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Improving impact assessments to reduce impacts of deep-sea fisheries on vulnerable marine ecosystems

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ABSTRACT

Robust impact assessments (IAs) for deep-sea fisheries are essential for safeguarding deep-sea ecosystems against the impacts of bottom fishing. In the high seas, United Nations Resolution commitments require States (independently or through Regional Fisheries Management Organisations (RFMOs)) to conduct IAs to evaluate if fishing is putting vulnerable marine ecosystems (VMEs) at risk. To enhance the efficacy of future IAs, this study evaluated nine IAs against the criteria in the FAO International Guidelines for the Management of Deep-Sea Fisheries in the High Seas. We find that in all IAs, the information required by the FAO Guidelines is either completely lacking or only partially addressed. The main shortcoming of the IAs was inadequate description of the ecosystems potentially affected by fishing. Additional shortcomings include incomplete description of the proposed fishing activities, lack of baseline data and risk assessments, and limited consideration of the indirect impacts of fishing. This study identifies several ways to strengthen the IA process; i) making IAs publicly available; ii) improved collection of baseline data and VME identification; iii) assessment of impacts on broader

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range of species associated with VMEs or potentially impacted by deep-sea fishing; iv) enhanced cooperation between RFMOs and more streamlined IA processes; v) comprehensive assessment of different types of impacts from fishing and climate change, and vii) improved consideration of uncertainty. Fully compliant IAs are a minimum requirement for the effective function of RFMOs, since they are the primary tool for preventing significant adverse impacts upon vulnerable marine ecosystems and the wider deep-sea environment.

1. Introduction

Concerns over the environmental impacts of deep-sea fisheries in the 'high seas' (also known as areas beyond national jurisdiction, ABNJ) prompted the United Nations General Assembly (UNGA) to adopt a series of (non-binding) resolutions to address the issue (UNGA resolutions 61/105 and 64/72, Table 1). The UNGA resolution 61/105 adopted in 2006 committed States fishing in the high seas to apply the precautionary approach and ecosystem approach by conducting impact assessments (IAs) to determine whether bottom fisheries would put the deep-sea environment, including vulnerable marine ecosystems (VMEs, Table 2) and non-target fish species, at risk to impacts (UNGA 61/105). Based on the outcome of the IAs, States are committed to prohibit a bottom fishery if it is not possible to demonstrate that the fishery can be managed to "prevent significant adverse impacts on vulnerable marine ecosystems" (UNGA 61/105). Despite progress made by States,

Table 1
Overview of the United Nations General Assembly (UNGA) resolutions relevant for deep-sea fishing impact assessments in the high seas.

UNGA resolution	Year adopted	Description
UNGA 61/105	2006	Committed States fishing on the high seas to apply the precautionary approach and ecosystem approach through conducting impact assessments (IAs) to determine whether bottom fisheries would put potential vulnerable marine ecosystems at risk. Based on the outcome of the IAs, States further committed to prohibit a bottom fishery if it was not possible to demonstrate that the fishery can be managed so as to "prevent significant adverse impacts on vulnerable marine ecosystems"
UNGA 64/72	2009	Called on States and RFMO/As to: "conduct the [impact] assessments consistent with the [FAO] Guidelines, and to ensure that vessels do not engage in bottom fishing until such assessments have been carried out" (paragraph 119 (a)) and reinforced the call on flag States and RFMO/As to adopt and implement measures: "…consistent with the [FAO] Guidelines, and not to authorise bottom fishing activities until such measures have been adopted and implemented" (paragraph 120).
UNGA 71/123	2016	Committed States and RFMO/As: "to ensure that impact assessments, including for cumulative impacts of activities covered by the assessment, are conducted consistently with the [FAO] Guidelines, particularly paragraph 47 thereof, are reviewed periodically and are revised thereafter whenever a substantial change in the fishery has occurred or there is relevant new information, and that, where such impact assessments have not been undertaken, they should be carried out as a priority before authorising bottom fishing activities".

Table 2
Glossary of key definitions.

Abbreviation	Full name	Definition
FAO guidelines	FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas (2009)	Based on a decision made by countries at the 2007 meeting of the UN FAO Committee on Fisheries, states negotiated a set of guidelines – the International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (often referred to as the 'FAO Guidelines') through a political process set up under the auspices of the UN FAO. The FAO Guidelines establish internationally agreed criteria for conducting IAs of high seas bottom fisheries (paragraph 47), identifying vulnerable marine ecosystems (paragraph 42) and assessing for significant adverse impacts on benthic and pelagic ecosystem components from fishing activities (paragraphs 16–20). The Guidelines were subsequently endorsed by the UN General Assembly, in UNGA resolution 64/72 adopted in 2009.
RFMO/A	Regional Fisheries Management Organisation or Agreement	International organisations regulating regional fishing activities in the high seas. Countries with fishing interests in a given geographical area form specific RFMO/As.
SAI	Significant adverse impact	The FAO Guidelines define Significant Adverse Impacts as those that compromise ecosystem integrity by altering ecosystem structure or function in a permanent or long-lasting manner. The FAO Guidelines established six factors that should be considered when determining the scale and significance of an impact: 1. intensity or severity of the impact at the specific site being affected; 2. spatial extent of the impact relative to the availability of the habitat type affected; 3. sensitivity/vulnerability of the ecosystem to the impact; 4. ability of an ecosystem to recover from harm, and the rate of such recovery; 5. the extent to which ecosystem functions may be altered by the impact; 6. timing and duration of the impacts relative to the period in which a species needs the habitat during one or more of its life-history stages. The Guidelines define temporary impacts as those that are limited in duration and allow the ecosystem to recover over an acceptable period of time (set to 5–20 years).
VME	Vulnerable marine ecosystem	Vulnerable marine ecosystems (VMEs) are defined by the FAO Guidelines as populations, communities or habitats that are easily damaged and slow to recover from impacts of short-term or chronic disturbance; in this context, bottom-contact fishing activities. Criteria for identifying VMEs include: • Uniqueness or rarity • Functional significance of the habitat • Fragility • Life-history traits of component species that make recovery difficult, e.g., slow growth rates associated with longevity, and episodic recruitment. • Structural complexity To facilitate identification of VMEs, the FAO Guidelines provide examples of populations, communities, habitats, and features that could support VMEs (paragraph 42 and Annex 1 of the FAO Guidelines). In addition to these examples, RFMOs have identified VME indicator taxa present in their jurisdictions that when present in bycatch signifies the possible occurrence of VMEs. In areas where VMEs have been identified and fishing activities are assessed to cause, or likely cause, SAIs, the FAO Guidelines recommend a range of conservation and management measures to prevent SAI on VMEs (e.g., paragraph 70–71).

independently or through Regional Fisheries Management Organisations and Agreements (hereafter referred to collectively as RFMOs), in conducting IAs, concerns have been raised about whether the IAs follow the internationally agreed criteria and commitments in the UNGA resolutions [1,2].

The footprint of deep-sea fishing extends across all ocean basins and includes the jurisdictional waters of nations, as well as the high seas [3,4]. In the high seas, deep-sea fishing grounds include continental slopes, seamounts, ridge systems, banks, and canyons [5]. Deep-sea bottom fisheries account for just 0.5 % of global marine fish landing [4], yet they may have detrimental and long-lasting impacts on deep-sea ecosystems [6]. Commonly described impacts include direct physical disturbance of the seafloor, resulting in removal or damage to benthic organisms through the use of bottom-contact fishing gear, including bottom trawling, bottom longlining, and gillnets [7] (Fig. 1). Bottom trawling produces the highest rates of discards when compared to other fishing methods [8]. Bottom longlining, while affecting a smaller area than trawling, can still impact organisms through crushing, movement (dragging, rolling, bouncing [9]), and unintentional bycatch [10]. Entangled, lost and/or discarded gear within a fished area causes additional impacts, leading to continuous ghost fishing and damage to the habitat [11].

