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Standards to Inform an Ecosystem Approach to Deep-sea Bottom Fisheries Management in the High Seas: Examples from the South Pacific Ocean

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Abstract

The South Pacific Regional Fisheries Management Organisation (SPRFMO) Convention requires consideration of risks and impacts as part of an ecosystem approach to fisheries management. In SPRFMO, assessments of the impact of demersal fisheries are guided by the Bottom Fishery Impact Assessment Standard and the Encounter Review Standard. The Bottom Fishery Impact Assessment Standard describes a standardised approach for assessing cumulative impacts of bottom fishing, including for new and exploratory fisheries, on Vulnerable Marine Ecosystems (VMEs), deep-sea fish stocks and marine mammals, reptiles, seabirds and other species of concern. The Encounter Review Standard describes responsibilities when reviewing potential encounters with VMEs, which occur when bycatch of VME indicator taxa (*e.g.*, stony corals) in any trawl tow reach or exceed predefined encounter thresholds, resulting in temporary suspension of fishing in the encounter area. Both the Bottom Fishery Impact Assessment Standard and the Encounter Review Standard are periodically updated to reflect best practice, alignment with the FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas, and account for the best available scientific information required to protect VMEs from significant adverse impacts while ensuring sustainable management of bottom fisheries. Here, we detail the structure and function of these two standards, their periodic updates to reflect best practice and scientific knowledge, and their role in operationalising an ecosystem approach. We also discuss gaps, uncertainties, and potential future improvements for these standards, including the need for better integration of cumulative impacts (such as climate change and cross-sectoral pressures) into the standards, and the usefulness of having universal assessment standards for RFMOs. Through the examples from SPRFMO, we illustrate the importance and role standards can play in achieving sustainable, science-based management of deep-sea fisheries in areas beyond national jurisdiction.

Keywords: benthic impact assessments; deep-sea fisheries; ecosystem approach; risk assessment; significant adverse impacts; vulnerable marine ecosystems; regional fisheries management organisations.

Introduction

Until the early-to-mid 2000s, deep-sea fisheries across the South Pacific Ocean were mainly regulated by the domestic provisions imposed on fishing operators by flag States. In 2006, Australia, Chile and New Zealand initiated consultations among relevant States to address key gaps in the international conservation and management of fisheries resources, as well as the protection of the broader marine environment in the South Pacific high seas. Shortly after, the United Nations General Assembly (UNGA) adopted Resolution 61/105, which called upon the Regional

Fisheries Management Organisation (RFMO) bodies to:

> "*83 (a) To assess, on the basis of the best available scientific information, whether individual bottom fishing activities would have significant adverse impacts on vulnerable marine ecosystems, and to ensure that if it is assessed that these activities would have significant adverse impacts, they are managed to prevent such impacts, or not authorized to proceed;*"

Key elements of Resolution 61/105 included undertaking bottom fishing impact assessments to determine whether bottom fishing would risk exposing vulnerable marine ecosystems (VMEs) to significant adverse impacts (SAIs), identifying VME locations, establishing move-on rules and protocols, ensuring the sustainable management of deep-sea fish stocks, and establishing effective monitoring, control and surveillance of fishing operations and their environmental impacts.

In 2009, the FAO published the International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (FAO, 2009), hereafter referred to as the Deep-Sea Fisheries Guidelines. These guidelines provided recommendations on governance and management frameworks of deep-sea fisheries aimed at ensuring long-term conservation and sustainable use of marine living resources in the deep-sea, while preventing SAIs on VMEs. These guidelines provided specific advice on the characteristics which should be used to identify VMEs, and a definition of SAIs (both of which were not provided by previous UNGA Resolution 61/105). The Deep-Sea Fisheries Guidelines have been a transformational document widely used by Regional Fisheries Management Organisations (RFMOs) engaging with demersal fisheries to the current day. Shortly after, in 2011, the UNGA adopted Resolution 66/68, reaffirming earlier Resolutions on sustainable fisheries and calling on States and RFMOs to apply a precautionary approach and to implement the Deep-Sea Fisheries Guidelines.

The Deep-Sea Fisheries Guidelines and relevant UNGA Resolutions informed the development of interim measures during international consultations on the establishment of the South Pacific Regional Fisheries Management Organisation (SPRFMO). These measures included early drafts of the Bottom Fishery Impact Assessment Standard (BFIAS) and the Standards for the Collection, Reporting, Verification and exchange of Data (*e.g.*, SPRFMO, 2009b), hereafter referred to as Data Standards. The initial BFIAS developed for SPRFMO aimed to establish a minimum standard for assessing the potential impacts of proposed bottom fishing activities on VMEs and deep-sea fish stocks. Complementing this, the Data Standards set out requirements for Member States to submit fishing effort and catch data, including the mandatory reporting of accidental catches of any sensitive benthic species, particularly vulnerable or habitat-forming species such as sponges, sea-fans or corals. To the present day, there is no universal benthic impact assessment standard being followed across international resource management and conservation bodies (including RFMOs), but SPRFMO and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (Sharp *et al*, 2009) were among the first such bodies to develop their own benthic impact assessment standards (DOSI, 2022; Kaikkonen *et al*., 2024).

SPRFMO was officially established in 2012. Australia and New Zealand were the only Members engaging in established bottom fisheries at that time. Based on early international agreements, UNGA Resolution 61/105 and the Deep-Sea Fisheries Guidelines, these two Members drove the implementation of the management arrangements that would satisfy the varied international obligations and objectives as manifested through the SPRFMO Convention and related non-binding instruments. This work led to the first Conservation and Management Measure (CMM) for the Management of Bottom Fishing in the SPRFMO Convention Area (Fig. 1) being in force in 2014 (SPRFMO, 2014).

