 %.One of the most commercially valuable stocks assessed by NAFO is the Atlantic cod in Flemish Cap (NAFO Division 3 M). This stock is assessed each year in the June NAFO Scientific Council Committee as a unique stock unit with a Bayesian statistical catch-at-age [44]. The input and output data of the assessment is available in the website of NAFO as a Scientific Council Document (SCR), while the model script implemented for the advice is not publicly available. This stock was benchmarked in 2018 by NAFO. Two MSEs processes were carried out for this stock [24,43], but none of them found a Harvest Control Rule (HCR) that met the management objectives established by the Commission. At the moment the stock is assessed following the principles of the precautionary approach but no ecosystem component is considered in the process, although the prior of the natural mortality (M) to be included in the model was derived, among others, from the multispecies model GadCap [47]. Stakeholders are involved in the assessment process each year. During the benchmark process [43], B_{lim} was set as SSB_{2007}, as this is the highest SSB value of the three years (2005–2007) in which good recruitment leading to stock recovery was observed in the past. The highest value, rather than the mean of the three, was chosen to give a degree of security. Results presented during that second MSE process indicated that $F_{30\ \%SPR}$ is a fairly robust F_{lim}=F_{msy} proxy for this stock. Yield corresponding to F less than or equal to 3/4 F_{lim} (median value 0.125) in 2023 results in a very low probability ($\leq$10 %) of SSB being below B_{lim} in 2024 and a very low probability ($\leq$10 %) of exceeding F_{lim} in the same year. However, given the present level of the SSB and projected decline of total biomass under any fishing scenario, in order to promote growth in SSB with more than 60 % probability, SC advises scenarios with F no more than Fsq (median value 0.089) [44].

As management measures, the fishery for cod in Division 3 M is closed between 1 January and 31 March to protect the spawning season. In addition, each Contracting Party shall ensure that its trawl vessels conducting a directed fishery for cod in Division 3 M use a sorting grid for the purpose of reducing the catches of smaller individuals of cod. The minimum bar spacing of the sorting grid shall be 55 mm. The sorting grid must be placed in the top-side panel of the trawl preceding the codend [44].

In CECAF Black hakes are assessed as a single stock (*Merluccius* spp.) in all the area. Biodyn is used to provide MSY reference points (F_{MSY} and B_{MSY} as limits) meanwhile target reference points are theoretically stipulated as as $B_{0.1}$= 1.1·B_{msy}, $F_{0.1}$= 0.9·F_{msy}. Alternatively, $F_{0.1}$ can be calculated from yield-per-recruit analysis. Recently other models were tested (SPiCT, JABBA), although not officially used [52]. No benchmark has ever been done for this stock. Data and models are not publicly available. Neither PA or EBFM are considered in this assessment. The process to include stakeholders in this assessment procedure is still not yet implemented. The WG recommends a significant reduction in fishing effort and a reduction in catch to reach a sustainable catch level (MSY). In addition, provisions must be made for a significant reduction in incidental catches of black hake (reported as 5 700 tonnes in 2021) from other fisheries, in particular pelagic, to the average level for the period 2002–2014, i.e. 900 tonnes at most. There are also spatio-temporal closures implemented to protect the spawning and recruitment areas when appropriate. Management measures are adopted outside CECAF and established by the Coastal states Morocco, Mauritania and Senegal independently for each ZEE. TAC are imposed to EU vessels under the Fishing Partnership Agreements (FPA).

In ICES the European hake is assessed as two different stock units: southern (ICES divisions 8.c and 9.a) and northern (ICES subareas 4, 6, and 7, and divisions 3.a, 8.a–b, and 8.d) (Table 1). For both stocks the Stock Synthesis (SS) model [41] is used. These stocks were benchmarked in 2021 during the Benchmark workshop on anglerfish and hake (WKANGHAKE; [37]).