The impacts of deep-sea fisheries are compounded by the longevity, slow growth rates, and reproductive characteristics of many deep-sea species, including those targeted for fishing [12–14]. Recovery times for impacted seafloor communities and fish populations are estimated to range from decades to centuries [6,15–18]. Many exploited deep-sea fish populations, such as the Antarctic toothfish (*Dissostichus mawsoni*) and roughhead grenadier (*Macrourus berglax*), face heightened risks of local or global extinction due to their vulnerability to fishing pressure and climate change [19].

Deep-sea bottom fisheries in the high seas are managed by seven RFMOs and one Antarctic Treaty organisation and these bodies have a legal mandate to enact binding measures in ABNJ. In addition, there are two regional fisheries bodies in the equatorial Atlantic,[1] which are limited to advisory roles. There are also large areas where bottom fishing is not regulated by an RFMO (Fig. 2).

To determine whether fishing can be conducted in a sustainable manner that prevents impacts on VMEs, States agreed on criteria for conducting IAs for deep-sea fisheries through a set of guidelines negotiated under the auspices of the United Nations Food and Agriculture Organisation (FAO) (International Guidelines for the Management of Deep-Sea Fisheries in the High Seas, hereafter referred to as the FAO Guidelines, see Tables 2–3). The FAO Guidelines were adopted in 2008 [20] and later that year the UNGA expressly committed states to ensuring that bottom fishing is prohibited unless prior IAs, consistent with the FAO Guidelines, have been carried out (UNGA 64/72). The key provisions of the (non-binding) FAO Guidelines establish internationally agreed criteria for conducting IAs of deep-sea fisheries (paragraph 47; Table 3), identifying VMEs (paragraph 42), and conducting assessments of Significant Adverse Impacts (SAIs, Table 2) (paragraphs 16–20)[20]. States must use IAs to evaluate the impacts fishing activities are having or are likely to have on the environment, particularly VMEs and target and non-target fishes. The Guidelines also commit States and RFMOs to make the IAs publicly available to allow other States, scientists, non-governmental organisations (NGOs), and other concerned parties to evaluate the assessments (para. 51 of the FAO Guidelines). States also agreed to stop fishing activities in areas where VMEs are known or likely to occur unless the fishing can be managed to prevent SAIs on VMEs (UNGA 61/105). In 2016, UNGA resolution 71/123 stressed the importance of IAs as the primary means for implementing previous resolutions, urging states and RFMOs to consistently conduct IAs, including cumulative impacts, in accordance with FAO Guidelines (UNGA 71/123). This resolution emphasised the need for periodic reviews and revisions when substantial fishery changes occur, or relevant new information emerges. The resolution also prioritised conducting IAs before authorising bottom fishing activities in cases where they have not been undertaken.

Under international law, States are required to “assess the impacts of fishing, other human activities and environmental factors on target stocks and species belonging to the same ecosystem or associated with or dependent upon the target stocks” (1995 UN Fish Stocks Agreement (Article 5(d)). Most of the RFMOs have adopted measures to implement the provisions of the UNGA resolutions on managing deep-sea fisheries in the high seas and key provisions of the FAO Guidelines [1,2], including IAs (Table 4). However, previous studies show how the implementation of the resolutions and criteria varies widely across RFMOs and States and is often unsatisfactory [2,21,22]. These differences are driven by the age of the organisation, the capacity of its members to conduct the requisite research, and its legal status[1]. While concerns have been raised about the effectiveness of IAs in the high seas, their compliance with respect to the UN resolutions is yet to be systematically evaluated.

This study evaluates the compliance of IAs with UN resolutions by scrutinising the content and consistency of a specific set of IAs against the science-based criteria in the FAO Guidelines. We

identify criteria that are fulfilled and those that are not, discuss prominent challenges with the IAs, and offer recommendations for enhancing their compliance with the UNGA resolutions.

2. Material and methods

We evaluated nine IAs to gain an overview of different approaches for conducting IAs and their compliance with the UNGA resolutions to avoid SAIs on VMEs and the wider deep-sea environment (Table 5). The selected IAs represented: 1) primary fisheries occurring in the high seas across different ocean basins; 2) geographical variability (i.e., IAs prepared by different States and RFMOs); 3) fishing conducted by different gear types; and 4) the accessibility of documents. This review only includes documents which were publicly available online or could be accessed through the RFMOs' online documents libraries. We attempted to seek out additional IAs directly from RFMO Contracting Parties but were not successful, in particular from CCAMLR where we were unable to access any IA. As there is no shared repository for all IAs prepared by individual States or submitted to RFMOs, we could not evaluate the total number of all IAs conducted to date or how many of these IAs would be publicly available. We are therefore not able to assess the representativity of our sample of IAs and cannot make quantitative estimates of the entirety of all IAs done. The most recent version of the IA and any known updates to the IA were considered in the review. We also acknowledge the IA related process by NEAFC, carried out by ICES [24], which only focuses on VME identification. As no other information on the NEAFC IA procedure is publicly available to support a comprehensive review, we have omitted this RFMO from the study.

The reviewed IAs included both those focusing on the fishing activity and estimating the intensity of fishing in specific areas, and those prioritising assessment of VMEs to estimate impacts of fishing. Most of the reviewed IAs are for existing fisheries or for past fishing activities. In the case of the Southwest Atlantic where no RMFO has been established, an IA conducted by the Spanish Institute of Oceanography for the bottom trawl fishery by the Spanish fleet operating in the high seas in the Southwest Atlantic was selected. We acknowledge that the nine IAs do not fully portray all existing approaches taken by RFMOs and States or cover all high seas regions where bottom fishing occurs but consider that they provide a representative sample of different methodological approaches to assess impacts of fishing in the high seas as required by the UNGA resolutions. Due to difficulties in accessing IAs, stemming from documents not being publicly available and RFMO contracting party

[1] Fisheries Committee for the Eastern Central Atlantic (CECAF) and Western Central Atlantic Fishery Commission (WECAFC).

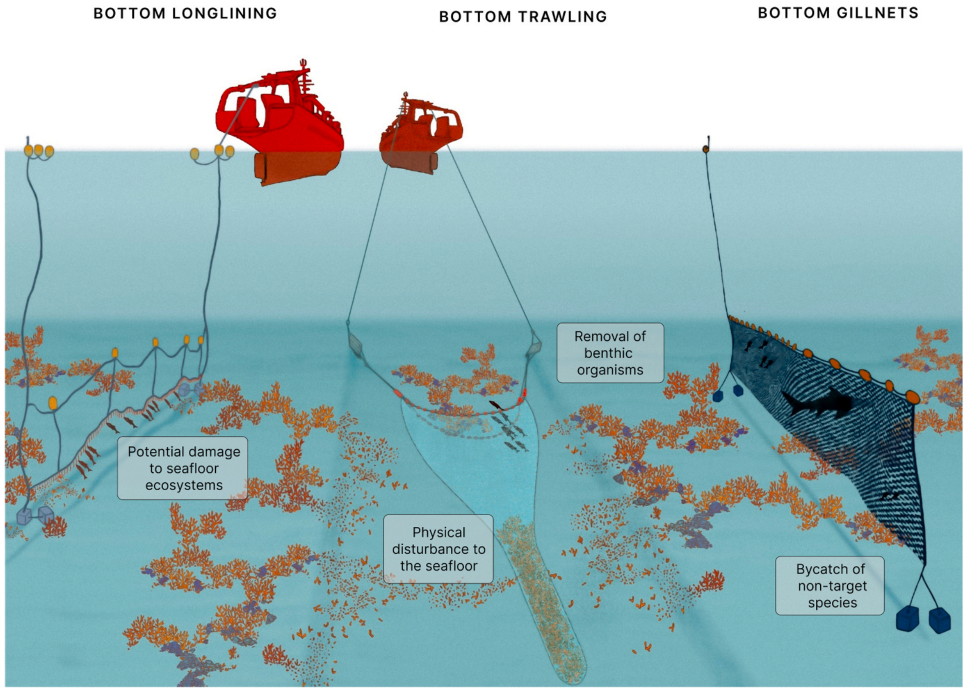

Fig. 1. Overview of the deep-sea fishing methods that are evaluated by impact assessments. Bottom long-line fishing (left) may harm structure-forming organisms, such as coral and sponges when the fishing gear is retrieved from the bottom. Bottom trawling (middle) is considered to be the most damaging to benthic ecosystems as the gear is dragged across the seabed [23]. Bottom gillnet fishing (right) causes mortality of non-target species and if lowered directly onto the seafloor, may harm vulnerable marine ecosystems. Figure not to scale.