In 2016, the UNGA adopted Resolution 71/123, which emphasised the importance of strengthening procedures for carrying out, reviewing and evaluating impact assessments, taking into account individual collective and cumulative impacts, and ensuring that any measures are based on best available scientific information, and adopt an ecosystem approach (Garcia and Cochrane, 2005). The 2016 Resolution also highlighted inconsistencies in implementation of the earlier Resolutions on sustainable fisheries across RFMOs. Recognising that implementation of SPRFMO bottom fishing measures by Members was sub-optimal, the SPRFMO Commission supported efforts led by Australia and New Zealand to initiate discussions aimed at revising the bottom fishing measure. The objective was to establish consistent management arrangements for all Members engaged in established bottom fisheries in the SPRFMO Convention Area. As a result of further work led by Australia and New Zealand and supported by other Members including the Cook Islands, the European Union (EU) and the United States (US), a comprehensive package of measures designed to assess, monitor and control bottom fisheries were developed and compiled into an updated CMM for the Management of Bottom Fishing in the SPRFMO Convention Area, hereafter referred to as CMM03 (SPRFMO, 2019b). Key measures provided by CMM03 included the designation of three different types of Management Areas to allow for bottom fisheries (based on fishing gear: bottom line; midwater trawl; and bottom trawl), the design of areas in which bottom fishing could be conducted using a spatial prioritisation approach (Cryer *et al*., 2018; Grantham *et al*., 2024; Rowden *et al*., 2026), and a VME encounter protocol and move-on rule to be

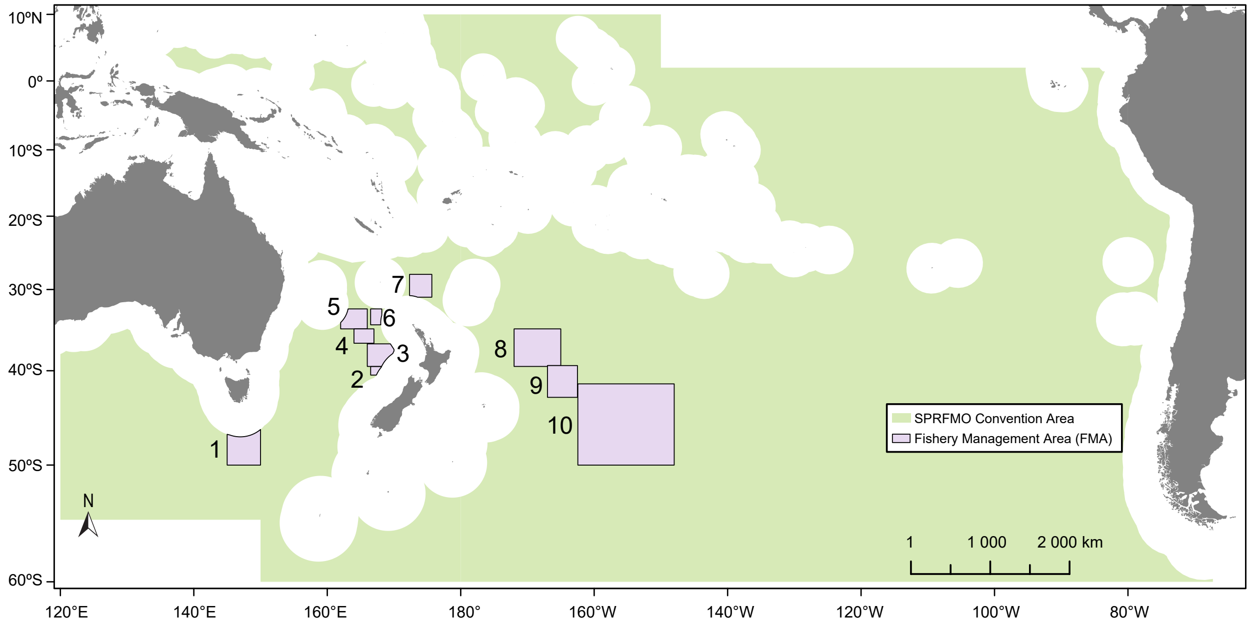

Fig. 1. SPRFMO Convention Area (in green) and the Fishery Management Areas (FMAs) where bottom fishing occurs (in defined sub-areas within the FMAs, referred to Bottom Trawl, Midwater Trawl and Bottom Line Management Areas, with the exception of the Gascoyne Bottom and the Capel Bank Line Management Areas). FMAs are labelled as: 1) South Tasman Rise (this FMA has been closed to all demersal fishing since 2007, see Fig. S1), 2) Westpac Bank, 3) Northwest Challenger, 4) Central Lord Howe Rise, 5) North Lord Howe Rise, 6) West Norfolk, 7) Three Kings, 8) North Louisville, 9) Central Louisville, 10) South Louisville. Individual figures for each FMA and nested Bottom Trawl, Midwater Trawl and Bottom Line Management Areas are provided in the Supplementary Materials (Figs. S1-S10), along the Gascoyne and Capel Bank Bottom Line Management Areas (Fig. S11).

consistently implemented across Members engaging in midwater (targeting bentho-pelagic species) and bottom trawling (Geange *et al*., 2020; Penney, 2014; Rowden *et al*., 2025). No bottom fishing (other than exploratory fisheries which are covered under other SPRFMO CMMs) is allowed outside of the Fishery Management Areas (FMAs), except for standalone Bottom Line Management Areas "Capel Bank" and "Gascoyne" (Fig. S11), which do not have an assigned FMA.

Since 2019, CMM03 has been regularly updated to reflect best available information (SPRFMO, 2025a), including the development of the recently adopted Encounter Review Standard (ERS), the first such standard among deep-sea RFMOs (SPRFMO, 2024). The ERS describes Member or Cooperating Non-Contracting Party (CNCP) and Scientific Committee responsibilities when reviewing encounters with potential VMEs, which occur when bycatch of VME indicator taxa (*e.g.*, stony corals) in any trawl tow exceed predefined encounter thresholds, resulting in temporary suspension of fishing in the encounter area. Both the BFIAS and the ERS are periodically updated through a participatory process to reflect best practice, alignment with the Deep-Sea Fisheries Guidelines, and account for the best available scientific information. In combination with the Data Standards (SPRFMO, 2025b), these Standards are at the core of an ecosystem approach to deep-sea fisheries management in the SPRFMO Convention Area.