PA is applied in both stocks, while no ecosystem component is considered quantitatively. For both stocks BRPs MSY reference points (with associated uncertainty) are implemented, including MSY $B_{trigger}$. and other precautionary and limit reference points that ensure that the stock does not have reduced reproductive capacity, such as F_{lim}, B_{lim}, Bpa, and Fpa.

According to ICES advice, released and made public in June 2023, for the southern stock catches in 2024 corresponding to the stock projection at F_{msy} ranges should be between 9119 tonnes and 17445 tonnes. According to the EU multiannual plan for stocks in the western waters, catches higher than those corresponding to F_{msy} (12919 tonnes) can only be taken under conditions specified in the plan. Under mixed fisheries catches for one stock may constrain catches of other stocks from the same fisheries and catch ranges can be used to balance the exploitation of the different stocks. In this fishery, hake catches usually constraint megrims and monkfish catches, which eventually can drive to a TAC above those catches corresponding to Southern hake's F_{msy}, but below catches corresponding to F_{upper}.

For the northern hake stock ICES advises that when the MSY approach is applied, catches in 2024 should be no more than 72 839 tonnes. In this case, the ICES advice does not include the FMSY ranges approved in the Multiannual Plan for stocks in the western waters because the UK, one of the fishing nations for this stock, has not approved the plan.

10. Discussion and conclusions

The analyses of individual RFMOs in this study revealed that these organizations collectively are making substantial progress towards implementing science-based fisheries management and conservation (Fig. 1). However, challenges still remain regarding the particular sectoral contexts and configurations of the RFMO.

Internally, the stock assessment process has specificities in the various RFMOs. Methodologically, the differences in evaluation criteria could present some difficulties in reporting, interpreting and comparing the results. Overall, the quality of scientific advice is based on data submitted by the Member States, which often depend on the support of their fishing industry. However, in all RFMOs data transmission is not always on time and in some cases, it can be incomplete. Furthermore, in some RFMOs, such as CECAF, there are inconsistencies in data collection due to non-declared catches of Members and long-term monitoring programs addressing important aspects of the ecosystem approach. It is important to note that this aspect is often influenced in some countries by the lack of availability of resources or the lack of required scientific expertise which prevents them from effectively engaging in the process [26,50].

Benchmarks are key procedures to improve the quality of scientific advice evaluating the current data and assessment methodology and to propose improvements outside of the annual assessment environment with inclusion of independent external reviewers. During the benchmark, external experts and stock assessors work together to improve new methodology that will be implemented in the upcoming few years (around 4 or 5 years). This methodology includes input data, model and reference points. One of the advantages of this methodology is that the assessment working group does not need to open discussions on alternative data and methods every year, unless there is a serious concern with the agreed assessment. For this reason, it is a practice that the different RFMOs could incorporate into their evaluation processes. Of

the studied RFMOs, ICES has been a pioneer in incorporating benchmarks into its assessment procedure developing a clear framework and guidelines for this process. Most recently, in 2018, GFCM has launched a benchmark process to cover priority stocks and, currently, NAFO is also considering options to carry out benchmark processes. ICES benchmark framework may be considered as an example for other RFMOs which are developing benchmark process guidelines. In fact, NAFO is evaluating the possibility of performing joint benchmarks with ICES. It is also important that benchmark procedures also cover non-priority stocks as is done in ICES, a point that other RFMOs have yet to address.

The ecosystem approach is an important aspect of sustainable management and RFMOs are working to integrate them into their management. For example, some of the studied RFMOs are implementing area closures to protect VME, which are important components of the ecosystem approach. Another aspect of EAFM that has gained some attention is the assessment of protected species (e.g. seabirds, sea turtles, marine mammals, elasmobranchs). However, there are issues that still need further work, such as cumulative impact assessments [54] or a wider view of the marine ecosystem components in their management approach [23].