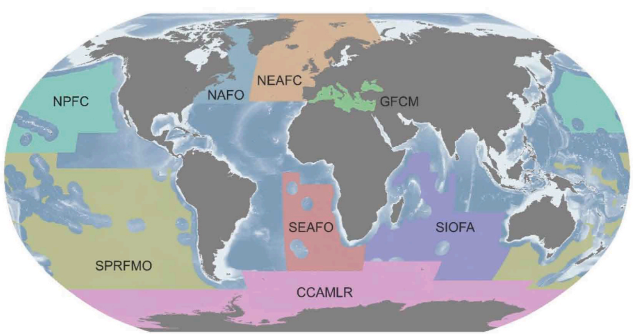

Fig. 2. Map of the RFMOs and CCAMLR regulating bottom fisheries in the high seas. Source of shapefiles: FAO. NAFO - Northwest Atlantic Fisheries Organisation, NEAFC - North East Atlantic Fisheries Commission, SEAFO - South East Atlantic Fisheries Organisation, CCAMLR- Commission for the Conservation of Antarctic Marine Living Resources, SIOFA - Southern Indian Ocean Fisheries Agreement, NPFC - North Pacific Fisheries Commission, SPRFMO - South Pacific Regional Fisheries Management Organisation.

representatives not responding to our requests to access IAs, the reviewed IAs do not fully cover all major fisheries in the high seas. Many of the countries represented are, however, among the top bottom fishing countries in terms of annual landings in the past decades [5].

To evaluate how well the selected IAs addressed the IA criteria of the FAO Guidelines (Table 3), we developed a review form (Table 6) to aid in the assessment of whether the IAs provide sufficient information to evaluate the impacts of fishing activities on VMEs and low productivity fishery resources. The aim of the form was to enable standard evaluation of contents of the IAs. The review form included both multiple-choice and open-ended questions based on the IA criteria in the FAO Guidelines [20]. Open-ended questions were used to record detailed aspects of the methods and the scope of the different sections of the IAs (e.g., 'what is the focus of the risk assessment') and were always accompanied by a multiple-choice question that was used to simplify the result for the final assessment.

Where possible, the questions were formulated to be answerable with the following grading system:

No: No mention of the topic in the IA or relevant terms appear in general preambles or as passing mentions in various parts of the document but not in the overall aims or specific objectives of the impact assessments, suggesting that the criteria were not the focus of the evaluation.

Partial inclusion: Key terms appear in the document, but no detail is presented in subsequent sections that focus on the specific criteria or only part of the topics included in the sections are covered.

Yes: Key terms of the criteria appear in clearly stated sections and are discussed in the IA. There was clear discussion in the document of how the criteria in question was analysed.

In cases where the criteria could not be directly simplified to this grading system, the results from the multiple choice and open-ended were used to assign a grade to the section by the reviewers. This same system was used to grade each section of the IAs (grouped by the criteria in the FAO Guidelines), based on the open-ended review results and the grade for each subsection of the IA criteria (questions in Table 6). The overall grade for each criterion (shown in Fig. 4 in the results section) has been attributed based on the assessment result on most of the subsections (questions) of the criteria (i.e., the overall grade for a section does not mean all the questions in that section received the same grade, but there may have been parts of the IA that were better or worse addressed within the same IA criterion, see Supplementary for full results).

The selected IA documents were reviewed by the authors of this study who represent a multidisciplinary group of deep-sea ecology, fisheries, and policy experts. Each IA document was evaluated by 2–3 reviewers. The results were discussed among the reviewers to reach an agreement on the assessment results. Where there was discrepancy between the reviewer assessments, preference was given to the 'partially addressed' option, with additional comments included in the final

Table 3
Criteria for carrying out impact assessments (IAs) outlined in paragraph 47 in the International Guidelines for the Management of Deep-sea Fisheries in the High Seas [20].

"47. Flag States and RFMO/As should conduct assessments to establish if deep-sea fishing activities are likely to produce significant adverse impacts in a given area. Such an impact assessment should address, inter alia:
i. type(s) of fishing conducted or contemplated, including vessels and gear types, fishing areas, target and potential bycatch species, fishing effort levels and duration of fishing, harvesting plan;
ii. best available scientific and technical information on the current state of fishery resources and baseline information on the ecosystems, habitats and communities in the fishing area, against which future changes are to be compared;
iii. identification, description and mapping of VMEs known or likely to occur in the fishing area;
iv. data and methods used to identify, describe and assess the impacts of the activity, the identification of gaps in knowledge, and an evaluation of uncertainties in the information presented in the assessment;
v. identification, description and evaluation of the occurrence, scale and duration of likely impacts, including cumulative impacts of activities covered by the assessment on VMEs and low-productivity fishery resources in the fishing area;
vi. risk assessment of likely impacts by the fishing operations to determine which impacts are likely to be significant adverse impacts, particularly impacts on VMEs and low-productivity fishery resources; and
vii. the proposed mitigation and management measures to be used to prevent significant adverse impacts on VMEs and ensure long-term conservation and sustainable utilisation of low-productivity fishery resources, and the measures to be used to monitor effects of the fishing operations."

Table 4
Overview of impact assessment (IA) practices and equivalent process of the high seas bottom fishing RFMOs.

RFMO/A	Summary of IA practices
CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources)	IAs carried out by Contracting Parties in respect of their flagged vessels authorised to bottom fish.
GFCM (General Fisheries Commission for the Mediterranean)	No IAs conducted: The GCFM has not completed IAs and does not have any requirements to provide them.
NAFO (Northwest Atlantic Fisheries Organisation)	IAs conducted by the NAFO 'collective' assessments of the bottom fishing fleets by all countries combined, primarily focused on identifying areas where VMEs are known to occur within a bottom fisheries 'footprint'.
NEAFC (North East Atlantic Fisheries Commission)	IA-equivalent process focused on protection of VMEs is carried out by the International Council for the Exploration of the Sea (ICES), which plays the same role as the Scientific committees for other RFMO/As, using data supplied by NEAFC Contracting Parties. Advice from the process is supplied annually to the NEAFC Scientific Committee.
NPFC (North Pacific Fisheries Commission)	IAs carried out by Contracting Parties with respect to their flagged vessels authorised to bottom fish.
SEAFO (South East Atlantic Fisheries Organisation)	IAs carried out by a single Contracting Party under an exploratory fisheries protocol, based on the FAO Guidelines, for fishing in new areas outside of areas designated as existing or permissible fishing areas.
SIOFA (Southern Indian Ocean Fisheries Agreement)	IAs carried out by Contracting Parties with respect to their flagged vessels authorised to bottom fish.
SPRFMO (South Pacific Regional Fisheries Management Organisation)	IAs carried out by Contracting Parties with respect to their flagged vessels authorised to bottom fish.

assessment to clarify which parts of the criteria had been addressed (see full results in Supplementary information).