Standards can be fundamental to effective fisheries management, providing a structured and scientifically grounded basis for decision-making. Standards enable consistent application of methodologies across jurisdictions, facilitate the collection and exchange of comparable data, and support transparent evaluation of management outcomes (Anderson *et al*., 2015; Kirby and Ward, 2014). By incorporating best available science, standards help assess ecological risks, guide sustainable exploitation of marine resources, and ensure the protection of vulnerable marine ecosystems (Ardron *et al*., 2014; Cooke *et al*., 2023). Moreover, standards underpin adaptive management by allowing for systematic updates in response to emerging evidence and changing environmental conditions, thereby enhancing the resilience and accountability of fisheries governance frameworks (Free *et al*., 2020).

Here, we detail the structure and function of the BFIAS and ERS, their periodic updates to reflect best practice and scientific knowledge, and their role in operationalising an ecosystem approach to fisheries management. We also discuss gaps, uncertainties, and potential future improvements for these standards, including the better integration of cumulative impacts (such as climate change and cross-sectoral pressures), and discuss the need for universal impact assessment frameworks for RFMOs. Through the examples from SPRFMO, we illustrate the importance and role standards can play in achieving sustainable, science-based management of deep-sea fisheries in areas beyond national jurisdiction.

Bottom Fishery Impact Assessment Standard

The first BFIAS was adopted prior to the formalisation of SPRFMO in 2012, and since then, SPRFMO has progressively developed and implemented a fully formed package of CMMs which are key to achieving the objectives set in the Convention. Prior to the adoption of the BFIAS, bottom fishing impact assessments undertaken by Australia and New Zealand generally met the requirement to consider the impacts of fishing on VMEs, despite limited data on their distribution. However, the assessments did not adequately address the impacts on deep-sea target fish stocks (*e.g.*, Williams, 2011; SPRFMO, 2008). Both Members focussed their analysis of potential impacts on VMEs on the spatial footprint of fishing activities in relation to the likely distribution of VMEs to make inferences about the likelihood of SAIs on VMEs. Most importantly, the assessments failed to consider cumulative impacts from the combined effort footprints and/or catches of the two Members together as well as those impacts caused by other parties that had engaged in deep-sea fisheries in the past. Furthermore, several components of the initial BFIAS were subsequently superseded by the implementation of multiple CMMs, rendering them redundant.

In response to these issues, Australia and New Zealand agreed to review the initial BFIAS, recognising that it did not fully meet the key requirement of implementing an ecosystem approach, as mandated by the SPRFMO Convention. Assessing bottom fishing impacts on non-targeted fish species (quantification of discards) and non-fish species such as seabirds, marine mammals and reptiles was one of the key additions to help fill the ecosystem approach gap (Georgeson *et al*., 2018). An intersessional working group formed by the Members of Australia, New Zealand, the EU, the US, the SPRFMO Secretariat and the New Zealand High Seas Fishing Group (a body representing fishing industry interests) supported a comprehensive review of the BFIAS (Georgeson and Cryer, 2019). As a result, the BFIAS (SPRFMO, 2019a), was re-structured around the following key components: a) description of fishing activities, b) mapping and description of fishing areas and c) a risk and impact assessment framework. While the description of fishing activities and areas did not substantially change, the inclusion of an assessment framework was key to align the BFIAS with an ecosystem approach as required by the overarching SPRFMO Convention.

Risk and impact assessment framework

To support an ecosystem approach to fisheries management, the risk and impact assessment framework contained in the BFIAS is based on the methodology of Hobday *et al*. (2011) (Fig. 2). The first step of the framework includes defining the objectives, which are set in the SPRFMO Convention (SPRFMO, 2022):

> "*…through the application of the precautionary approach and an ecosystem approach to fisheries management, to ensure the long-term conservation and sustainable use of fishery resources and, in so doing, to safeguard the marine ecosystems in which these resources occur*."

The first step also includes identifying the assets (*e.g.*, target species and other ecosystem components) and the hazards these may face (*e.g.*, the fishing activity). The second step is the identification and assessment of risks, based on the previously identified assets and hazards. The third step is the identification of monitoring and mitigation measures, which should be iteratively evaluated to assess their performance. The framework is iterative and adaptive in that risks and impacts are periodically reassessed (hierarchically; individually and in combination) and management and monitoring plans are updated accordingly (Fig. 2).

Revision of the BFIAS is currently scheduled to occur at least every five years (earlier if needed), and this typically involves at least one Member that engages in bottom fisheries (*e.g.*, New Zealand) to run a participatory process with other Members who may have interests in bottom fisheries, independent scientists, fishing industry representatives, and environmental organisations. This type of approach, which is used by some Members in the management of fisheries within their national jurisdictions (McCay and Jentoft, 1996), allows for the identification of potential improvements from diverse perspectives. These suggestions are then reconciled by the leading Member and further presented to the SPRFMO Scientific Committee for consideration. Finally, the Scientific Committee provides advice to the SPRFMO Commission, which may adopt the BFIAS revision along with other scientific recommendations tabled by the Scientific Committee for that year.

Risk assessment for target species

Risk assessments for target fisheries species within the SPRFMO framework are undertaken following a structured, science-based process designed to evaluate the cumulative impacts of bottom fishing activities on principal target stocks, such as orange roughy (*Hoplostethus atlanticus*) and other target deep-sea species. The initial phase involves compiling detailed