Another important point is the way in which the members make decisions. Notably, in the consensus-based model, members who are unwilling to take more stringent measures impose a potential risk on agreed measures. This fact not only affects the RFMO's ability to reach agreement on certain issues, but it also interferes with the scientific process [49]. Unlike the other RFMOs, the essential problem in CECAF is the lack of authority to provide an agreed mandatory advice for all members over shared stocks exploited by local and non-local fisheries that takes priority over national management decisions by Coastal States. The scientific assessments carried out in CECAF should be the basis for a regional management of fish stocks in Northwest Africa.

With respect to transparency, and with the exception of CECAF, individually each of the RFMOs examined has good practices and is working to improve this aspect, for example by making more information publicly available. Nonetheless, to increase their transparency, RFMOs could learn from each other and adopt each other's best practice examples [4].

All the studied RFMOs are making progress in stakeholder engagement. However, this should not adversely affect fish stocks and its ecosystem, rather it should ensure that the actions taken are preventive in case it is assumed that further activities could damage resources or the environment [7].

The RFMOs provide management advice and describe stock status based on a biological reference points framework. Reference points are the cornerstone to implement the precautionary approach and the MSY approach. However, clear differences exist among the approaches in each of the RFMOs, both in the type of reference points used (target and limit reference points) and also in their definitions. Specifically, the NAFO approach is based solely on limit reference points, i.e., no target reference points are considered (although this approach is currently being revised), whereas CECAF, GFCM and ICES define both target and limit reference points. In relation to the limit and target reference points considered in each of the RFMOs, it is important to highlight some differences in their definition. For example, NAFO is the only one that sets F_{msy} as a limit reference point, as it is intended in UNFSA [56] whereas it is a target in ICES, where F_{lim} is set based on B_{lim} reference point. In the same line GFCM also considers the $F_{0.1}$ reference point as a proxy for F_{msy}. ICES has integrated both the MSY and precautionary reference points using an MSE framework that guarantees that MSY reference points do not compromise the stock sustainability.

This overview of the selected RFMOs allows to identify the issues that require further development. In the case of GFCM efficient coordination between GFCM-SAC and the EU-STECF should be enhanced, in order to avoid the duplication of advice on the status of the stocks that is currently happening, which even leads to contradictory results and advice. In CECAF the main problem in the management of the stocks is the lack of reliable data on which to base quantitative formal assessments, so initiatives to overcome this limitation are required. In addition, CECAF should continue addressing the transition from the Biodyn surplus production model to alternative more reliable assessment models as those recently explored in some of their WGs. Further, formal transparency guidelines should also be developed in CECAF. A common future step for all the RFMOs is to move fisheries management towards an ecosystem-based approach, since although in the last decade the RFMOs have made significant progress towards EAFM, the ecosystem approach is still only used to provide strategic information to decision-makers and not tactical advice. Experts on ecosystem-based approach of the different RFMOs, that is, participants of NAFO WG-ESA, FishEBM BS and FishEBM MED GFCM as well as ICES' advisory and science committees, should address this challenge together to achieve it.

This overview provides clear knowledge of the main differences and similarities among reference point frameworks of each RFMO, helping collaboration between them. Additionally, delving into the reasons behind the consideration and definition of the different reference points in each RFMO could allow possible improvements of the RFMO reference point frameworks to obtain more similar approaches that help collaboration among scientists from different RFMOs.

CRediT authorship contribution statement

Santiago Cerviño: Conceptualization, Writing – review & editing. **Marta Cousido-Rocha:** Methodology, Writing – original draft, Writing – review & editing, Data curation. **Maria Grazia Pennino:** Methodology, Writing – original draft, Conceptualization, Writing – review & editing, Investigation. **Gonzalez Ferando:** Writing – review & editing. **Beatriz Guijarro:** Writing – review & editing. **Ruth Fernandez:** Conceptualization, Writing – original draft, Writing – review & editing. **Diana Gonzalez-Troncoso:** Conceptualization, Writing – original draft, Writing – review & editing. **José Luis Pérez Gil:** Writing – review & editing. **Maria Soto:** Conceptualization, Writing – original draft, Writing – review & editing.

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Data availability

No data was used for the research described in the article.

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