3. Results

Proportionally, the highest compliance with the FAO Guideline criteria was for description of the data and methods used, which were well described in four out of the nine IAs. Overall, the main shortcoming of the IAs was the inadequate description of the ecosystems potentially affected by fishing and the assessment of the impacts of fishing. In addition, mitigation and management measures were only partially covered in most IAs. The results comparing the IA criteria against the FAO Guidelines are summarised in Figs. 3–4 and described below by assessment criterion. For full results and examples, please see supplementary information.

3.1. *Criterion i. Description of fishing activity*

Description of the fishing gear and vessels was overall the best covered criterion (Fig. 3) as all IAs contained some information about the fishing activity (Fig. 4). In Spain's IA for SPRFMO the gear and vessels were described only in diagrams which were illegible due to poor image quality, and Japan's IA for NPFC only mentioned the used gears without vessel information.

Information on the fishery was often brief, with one IA not containing any information on the fishery target species (Japan-NPFC) and two out of nine IAs only including a list of targeted species with no further information (Spain-SPRFMO, and Japan-SIOFA). Bycatch information was given at a coarse taxonomic level, and mostly concerned bycatch of VME indicator taxa. In certain IAs, chondrichthyans and seabirds were listed as potential bycatch species (Cook Islands-SIOFA, Australia-NZ IA for SPRFMO and the NAFO IA). While some IAs mentioned high (up to 100 %) observer coverage on the fishing vessels, no bycatch data (e.g., species caught as bycatch and the amounts) were presented in the IAs.

3.2. *Criterion ii. Baseline data*

The description of the baseline information on the current state of fishery resources and environment was limited in the reviewed IAs (Fig. 5, A). Only three IAs contained specific information on the stock status of the target species, and four out of the nine IAs did not contain any information on the environmental conditions or habitats in the areas targeted for fishing. In many IAs, additional information was suggested to be available, but was not presented or referenced in the documents.

Most IA documents lacked baseline information on ecosystem components beyond targeted species, with the few including environmental data focusing primarily on VME indicator taxa and benthic fauna. An exception to this was the Australian-NZ IA for SPRFMO, which included estimates of the distribution of seabirds that could be directly affected by the fishing activity. Information on pelagic ecosystem components, including non-target fish species, were missing in all documents, except for certain fish species (teleosts and chondrichthyes) mentioned briefly as potential bycatch for the fishery.

3.3. *Criterion iii. VME identification*

The definitions of VMEs varied in the reviewed IAs. Some explicitly listed taxa as indicators for potential VME presence. For example, the joint SPRFMO IA by Australia and New Zealand used VME indicator taxa

Table 5
Overview of the reviewed impact assessments. Full details of the documents are contained in Supplementary material.

Document title	Submitted / prepared by	RFMO/A	Area	Year	Abbreviation used in this study
Cook Islands SIOFA Bottom Fishery Impact Assessment	Cook Islands	SIOFA	Southern Indian Ocean	2018	Cook Islands-SIOFA
Australian report for the Southern Indian Ocean	Australia	SIOFA	Southern Indian Ocean	2011 (with an update from 2020)	Australia-SIOFA
Provisional Bottom Fishing Impact Assessment for Japanese bottom trawl fisheries in SIOFA convention area	Japan	SIOFA	Southern Indian Ocean	2017	Japan-SIOFA
Cumulative Bottom Fishery Impact Assessment for Australian and New Zealand bottom fisheries in the SPRFMO Convention Area, 2020	Australia and New Zealand	SPRFMO	South Pacific	2020	Australia-NZ SPRFMO
An assessment of the potential impacts of Japanese bottom fisheries on vulnerable marine ecosystems (VMEs) within fished seamounts of the Emperor Seamounts region	Japan	NPFC	North Pacific	2018	Japan-NPFC
Study of Vulnerable Marine Ecosystems in international waters of the Southwest Atlantic	Spain	No RFMO	Southwest Atlantic	2012	Spain-SW Atlantic
Report of the NAFO Scientific Council Meeting 2021	NAFO Working Group on Ecosystem Science and Assessment (WG-ESA)	NAFO	Northwest Atlantic	2021	NAFO
Notice of Intent and preliminary impact assessment for the 2019 exploratory fishing by Japan	Japan	SEAFO	Southeast Atlantic	2019	Japan-SEAFO
Spanish IA for its proposed deepwater bottom gillnet fisheries in the South Pacific	Spain	SPRFMO	South Pacific	2009	Spain Gillnet-SPRFMO

defined by the SPRFMO Scientific Committee [25]. NPFC and NAFO assessments referred to RFMO-defined taxa based on FAO VME criteria. However, the NPFC IA focused on a limited number of coral groups as VME indicators. In some cases, IAs referenced definitions from other entities; for instance, Australia's SIOFA IA based its definitions on CCAMLR taxa [26]. While some RFMOs have known VME indicator taxa lists, not all IAs explicitly mentioned them. In cases with no formal definition, live corals and sponges were cited as VME indicator taxa considered in bycatch monitoring.

Bycatch information from observer programmes and/or fishery logbooks, and trawl catches from scientific fishery surveys were the most common data sources for inferring the location of potential VMEs (Fig. 5C). Only two IAs, Spain's evaluation of VMEs in the SW Atlantic and Japan's assessment in the NPFC area, utilised visual seafloor surveys to identify VMEs. In the case of Japan, only a small selection of the many images taken have been made public. These assessments primarily concentrated on mapping VMEs rather than providing extensive information on fishing impacts. In the Cook Islands' IA for SIOFA, acoustic seafloor mapping was employed, but the document lacked details regarding the validation of the mapping results.

Habitat Suitability Models (HSMs) or Species Distribution Models (SDMs) were used in three of the analysed IAs to identify the distribution of potential VMEs (Fig. 5C). In the NAFO and SPRFMO IAs, the VME indicator taxa data underpinning the modelling were based on scientific surveys and VME indicator taxa bycatch data. The NAFO assessment referred to a previous submission to the NAFO Scientific Committee for the presentation of validation results not included in the reviewed IA [27]. The Spanish IA in the SW Atlantic also used modelling techniques, yet the IA lacks detailed information on this aspect, which is more thoroughly explained in an English translation of the study [28].

3.4. Criterion iv. Description of data and methods used

Most of the data presented in the IAs originated from fishery logs or other data sources related to fishing activities, including bycatch data, vessel monitoring system (VMS) data, and observer data (Fig. 5B). Most of the reviewed documents exhibited ambiguity regarding the data used in their IA (Fig. 4). While certain data sources were more thoroughly described than others, all documents included sources that could not be independently verified. The documents often lacked clear specifications for data and units. Some, like the Spain gillnet IA for SPRFMO and Cook Islands IA for SIOFA, showed no data, while others, including the Australian-NZ IA for SPRFMO, provided only partial data. In some cases, units, such as those for "fishing footprint" in the Australian IA for SIOFA, were not specified.

Out of the nine IAs, four lacked details on the assessment methods. Some IAs presented evidence, including fishing footprint calculations, but lacked clarity on defining fishing impacts on VMEs and other ecosystem components. In contrast, detailed methods were provided by IAs like NAFO, Australian-NZ for SPRFMO, and Japan for NPFC. Two IAs used modelling with generally well-described methodologies.

The majority of IAs failed to convey the uncertainties inherent in the diverse analyses they encompassed. This issue spanned from overlooking discussions on data gaps to neglecting the incorporation of uncertainties' impacts in the conclusive assessment. The most common data gaps mentioned were related to the location of potential VMEs, and uncertainties were best addressed with respect to model uncertainty for estimating VME indicator taxa occurrence in IAs that used SDMs and HSMs.