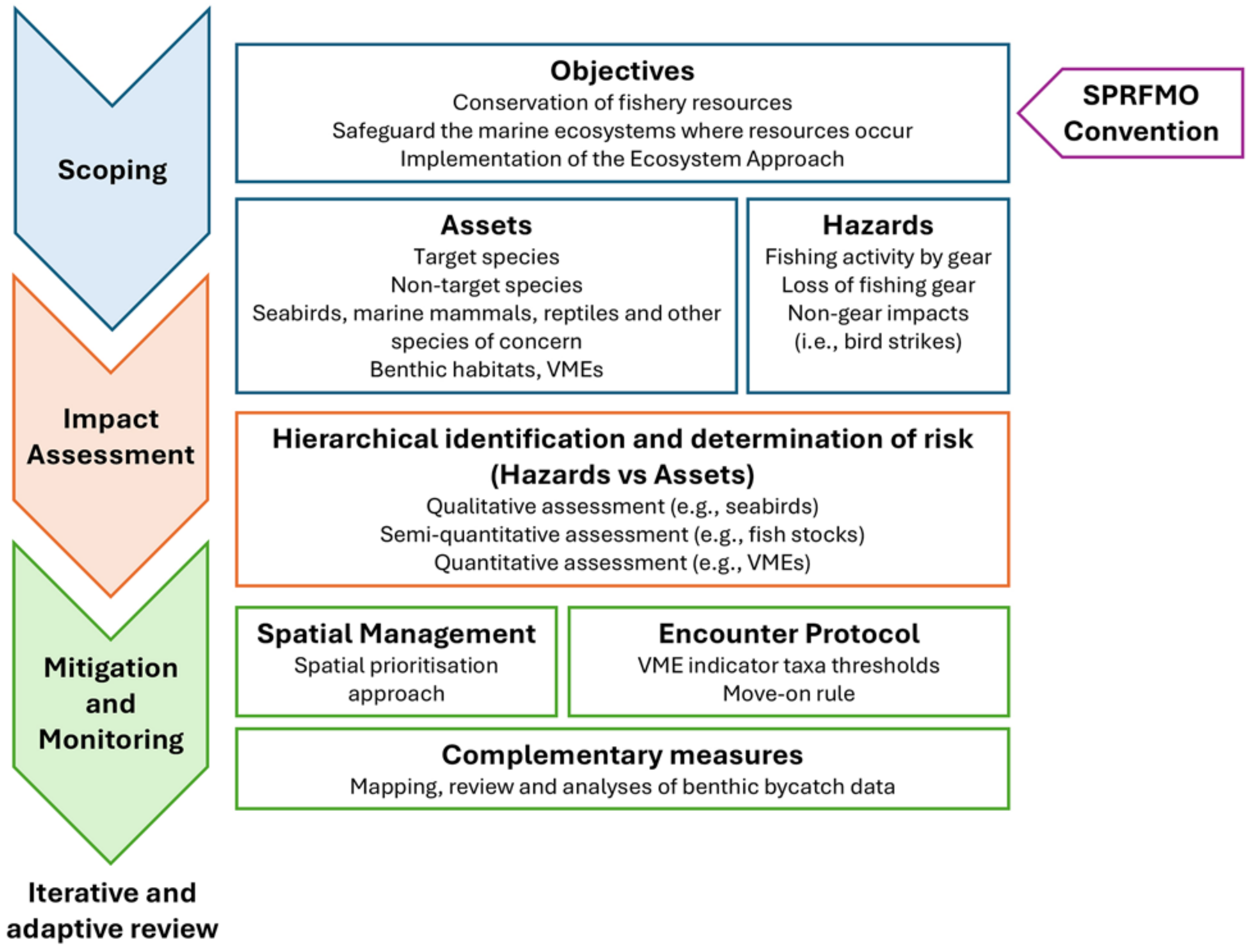

Fig. 2. Diagram depicting the main components of the risk and impact assessment framework provided by the BFIAS (SPRFMO, 2019). Mitigation and monitoring measures herein relate to impacts on VMEs.

catch and effort datasets, encompassing both spatial and temporal distributions of fishing activities. These data inform assessments of the current status of target populations. Biological parameters—including growth rates, longevity, productivity, and stock structure—are incorporated to evaluate the resilience and vulnerability of these populations to fishing pressure.

The assessment approach combines both qualitative and quantitative methodologies, including formal stock assessments, biomass indices, and the establishment of reference points to guide sustainable exploitation. In circumstances where data are limited, the application of precautionary principles is emphasised, with uncertainties explicitly recognised throughout the process. The assessment of cumulative impacts accounts for fishing activities across multiple fleets and jurisdictions, ensuring that management decisions are underpinned by the best available science and reflect the ecosystem approach mandated by the SPRFMO Convention. This risk assessment process is adaptive, with periodic updates in response to new data and scientific advancements and is subject to review by the SPRFMO Scientific Committee to ensure transparency and accountability.

Risk assessment for marine mammals, seabirds, reptiles and other species of concern

Risk assessments for non-target species—including marine mammals, seabirds, reptiles, and other species of concern—within the SPRFMO framework are undertaken using a structured blend of qualitative and quantitative methodologies. The process is initiated with the identification of potentially impacted species, utilising observer data, bycatch records, and available species distribution information. For each taxonomic group, assessments consider the likelihood of interaction with fishing gear, the frequency and severity of observed bycatch events, and biological characteristics influencing vulnerability, such as population size, reproductive capacity, and migratory behaviour.

Where sufficient data are available, formal ecological risk assessment tools—such as Productivity-Susceptibility

Analysis (PSA) (Hobday *et al*., 2007, 2011) or Sustainability Assessment for Fishing Effects (SAFE) (Zhou and Griffiths, 2008)—are employed to evaluate the relative risks faced by different species. For example, a SAFE assessment for teleost and chondrichthyan species in the SPRFMO Convention Area was completed in 2025 (Keller *et al*., 2025). The SAFE methodology derives a proxy for fishing mortality based on four susceptibility components (availability of the species to the fishing fleet, encounterability of the gear given the species' vertical distribution, gear selectivity, and post-capture survival) and compares this to F-based (sustainability) reference points (*e.g.* F_{msy}, F_{lim}, and F_{crash}) derived from basic life-history parameters. Keller *et al*. (2025) concluded that from all the assessed taxa, deepwater sharks are the taxonomic group at the highest risk for bottom fishing and the SPRFMO Scientific Committee has recommended several management measures to mitigate this risk (SPRFMO, 2025c).

In instances where data are limited, expert judgement and precautionary principles are applied, with uncertainties explicitly acknowledged. The assessment of cumulative impacts integrates information across fleets and years, ensuring that management measures address both direct and indirect effects of fishing activities. Outcomes from these assessments inform the development and refinement of mitigation measures, including gear modifications, spatial closures, and reporting requirements, which are subsequently reviewed by the SPRFMO Scientific Committee. This process ensures that management actions are evidence-based, transparent, and consistent with the broader ecosystem approach mandated by the SPRFMO Convention.

Risk assessment for benthic habitats and VMEs

When assessing risks to benthic habitats and VMEs under the BFIAS, criteria such as bottom fishing intensity, duration, spatial extent, and cumulative impacts are systematically evaluated. In combination, these factors provide a comprehensive assessment of the overall risk posed by fishing activities to benthic environments and VMEs. The BFIAS provides examples of qualitative and quantitative methodologies to help assess risks and impacts of bottom fishing on VMEs, with the most recent iteration of the Bottom Fishery Impact Assessment (BFIA) for New Zealand and Australian bottom fisheries (Anderson *et al*., 2024) including a benthic quantitative impact assessment based on the dynamic relative benthic status (dRBS), a fully quantitative methodology to estimate the benthic status of a species, species group, or habitat (Pitcher *et al*., 2017). The dRBS as applied in the BFIA makes use of historical fishing effort annual data (as swept area ratio; SAR), habitat suitability data layers for VME indicator taxa (transformed to better reflect the presence of a VME, and account for model uncertainty) (Stephenson *et al*., 2021), and VME indicator taxon-specific depletion and recovery rates (Anderson *et al*., 2024). The BFIAS indicates that benthic impact assessments should be conducted at spatial scales that are ecologically relevant; however, it acknowledges that data limitations may necessitate the use of alternative spatial units, such as undersea features or management areas. The current focus of the application of the dRBS status assessment is for Fishery Management Areas (FMAs), which include areas open (Bottom Trawl, Midwater trawl and Bottom Line Management Areas) and closed (the remainder of the FMA) to bottom fishing. Estimates of the dRBS for each assessed VME indicator taxon are used to determine whether predicted suitable habitats in FMAs are adequately protected from SAIs. Consistent with the Marine Stewardship Standard (MSC, 2024), dRBS values averaged over the FMA below 80% are interpreted "*as reductions in habitat structure and function below 80% of the unimpacted state*" that signal "*serious or irreversible harm*" (*i.e.*, SAIs) for these "*more sensitive*" habitats, such as VMEs. This approach therefore assumes that a certain level of impact (due to fishing) can be compatible with avoiding SAIs on VMEs. It is important to note that such thresholds are inherently scale-dependent, and their interpretation may vary with the spatial resolution of the assessment.

Mitigation, management and monitoring measures

Under CMM03, most of the SPRFMO Convention Area remains closed to bottom fishing (excluding exploratory fisheries), with the exception of designated FMAs that allow bottom long lining, bottom trawling and midwater trawling (targeting bentho-pelagic species such as alfonsinos) within clearly defined boundaries (with the exception of the Capel Bank and the Gascoyne Bottom Line Management Areas, see Fig. S11) (Table 1). This spatial management approach was designed to ensure that a large percentage of the model-predicted suitable habitat for VME indicator taxa remains outside areas open to bottom fishing, thereby providing for the long-term conservation and sustainable use of deep-sea fishery resources. The design of this measure aims to provide an assurance that bottom fishing would not have SAIs on VMEs, considering the spatial extent of the impact of fishing activities relative to the availability of predicted habitat for VME indicator taxa within the broader SPRFMO area. As of 2026, approximately 12.2% and 12.7% of the SPRFMO Convention Area within fishable depths remain open to bottom and midwater trawling, respectively (Table 1).

To account for the residual risk associated with the spatial management approach (see subheading - Key gaps and uncertainties), a VME encounter protocol was established as the main complementary management measure. The protocol includes the temporary closure of an area if specified weights of VME indicator taxa are exceeded in a trawl. This protocol provides a

Table 1. Size (area in km^2) of the entire SPRFMO Convention Area and its overlap with fishable depths (approximately to a 1 400m depth), and percentage of area open to bottom fishing (broken down by gear).

Zone	Area (km^2)	% Open to bottom trawling	% Open to midwater trawl	% Open to bottom long line
Convention Area	59 118 289	0.108	0.111	0.201
Convention Area (0–1 400m depth)	349 320	12.178	12.735	25.454

mechanism for the rapid curtailment of bottom fishing in an area where the bycatch of VME indicator taxa is unexpectedly high relative to taxon-specific cumulative distributions of historical VME indicator taxa bycatch from within the SPRFMO Convention Area (> than the 99th percentile of historic catches) (Geange *et al.*, 2020; Rowden *et al.*, 2025). Following the triggering of an encounter, the encounter is reviewed by the Member state and then by the Scientific Committee following the requirements provided by the Encounter Review Standard (see heading - Encounter Review Standard), with appropriate management recommendations put forward to the SPRFMO Commission. The BFIAS mandates the reporting of these existing management measures, and the inclusion of other complementary monitoring measures (such as fine-resolution mapping of benthic bycatch; Tablada *et al.*, 2022; 2023), providing for a continuous evaluation based on best available information.

Key gaps and uncertainties

The BFIAS requires that uncertainties within the risk and impact assessment framework be explicitly stated. This statement includes identifying areas where future research or additional data collection may be necessary to reduce or resolve these uncertainties. Current uncertainties for key fish stock assessments include poor knowledge of the stock structure for target species (*i.e.*, orange roughy), gaps in key biological information (growth, longevity, productivity) and indices of biomass and/or fishing mortality for key target stocks and SPRFMO-specific management targets and limits for key targets and other stocks. Due to the inherently low productivity of deep-sea fisheries and the life history traits of the main target species such as orange roughy, as well as the characteristics of the ecosystems that support them, significant ecological changes in these systems are likely to develop, and recover, over much longer timescales compared with more productive shallower systems. As a result, the full extent of the impacts from existing orange roughy fisheries in the high seas of the South Pacific may not yet be fully apparent and, therefore, inherently hard to estimate (Tingley and Dunn, 2018). Uncertainties in the assessment of impacts on marine mammals, seabirds, reptiles and other species of concern arise from several sources, including inaccurate identification of caught specimens by fishers and observers, limited knowledge of the distribution of certain at-risk species, and insufficient estimates of population size and productivity for species with broad ranges and/or poorly understood biology. As an example, the most recent SAFE assessment for teleost and chondrichthyan species (Keller *et al.*, 2025) highlighted the lack of information about the distribution of these species in the SPRFMO Convention Area (and significant divergences between the different data sources) and the biological productivity attributes of some of the species assessed. For deep sea chondrichthyans, inaccurate species identification remains an issue.