3.5. Criterion v. Assessment of potential impacts

Most of the reviewed documents concentrated on the direct effects of fishing gear on benthic populations, communities, and habitats, overlooking assessments of impacts on other ecosystem components. An exception was the Australian-NZ IA for SPRFMO, which explored potential impacts on teleosts, sharks, rays, and seabirds. Although some IAs mentioned potential effects on bycatch taxa such as chondrichthyes, none of the examined assessments delved into the impacts on other pelagic organisms, including fishes, crustaceans, and cephalopods. Even in the case of IAs that provided a list of potential bycatch taxa, they did not discuss how they are affected by fishing. None of the IAs provided definitions for the term "low-productivity fishery resources" (e.g., non-target fish species, shellfish, cephalopods) or elaborated on the potential impacts on these organisms.

The only IA that quantitatively addressed SAIs was conducted by NAFO, basing it on the spatial coverage of potentially impacted habitats or communities. Other IAs approached SAIs more broadly, either defining it as any bottom-contact fishing activity and the status of VME indicator taxa (Australian-NZ IA for SPRFMO and Japan-NPFC) or referring to formal definitions of SAIs (Australia-SIOFA). Five out of nine IAs did not provide a definition for SAIs within the IA. Some assessments (e.g., Japan-SEAFO) claimed reduced risk of SAIs due to specific fishing gears, like longlining, but lacked clear references to evidence supporting

Table 6
Review form used to evaluate the impact assessments based on the impact assessment criteria in the FAO Guidelines [20].

Criterion number and topic under paragraph 47 of the FAO Guidelines	Question
i. Description of the fishing activity	Does the document describe the vessels and gear types used? Does the document include a harvesting plan? Are fishing grounds described in the document (location and spatial extent)? Does the document describe target species (including a list of species, their ecology, and population status)? Does the document describe potential bycatch species (including a list of species, their ecology and population status)?
ii. Baseline information	Does the document contain information on the state of the fishery resource? Does the document contain information on the topographical, environmental, and other features of the area relevant to assessing the ecological vulnerability† of the area? Does the document describe abiotic hydrographic properties of the area (e.g., T, S, O2, pH) likely to change over time and affect habitat suitability for target species? Are the biological components of the ecosystem, and information on their life history characteristics, connectivity, source and sink populations and other relevant information described in the document? Are variations in species composition, community structure by depth, latitude etc (e.g., 'biomes') specified, including both 'VME indicator' and other species belonging to the VME ecosystem?
iii. Identification of VMEs	What definition and criteria of VMEs is/are used (e.g., are existing definitions from literature cited, list of taxa/topographical features or other areas e.g., where "rare" species are known or likely to occur?) What methods are used to identify potential VMEs? If modelling studies or acoustic mapping is used, have the findings been validated?
iv. Description of data and methods used	What kind of data/information is used to assess impacts (e.g., empirical data, literature, modelling, expert assessment, fishery logs, traditional or local knowledge, not specified)? Does the impact assessment document describe (or present) the data used in the assessment? Does the impact assessment document describe the methods used in the assessment? Are the limitations and uncertainties of the assessment (e.g., gaps in data) acknowledged and how are they addressed?
v. Assessment of potential impacts	Does the document describe the spatial extent of direct impacts on the seafloor communities? Does the document describe or discuss the spatial extent of indirect impacts to nearby areas and depth zones? Does the document identify impacts on pelagic organisms (including bycatch species; low productivity 'fishery resources', rare species (cross reference paragraph 42), other species potentially impacted by the fishing)? Does the document define what the authors consider significant adverse impacts (SAI, reference paragraphs 17–20 in FAO Guidelines)? Does the document describe the temporal extent of the impacts? Are cumulative impacts‡ evaluated (i.e., is historical fishing impacts accounted for? Are interactions between different pressures evaluated e.g., climate-related impacts)? Is climate vulnerability included in the VME assessment? (e.g., discussion of warming, deoxygenation, acidification impacts). Is the scale on which impacts are evaluated (e.g., low/high impact) explained? Does the impact assessment demonstrate the basis on which conclusions of the severity of the impacts are drawn?
vi. Risk assessment	Are the potential risks identified? What is the focus of the risk assessment (e.g., fisheries/VMEs)? What type of a risk assessment is applied? Is the risk assessment methodology (adequately) described?
vii. Mitigation measures and monitoring	Are possible mitigation measures described? Does the document identify how to monitor implementation of these measures? If so, has the monitoring demonstrated that the mitigation measures are having the intended effect? Are alternative fishing scenarios identified (including displacement of activity, change of gear types, restricting fishing effort and its spatial footprint, and no fishing)? Does the document compare impacts of these alternatives to the proposed implementation plan?

† Ecological vulnerability refers to the potential of an ecosystem to modulate its response to fishing impacts across spatiotemporal scales - therefore accesses the inability of an ecosystem to tolerate the impacts of fishing
‡ Cumulative impacts in this context are considered to encompass the different pressures arising from fishing, accumulated effects of past fishing, as well as cross-sectoral impacts and environmental changes

the lesser bottom impact of different gear types. Overall, detailed justifications for the final impact statements were lacking in the reviewed IAs.

Cumulative impacts were not included in the assessment in seven out of the nine reviewed IAs. When cumulative impacts were considered, the focus was on direct effects from past fishing activities. Most IAs concentrated on the assessed fishing activity, without evaluating the presence of other industries and fisheries in the area, except for the Australian-NZ IA for SPRFMO and NAFO. Although several documents mentioned cumulative impacts from other sectors on the environment, these were not formally considered in the assessment or the subsequent management guidance. None of the IA documents addressed climate-change-related impacts, such as those induced by warming/stratification, acidification, or deoxygenation.

3.6. Criterion vi. Risk assessment

In four out of the nine IAs, risk assessments (RAs) were either absent (Fig. 5D) or inadequately described in terms of methodology. Among the IAs that included an RA, only three were quantitative or semi-quantitative, providing a concise overview of the applied methodology and information sources (Australian-NZ IA for SPRFMO, NAFO IA, and Australia-SIOFA). Three out of the nine RAs were qualitative, presenting a risk level statement without further analysis. Some IAs featured various types of RAs, while certain sections titled "Risk Assessment" lacked fundamental elements, raising questions about the validity of categorising them as RAs without data, expert assessments, methodology descriptions, or information on assessment sources.

In IAs containing an RA, the focus was on assessing the risk of SAIs on VMEs. An exception was the Australian-NZ IA for SPRFMO, which conducted separate RAs for various taxa, including seabirds, marine mammals, reptiles, fish stocks, and deep-water chondrichthyes. None of the RAs directly addressed potential impacts on low-productivity fishery resources.

3.7. Criterion vii. Mitigation measures and monitoring

VME encounter protocols ('move-on rules') and observer

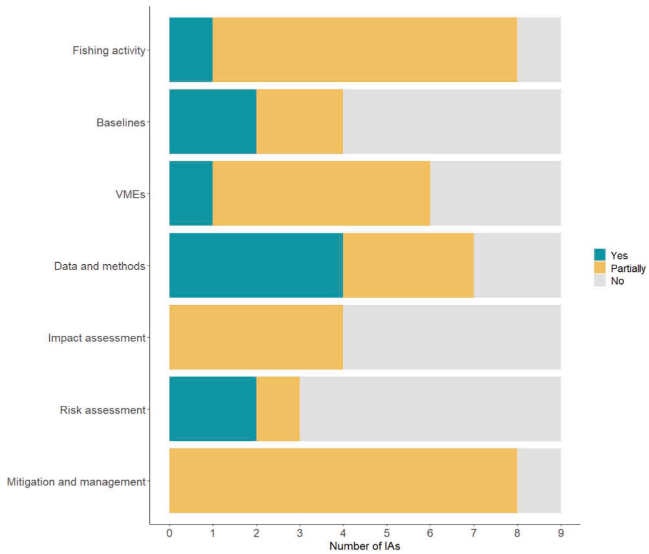

Fig. 3. Summary of the assessment results by IA criteria (for full results of all subcriteria see Supplementary information).

programmes on vessels for bycatch monitoring were the most mentioned mitigation measures to prevent SAIs on VMEs. Additionally, spatial conservation measures, such as fisheries closures, were another commonly mentioned approach to prevent SAIs on VMEs (e.g., NAFO, SPRFMO, and NPFC). Only one IA explicitly discussed the effectiveness and the monitoring of their implementation of these measures (Australian-NZ IA for SPRFMO).

Mitigation measures were deemed unnecessary in several IAs, as the assessments concluded the risk of SAIs on VMEs is low. However, in most cases, these claims lacked thorough justification in the assessment (Fig. 4). Despite containing references to previous studies on the impacts of various fishing gear types on VMEs, the IAs did not offer a robust description of the proposed fishing environment nor evaluate the impacts of the fishing methods to substantiate these conclusions.

Furthermore, the reviewed IAs did not account for the cumulative impact resulting from a sequence of small encounters in their evaluations. While most IAs briefly mentioned measures to monitor fishing effects, two IAs (Spain gillnet IA for SPRFMO and Japan's IA for NPFC, with a focus on VME mapping) lacked any mention of monitoring measures. Monitoring efforts for fishing effects were primarily limited to observer programmes for bycatch monitoring. Despite the majority of reviewed IAs concentrating on ongoing or past fishing operations, none described monitoring efforts for assessing the effects of fishing on VMEs or other ecosystem components.

4. Discussion

4.1. IAs do not provide evidence that SAIs can be avoided

Our assessment of nine high seas bottom fisheries IAs found insufficient evidence that the described fisheries can effectively prevent SAIs on VMEs and/or low-productivity fishery resources. None of the reviewed IAs completely adhere to the FAO Guidelines, as assessed against the criteria outlined in paragraph 47 [20]. While some IAs provide detailed information on certain aspects of the impacts of fishing on VMEs in the high seas, many essential sections and information required by FAO Guidelines are either completely missing or only partially covered. Notably, the lack of formal RAs and missing data undermines the IAs' claims that the fisheries are managed to prevent SAIs. The absence of formal risk assessments in the IAs results in a failure to consider and communicate uncertainties related to the impacts of bottom fishing with respect to the risk of SAIs on VMEs and low-productivity fishery resources [29].

With the exception of the NAFO IA, SAIs were not given quantitative operational definitions in the IAs. The lack of a clear definition is unexpected, considering the FAO Guidelines provide a comprehensive set of criteria for assessing SAIs, which can be adjusted for the specific areas and VMEs under evaluation. The absence of an explicit definition for SAIs hinders the IAs' ability to adequately assess the risk of SAIs, emphasising the importance of establishing clear definitions in the documents and within RFMOs.

Limited data availability, especially with regards to the environment potentially affected by fishing (including VMEs and non-target fishes), is another key factor impeding comprehensive IAs. The paucity of baseline information on the potentially affected ecosystem components in most of the analysed IAs stems from the fact that in many areas few scientific studies have been conducted, particularly in the southern hemisphere [30,31]. Certain RFMOs, like NAFO, have separate, dedicated working groups for assessment of VMEs and target species. Given the absence of much of this information from the reviewed IAs, it is possible that in other RFMOs more information on the environment is available than what was included or directly referenced in the IAs. Therefore, while the absence of this information from work focused upon SAIs is not necessarily a shortcoming of the work of that organisation, this supporting information must be considered in the IAs. If absent, IAs must explicitly address the consequences of missing or incomplete information.

In all IAs, the paucity of data on VMEs in their more holistic sense (e.g., location, associated species, community composition, and connectivity), as opposed to VME indicator taxa, was evident. The lack of direct and comprehensive data on VMEs has major implications on the future management of fishing operations, as it is unlikely that SAIs can be assessed and avoided if such baseline information is missing. In most areas covered by the reviewed IAs, no mapping has been carried out to identify VME locations. If VME indicator taxa are narrowly used, for instance, by modelling the distribution of just one or two species, the uncertainties from such generalisations should be acknowledged in the final assessment. Most of the reviewed IAs lacked consideration for the impacts on other ecosystem components beyond VMEs. Apart from assessing the risks to VMEs, the FAO Guidelines specify that IAs should also consider risks to target species and "low-productivity fishery resources"; most of the deep-sea fishes present [32]. When reporting potential bycatch, the IAs mentioned only a limited number of species and taxonomic groups.

Given the scarcity of data in the deep ocean within the high seas, the primary function of IAs as a management tool for deep-sea bottom fisheries is to navigate the uncertainties, promote precautionary measures, leverage available information, and foster ongoing research and collaboration [33]. To implement the UNGA resolutions, States must conduct IAs that evaluate the impacts fishing activities are having or are likely to have on the environment, and whether these impacts constitute as SAIs. Conducting robust IAs is essential for conserving fish stocks, and also sets a precedent for managing other human activities in the high seas. While States use RFMOs to uphold IAs, promote effective management, ensure sustainability within the deep-sea fishing industry, and the continued health of fish populations and ecosystems, RFMOs do not have agency on their own, but rely on States to agree to a way forward and the respective measures.

4.2. Recommendations to improve IAs in the high seas

Difficulties associated with sourcing IAs leads us to our first recommendation, that RFMOs make the IA and the associated procedures publicly available to comply with FAO Guidelines (Fig. 6). For example, NEAFC does not have an IA available for scrutiny, while CCAMLR Contracting Parties did not consent to share their IAs. The IAs themselves could be improved in several ways. First, the deficiencies in the reviewed IAs with respect to FAO Guideline criteria stem from the IAs not including all the required elements, or only partially considering

IA author	RFMO area	Description of fishing activity	Baseline information	Identification of VMEs	Description of data and methods	Assessment of potential impacts	Risk assessment	Mitigation measures and monitoring
Cook Islands	SIOFA	Partially	No	No (Acoustic mapping)	Partially	No	No	Partially
Australia	SIOFA	Partially	No	Partially (Bathymetry, trawl catches)	Partially	Partially	Partially	Partially
Japan	SIOFA	Partially	No	Partially (Trawl catches)	Partially	No	No	No
Australia-NZ	SPRFMO	Partially	Partially	Partially (SDMs, trawl catches)	Yes	Partially	Yes	Partially
Japan	NPFC	Partially	Partially	Partially (Visual surveys with small spatial coverage)	Yes	Partially	No	Partially
Spain	SW Atlantic (No Competent Authority	Partially	Yes	Yes (Visual surveys, trawl catches, topographical features)	Yes	No	No (N/A)	Partially
NAFO	NAFO	Yes	Yes	Partially (SDMs, trawl catches)	Yes	Partially	Yes	Partially
Japan	SEAFO	Partially	No	No (Long line catches)	No	No	No (N/A)	Partially
Spain	SPRFMO	No	No	No (Bycatch from gillnets)	No	No	No (N/A)	Partially

Fig. 4. Overview of the results of the RFMO IA review for the IA criteria in the FAO Guidelines. The cell responses indicate whether the IA addresses the IA criteria in paragraph 47 of the FAO Guidelines. The overall response is based on the assessment results for the majority of the subsections of the criterion (i.e., certain subsections may have received a different assessment than the overall response shown in the cell; see Supplementary information for detailed results). The note 'N/A' refers to the criterion being completely omitted from the IA. Colours in the table correspond to the evaluation grades.

these criteria. To comply with the IA criteria in the FAO Guidelines, we recommend standardising IA content to include the elements of the seven criteria. The need for a standardised IA and reporting framework for consistent reporting of the potential impacts on VMEs and other impacted biota from bottom fishing activity has already been recognised and applied within some RFMOs [34,35]. In addition to a template that ensures all criteria are addressed, this standardisation could include a toolbox with clear guidelines for identifying which methods are appropriate under which data availability and quality circumstances. This toolbox would offer precise instructions for selecting suitable methods based on data availability and type (qualitative, semi-quantitative, quantitative), approaches for evaluating SAIs, guidance on addressing varying levels of confidence and uncertainties, and strategies for communicating the results across each of the seven criteria. Given the large data gaps in many areas and varying capacity of RFMOs[1], it is important that this standardisation is done as a collaborative effort including all RFMOs and the FAO.