Regarding assessment of benthic habitats and VMEs, a considerable degree of uncertainty is associated with the modelling of the habitat suitability of VME indicator taxa across the western part of the SPRFMO Convention Area (Stephenson *et al.*, 2021). These models underpin the quantitative assessment of benthic impacts due to the impracticality of undertaking benthic surveys across such a large, deep and remote area. Recognising the limitations of habitat suitability index models, especially those based on presence-only data (Stephenson *et al.*, 2021), recent efforts have focused on the development of abundance models for VME indicator taxa (Bennion *et al.*, 2025a), which are based on observation data from sampled areas (seafloor video imagery) and represent an important step forward given the current lack of understanding between abundance and predictions of suitable habitat. However, data paucity regarding distribution of benthic taxa remains the biggest hurdle, with most of the survey data used in modelling efforts collected in areas adjacent to the western part of the SPRFMO Convention Area, mainly New Zealand's Exclusive Economic Zone (EEZ) (Bennion *et al.*, 2024, 2025a).

Future improvements

Despite the BFIAS having performed relatively well against an independent evaluation of impact assessments across deep-sea fisheries RFMOs (DOSI, 2022; Kaikkonen *et al.*, 2024), it can be improved in many respects. The most recent review of the BFIAS led by New Zealand acknowledges missing components to further progress the ecosystem approach to fisheries management, such as estimation of impacts across ecosystem levels (*e.g.*, through trophic modelling) and missing linkages between the assessed components of the ecosystem (Arkhipkin and Tablada, 2025). To be able to include and meaningfully inform such changes to the BFIAS, efforts must be made to collect more environmental and ecological data that would allow, among other things, improved environmental baseline information and better mapping and identification of VMEs and other important benthic habitats (DOSI, 2022; Kaikkonen *et al*., 2024). VME indicator taxa such as corals and sponges can form significant habitats known to support a variety of biodiversity, including commercially important fish species (De Clippele *et al*., 2025) and fulfil ecosystem functions such as bentho-pelagic coupling and nutrient and carbon cycling (*e.g.*, Maier at al., 2020; De Clippele *et al*., 2021). The limited availability of data on the composition and size structure of communities dominated by VME indicator taxa make it difficult to quantify their functional attributes. While ecosystem functions provided by VMEs are influenced by factors such as spatial extent, body size and age structure, accurately determining these effects requires abundance data collected at fine spatial scales (Susini *et al*., 2025; Vad *et al*., 2025).

The BFIAS provides for the use of alternative sources of information to direct observations from the seafloor to identify areas known or likely to support VMEs. These sources include benthic bycatch records, predictive models for VME indicator taxa and known distribution of underwater topographic features (particularly seamounts) that may support VME indicator taxa (*i.e.*, Clark *et al*., 2022). However, the BFIAS does not provide a multi-criteria framework for integrating these diverse sources of information (including data collected by seabed biodiversity surveys) to support identification of VMEs (Morato *et al*., 2018). Although data collected directly from areas of interest is generally considered the best way to map areas likely to host VMEs, there is currently no consensus among experts on how to identify VMEs using imagery data (although progress towards developing a consensus is being made; see Baco *et al*., 2023). Furthermore, the operational and logistical costs associated with such direct surveys are extremely high. The BFIAS would benefit from including a reference to a robust methodology to cost-effectively identify or estimate VMEs (Bennion *et al*., 2025a; Stephenson *et al*., 2025), which could subsequently be used to support an assessment of the likelihood of SAIs on VMEs due to fishing impacts. The Deep-Sea Fisheries Guidelines provide guidance for identifying VMEs and assessing SAIs; however, they offer limited practical direction for evaluating and operationalising what constitutes a SAI in practice (Rowden *et al*., 2024). An important management part of this gap is the absence of a pragmatic and practical threshold that can help differentiate between an acceptable and unacceptable impacted state (Hiddink *et al*., 2023). Without defined ecologically relevant thresholds to distinguish what constitutes a SAI, and without a systematic process for identifying areas that qualify as VMEs, the BFIAS is currently unable to fully operationalise the requirements of multiple UNGA Resolutions that call for the prevention of SAIs on VMEs in the high seas.

While the BFIAS provides for consideration of cumulative impacts from fishing, it currently does not require the inclusion of other impacts such as those derived from climate change resulting from increased water temperatures, ocean acidification and deoxygenation, or any other human activities other than fishing. The lack of this requirement is significant given the SPRFMO Convention's focus on an ecosystem-based approach to fisheries management. Climate change is already having impacts on marine ecosystems, which in the future may be exacerbated, including on water column productivity, on habitats of importance to commercial fish species and on fisheries (Pinkerton, 2017; Datta *et al*., 2024). Therefore, these other actual or potential impacts should be assessed as cumulative impacts alongside present and historical fishing activity (FAO, 2019). Although information on how climate change affects deep-sea communities remains limited, environmental shifts driven by climate change will increase uncertainty in assessing the impacts of bottom fishing, adding another degree of complexity to risk assessment and related management decisions (Cummings *et al*., 2021; Pentz, 2018). The exclusion of non-fishing impacts from the BFIAS reflects the current limited understanding of benthic ecosystems within areas open to bottom fishing in the SPRFMO Convention Area, rather a deliberate omission, noting that RFMOs are mandated to adopt rules for managing fisheries exclusively. For other RFMO areas, information about impacts from non-fishing activities may be available and can be included directly in impact assessments. For example, NAFO has started exploring the inclusion of impacts such as oil spills, noise and seabed litter (Durán Muñoz *et al*., 2022). In the South Pacific there are ongoing research efforts aimed at addressing the knowledge gaps around assessing cumulative impacts (*e.g.*, Gammon *et al*., 2018; Hitt *et al*., 2020; Tracey *et al*., 2024). Of particular relevance is the recent work exploring the implications for the management of deep-sea corals facing multiple human-driven impacts within New Zealand's national waters (Stephenson *et al*., 2023), which could be applied to the western part of the SPRFMO Convention Area. Characterising climate-driven changes in taxa occurrence, abundance and distributions is fundamental to any climate change strategy. In the context of SPRFMO bottom fisheries, key taxa include VME indicator taxa, vulnerable non-target species (*e.g.*, deep-water sharks, rays and chimaeras) and commercially valuable species. Extensive work undertaken by New Zealand within its jurisdictional waters has modelled the future distribution of suitable habitat for deep-water corals and demersal fish species, including orange roughy, under projected seafloor environmental conditions (Anderson *et al*., 2022; Brough *et al*., 2025) using climate models tailored to the South Pacific (Behrens *et al*., 2020). These approaches could be extended to the western part of SPRFMO Convention Area, where most of bottom fishing occurs, and incorporated into the BFIA to assess likely shifts in future fishing effort. This would enable forward looking risk assessments that account for future spatial overlap between fisheries species of interest and fisheries, identify potential climate refugia for VME indicator taxa, and support initial evaluation of cumulative impacts, including those arising by cross-sectoral activities (Judah *et al*., 2025; Zelli *et al*., 2025). Climate change vulnerability assessments (*e.g.*, Cerutti-Pereyra *et al*. 2024), which use species' life history traits to assess their capacity to persist under future environmental conditions, could also be adapted to the SPRFMO Convention Area and incorporated into future iterations of the BFIA, complementing existing risk assessments for chondrichthyans and other vulnerable taxa (*e.g.*, Keller *et al*. (2025), <u>see subheading - Risk assessment for marine mammals, seabirds, reptiles and other species of concern).</u>