The limited scientific knowledge of the deep-sea environment poses a significant challenge for assessing human impacts on deep-sea ecosystems [36,37]. The paucity of data underpinning the assessment of fisheries impacts and gaps in understanding how deep-sea ecosystems function highlights the need for IAs to better evaluate uncertainties and knowledge gaps and communicate them effectively to support management decisions. IAs should offer detailed descriptions of data sources and methods applied to support statements about the risk or severity of impacts and to ensure transparency and reproducibility. Improving the clarity of methods and data sources, especially regarding the incorporation of expert assessments in the final evaluation, would enhance transparency in the IAs. Although the FAO Guidelines allow the IAs to use "best available" evidence, uncertainties from incomplete datasets or uncertain data and analysis techniques must be explicitly communicated through confidence estimates and reflected in the final outcomes of the IAs.

To support more transparent and robust assessment of risks in the IAs, it is essential to undertake comprehensive RAs as a part of the IAs, where levels of precaution are directly related to the level of uncertainty [38]. By summarising information on the different outcomes, RAs have a significant role in dealing with uncertainty as a part of the IAs [39]. In its

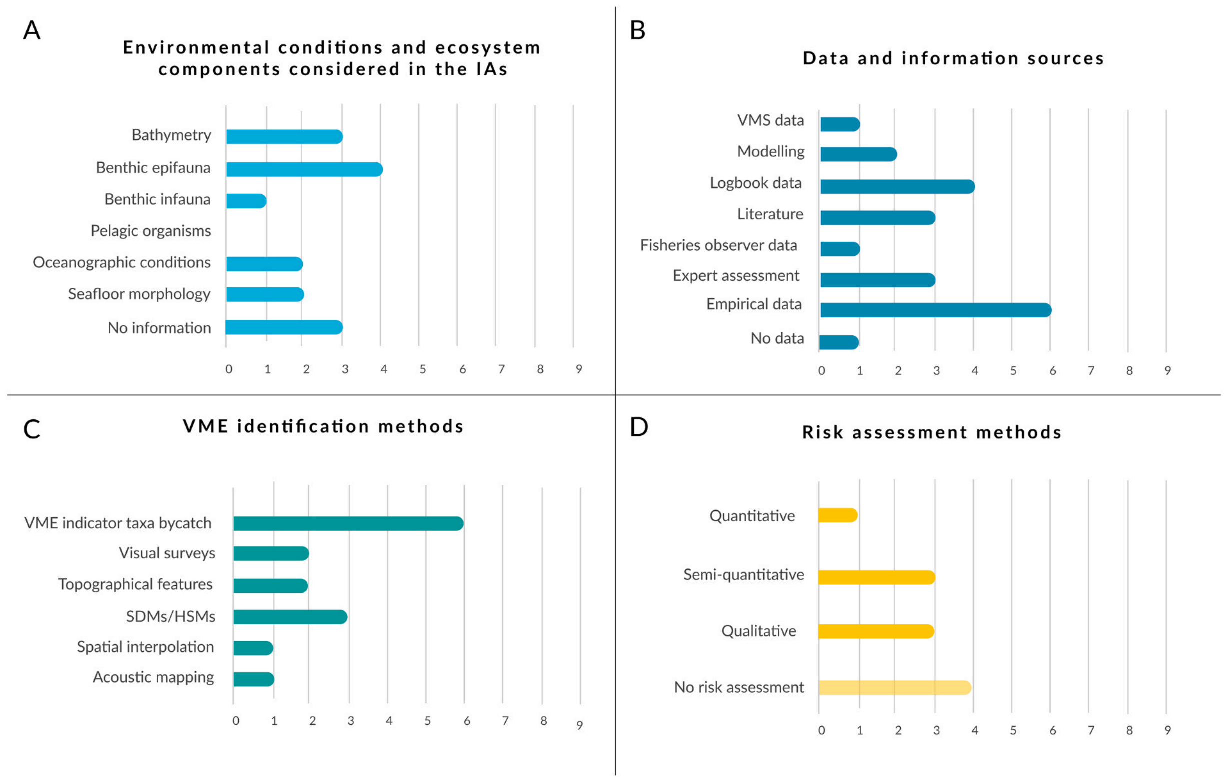

Fig. 5. Overview of the information contained in the nine reviewed IAs: A) Number of the nine reviewed IAs including different ecosystem components in the assessment (excluding the target species for the fishery). The category 'no information' refers to the number of IAs that did not contain any information about relevant environmental conditions, B) Sources of data and information used in the reviewed IAs to assess the impacts of fishing, C) Methods applied in the reviewed IAs to identify potential VMEs, and D) Type of risk assessments used in the IAs. Note that certain IAs contained several different types of risk assessments while some contained none. Acronyms: VMS: Vessel Monitoring System; SDM: Species distribution Model; HMS: Habitat suitability model; VME: Vulnerable marine ecosystem.

simplest form, an RA includes the stages of risk identification, risk analysis (the quantification of risks), and risk evaluation (consideration and comparison of risk reduction measures), with several existing standards to conducting RAs and applying formal risk management procedures (e.g., ISO 2018). The consequences and likelihood for each of the risks (e.g., in the context of fisheries, the risk of SAI on VMEs) should be evaluated separately. Although quantitative RAs are often considered the preferred approach, in instances of data-deficient fisheries or areas with limited understanding of ecological interactions, a qualitative risk assessment often proves to be the most cost-effective solution [40]. Regardless of the type of RA applied, the metrics employed should be tailored to accommodate the available data and must be thoroughly justified. For example, the assessment should include a clear definition of what constitutes low and high risk in order to ensure a well-founded evaluation [41].

Along with better consideration of uncertainties, additional efforts from fishing nations are needed to improve the knowledge base of the IAs to assess impacts of fishing. In the absence of comprehensive surveys in many areas, a cost-efficient option is to use publicly available deep-ocean data [42]. Furthermore, there already exist various useful outputs from global datasets that can be used to provide relevant ecological information for IAs. For example, information on the distribution of biogeographic provinces can be used to contextualise the potential effects of fishing in a broader ecological context [43–45]. However, the use of such proxies should not be seen as an alternative to updating scientific information on deep-sea ecosystems and continued data collection on the distribution of VMEs and their composite species within an RFMO's area of competence.