Encounter Review Standard

As already noted above, SPRFMO operates a VME encounter protocol as a complementary management measure to the spatial management which is the primary means by which SAIs to VMEs are prevented. As such, this standard is important for supporting the overall management measures that are put in place to implement an ecosystem approach to fisheries management. Specifically, CMM03 requires that "*where VME indicator taxa are encountered in any one tow at or above the weight threshold in Annex 6A, or three or more different VME indicator taxa at or above the weight thresholds in Annex 6B, Members and CNCPs shall require any vessel flying their flag to cease bottom fishing immediately within an encounter area of one (1) nautical mile either side of the trawl track extended by one (1) nautical mile at each end*" (hereafter referred to as the encounter area). Vessels are then required to report the encounter immediately to the Member or CNCP whose flag the vessel is flying and to the Secretariat, in accordance with the Guidelines for the preparation and submission of notifications of encounters with potential VMEs, contained in Annex 7 of CMM03.

Since the implementation of the encounter protocol in 2019, SPRFMO has progressively developed guidance to assess encounters with potential VMEs, which has been consolidated in the Encounter Review Standard (ERS). The ERS aligns with the Deep-sea Fisheries Guidelines, considers biologically relevant scales for assessing SAIs on VMEs (*i.e.*, bioregions, see Bennion *et al*., 2025b), and provides a streamlined, time-efficient method that accommodates the different capacities of Member States to participate and undertake encounter reviews. New Zealand developed the ERS based on existing materials (Milardi and Geange, 2021) through a participatory process that included representatives from both fishing industry and environmental organisations. The ERS is structured around the steps that the Member (or CNCP) and the Scientific Committee must follow after an encounter has been notified (Fig. 3).

Ultimately, the outcome of the application of the ERS is to provide advice to the SPRFMO Commission, which then can determine appropriate management actions for each encounter to prevent SAIs on VMEs, which may include: the closing of areas to some or all bottom fishing gear; temporal restrictions; spatial restrictions; and reopening areas.

Member review

Encounter detailed description

A Member needs to provide a detailed description of each encounter for the consideration by the Scientific Committee. This description should contain date and location, gear and vessel specifications, a detailed composition of the benthic bycatch associated to the encounter, including a characterisation of the ecology and biology of each VME indicator taxon encountered and the best available information related to its catchability (Stephenson *et al*., 2022). Location of historical bottom trawl tows (and associated benthic bycatch data) within the encounter area (and surrounding areas, ideally up to the entire Bottom Trawl Management Area within which the encounter took place) as well as spatial predictions of VME indicator taxa (habitat suitability index models, abundance models) need to be provided as well. Information regarding the oceanography, topography and geomorphology for the area of interest, where available, must be included. The ERS provides technical requirements for figures (maps) that the Member may develop to include some of these data and allows for the data confidentiality considerations. Where data is subject to internal regulations regarding the protection of private and commercially sensitive information, the Member can choose to either establish a formal data confidentiality agreement with the Scientific Committee or to withhold the data (while providing a clear description of the nature of the data being withheld along with its limitations).

VME assessment

The ERS does not provide a formalised mechanism to assess whether a VME is known or likely to occur within the encounter area but allows Members to use two complementary approaches. The first is a direct assessment, based on data collected from the encounter area (*i.e.*, seafloor imagery), and the second is an indirect assessment, based on best available information collated by the Member. While the ERS acknowledges that the direct assessment method is likely to provide the most robust information for identifying VMEs and should be preferred, evidence from a direct assessment can be further strengthened by integrating information from indirect assessments (Baco *et al*., 2023). However, there are often challenges related to the spatial scale of surveys and the