Improved VME identification requires employing additional suitable methodologies to complement the commonly used trawl by-catches. Research has shown that trawl by-catches underestimate the biomass

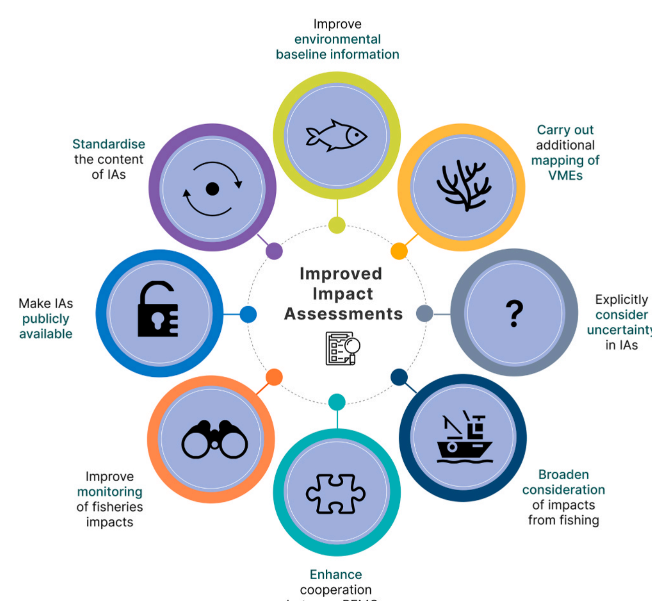

Fig. 6. Overview of the recommendations to improve impact assessments for deep-sea fisheries in the high seas.

and community composition of seafloor communities [46,47]. Underwater imagery (e.g., using Remotely Operated Vehicles (ROVs), Autonomous Underwater vehicles (AUVs), or towed cameras) has proved effective for collecting information on VMEs [48,49], as it allows description of community composition and associated fauna, determination of the extent of the associated habitat, and assessment of the damage caused by particular fishing gears [50]. However, due to high cost of operations associated with most *in situ* surveys (but see [51] for more affordable approaches), direct observations of VMEs are only available for a small fraction of the deep seabed [49]. The best compromise is to use detailed, sustained, multi-mode approaches (e.g., integrated acoustics, imaging, direct sampling, genetics) at study sites to identify good proxies for biodiversity [52]. Simpler broad-scale approaches that can measure these proxies in a standardised way could then be applied across RFMO areas.

Acknowledging the limited scientific knowledge, some RFMOs are undertaking seafloor mapping and modelling to address these knowledge gaps. Recognizing data scarcity as a challenge, these efforts aim to enhance future IAs, fostering more informed ocean management. In areas where data on the distribution of VMEs or VME indicator taxa are available, SDMs and HSMs may be used to predict where potential VMEs are likely to occur (as recognised in UNGA resolution 71/123 (UNGA 71/123, para 181)). These approaches are useful when data are limited, and where environmental data enable robust predictions. For example, Relative Environmental Suitability modelling techniques that rely on expert input can be used [53], or bathymetric data can be used to identify features (e.g., seamounts) that might potentially support VMEs [54,55]. Distribution models can also be transferred from data-rich regions into new areas so long as at least bathymetric data are available, an approach that has recently been demonstrated in the SEAFO Convention Area [56].The use of such modelling tools, however, requires the validation of the model outputs and consideration of the uncertainties in the predictions to better translate the confidence of the estimate to management purposes [57].

For an improved understanding of the ecological impacts of fishing, it is essential to comprehensively survey any new fishing areas. Ideally, these surveys would incorporate control sites to enhance ongoing monitoring, enabling a more accurate determination of impact and facilitating estimates of recovery time after fishing activity has ceased in the area. Additionally, refining the definition of cumulative impacts and their integration into overall IAs is crucial for advancing the rigour of these evaluations. To better assess cumulative impacts, there is a need for improved coordination between the RFMOs and States preparing the IAs to manage cumulative effects of different countries' fisheries.

Finally, we recommend that the consideration of cumulative impacts extends to encompass the effects of climate change on the environment, species distributions, food availability, and habitat [58,59].While there is still limited information about effects of climate change on deep-sea ecosystems, climate-induced changes in the environment will make the evaluation of impacts of fishing increasingly uncertain and affect the risk associated with management decisions [19,60]. Spatial representation of historical or projected changes in climate parameters and time of emergence (exceeding natural variability) can help identify areas that may serve as climate refugia and vulnerability hotspots in the near future[61], as well as bright spots where new fishing opportunities may emerge [62]. As a possible model for future RFMO actions, SPRFMO recently adopted Decision 13 which tasks the Scientific Committee, Compliance and Technical Committee, and annual agenda to consider climate change impacts and climate adaptation and resilience measures [63].

Our findings demonstrate several challenges in the IAs already implemented by States, through RFMOs managing fishing in the high seas. Similar challenges are likely to arise for environmental impact assessments (EIAs) for other activities, such as deep-sea mining [64,65]. These results emphasise the importance of following existing IA criteria for all high seas activities to regulate both current and emerging human activities that could endanger deep-sea ecosystems. Management actions should reflect uncertainties in assessments to align with the precautionary approach. The implementation of IAs for deep-sea fisheries sets precedents for the conduct of EIAs for other activities in the deep sea and high seas. Recently, the adoption by the United Nations of a legally binding instrument for the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction (also known as the BBNJ agreement) presents an opportunity to enhance and modernise the process of assessing environmental impacts in areas of the ocean beyond national jurisdiction [66]. Although the BBNJ Agreement will not directly enforce EIA procedures on established entities like RFMOs, these requirements will be applicable to States that have voluntarily accepted the provisions of the BBNJ Agreement by becoming Parties to it [67]. For any new fishing activities, in an area where there is no RFMO with jurisdiction over a proposed fishing activity in a specific area, the BBNJ provisions directly apply. Therefore, to ensure that high seas activities are managed effectively under the new treaty, States must first ensure that the existing criteria for IAs for all high seas activities are respected.

5. Conclusions

This study concludes that the reviewed IAs do not comprehensively demonstrate that deep-sea fishing activities in the high seas can be managed to prevent SAIs on VMEs or that fishing is conducted in a sustainable manner. For most criteria outlined in paragraph 47 of the FAO Guidelines, the information to effectively assess the impact of fishing is either completely lacking or inadequately addressed. Even the most comprehensive assessments are not fully compliant with the FAO Guidelines and, by extension, the UNGA resolutions. The main shortcoming of the IAs was the inadequate description of the ecosystems potentially affected by fishing and the narrow assessment of the impacts of fishing. Additional shortcomings include incomplete description of the proposed fishing activities, lack of baseline data and risk assessments, and limited consideration of the indirect impacts of fishing.

This study identifies several ways to strengthen the IA process; i) making IAs publicly available; ii) improved collection of baseline data and VME identification; iii) assessment of impacts on broader range of species associated with VMEs or otherwise potentially impacted by deep-sea fishing; iv) enhanced cooperation between RFMOs and more standardised IA processes; v) better consideration of different types of impacts from fishing and climate change, and vii) improved consideration of uncertainty in the impact estimates and risk assessments. Fisheries management should explicitly reflect the uncertainty in the evidence for sustainability and impact on the ecosystem, and where necessary apply a precautionary approach to fishing. Ultimately, conducting IAs that are in full compliance with the FAO Guidelines would reflect this uncertainty and are a crucial aspect of protecting deep-sea biodiversity from impacts of bottom fishing.

CRediT authorship contribution statement

Laura Kaikkonen: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Teresa Amaro:** Writing – review & editing. **Peter Auster:** Writing – review & editing, Formal analysis. **David M. Bailey:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **James B. Bell:** Writing – review & editing, Formal analysis. **Angelika Brandt:** Writing – review & editing. **Malcolm R. Clark:** Writing – review & editing. **Jeffrey C. Drazen:** Writing – review & editing, Formal analysis. **Cherisse Du Preez:** Writing – review & editing. **Elva Escobar-Briones:** Writing – review & editing. **Eva Giacomello:** Writing – review & editing, Formal analysis. **Matthew Gianni:** Writing – review & editing, Methodology, Conceptualization. **Andrew F. Johnson:** Writing – review & editing, Methodology. **Lisa A. Levin:** Writing – review & editing. **Rosanna J. Milligan:** Writing – review & editing. **Stephen Oduware:** Writing – review & editing, Formal analysis. **Tabitha R. R. Pearman:** Writing – review & editing. **Christopher K. Pham:** Writing – review & editing. **Sofia P. Ramalho:** Writing – review & editing, Formal analysis. **Ashley A. Rowden:** Writing – review & editing. **Tracey T. Sutton:** Writing – review & editing. **Michelle L. Taylor:** Writing – review & editing. **Les Watling:** Writing – review & editing. **Lissette Victorero:**

Writing – review & editing, Methodology, Funding acquisition, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare no conflict of interest.

Data availability

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

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2024.106281.

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