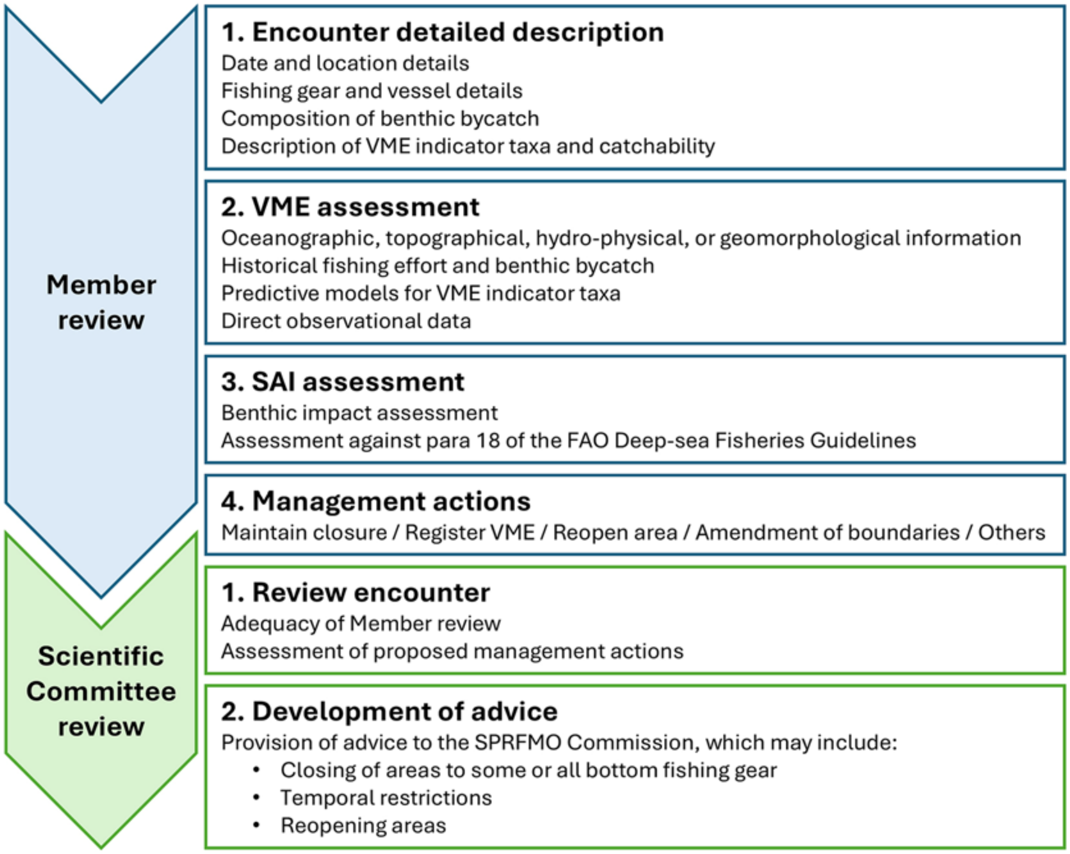

Fig. 3. Diagram depicting the main steps for both the Member and the Scientific Committee as outlined in the Encounter Review Standard (SPRFMO, 2024).

resourcing required to undertake surveys of areas likely to host VMEs, and only a very limited number of sites within the western part of the SPRFMO Convention Area have been surveyed in the past (Clark *et al*., 2015; Clark and Roberts, 2008).

The ERS also supports the use of multi-criteria analysis methods as a robust approach for evaluating different "lines of evidence" and the "weight" of these lines of evidence against sections of the Deep-Sea Fisheries Guidelines and determining whether an encounter constitutes evidence of a VME. Such a multi-criteria approach for assessments is widely used in environmental decision-making processes (*e.g.*, Turschwell *et al*., 2023, Vanegas-Cantarero *et al*., 2022) and is included in the Northwest Atlantic Fisheries Organization (NAFO) and International Council for the Exploration of the Sea (ICES) 'benchmark' processes for identifying VMEs and assessing SAIs (NAFO, 2020; ICES, 2022). Multi-criteria assessments following the ERS should integrate as much relevant information as possible into the process of identifying the known or likely occurrence of a VME. This assessment includes a variety of data sources, from direct observational methods such as video, echo-sounder and multi-beam surveys, to indirect methods such as evaluation of historical benthic bycatch, thresholding of predictive modelling for VME indicator taxa distribution, and assessment of the presence of topographical, hydro-physical or geomorphological features which may support VMEs. Other RFMOs have opted to start the process to formalise similar multi-criteria approaches to the one provided in the ERS to identify VMEs (*e.g.*, Curtis *et al*., 2020; Kenny *et al*., 2025; Warawa *et al*., 2025), but due to a lack of an explicit framework in SPRFMO to identify VMEs, the ERS currently provides flexibility to Members undertaking encounter reviews.

SAI assessment

The ERS requires an evaluation of whether reopening the encounter area will expose any VMEs to SAIs, noting that the range of relevant ecological spatial scales at which VMEs can be identified remains an open question. That determination should be made on a case-by-case basis through the application of relevant provisions in the Deep-sea Fisheries Guidelines, particularly Section 3.3 and Article 47. Like the multi-criteria approach in the VME assessment, the ERS provides flexibility to how Members can assess likelihood of SAIs on VMEs (if VMEs are deemed to be, or likely to be, in the encounter area). In the ERS, a minimum of an "expert judgement" approach is provided for, although semi-quantitative and fully quantitative impact assessment methods are recommended, subject to data availability and Member's capacity (Peixoto *et al*., 2025; Pitcher *et al*., 2017).

Management actions

The ERS requires Members undertaking encounter reviews to identify management actions they consider necessary to prevent SAIs on VMEs based on the results of their application of the ERS. The ERS offers a variety of actions Members can choose from (*i.e.*, maintaining a closure, re-opening an area) but also offers flexibility to allow Members to suggest other actions that may be deemed appropriate to the specific context of an encounter.

As of October 2025, the ERS has been put into practice once since its formal adoption, with New Zealand providing a review based on an indirect approach that makes use of the best available information, including information on the geomorphology and biogeography of the encounter area, historical VME indicator taxa bycatch data, habitat suitability index models and abundance models for VME indicator taxa, historical benthic invertebrates records and a quantitative benthic impact assessment using the dRBS approach (New Zealand, 2025).

Scientific Committee review

At its annual meeting, the SPRFMO Scientific Committee must review all encounter reviews tabled by Members or CNCPs. In reviewing the assessments provided by Members, for each encounter, the Scientific Committee is required to consider the detailed analyses while applying the Deep-sea Fisheries Guidelines, and to determine the adequacy of the review, including the suggested management actions. The ERS suggests that the Scientific Committee develops management actions and advice to the SPRFMO Commission based on the Member's recommendations but provides flexibility in allowing the Scientific Committee to determine any action or advice it may consider appropriate for each encounter area and, as appropriate, all encounter areas combined. Ultimately, final decisions on management actions for each encounter are decided by the SPRFMO Commission.

Key gaps and uncertainties

Like the BFIAS, the ERS requires Members to explicitly refer to known limitations and uncertainties of their analysis, including how these are reflected in their suggested management actions. The ERS acknowledges that almost every source of information regarding the identification and location of VMEs in the South Pacific high seas, as well as the definition of what constitutes a SAI, is embedded in a significant degree of uncertainty. For example, with respect to identifying VMEs, there is a lack of specific understanding about the trawl catchability of VME indicator taxa, which is likely to be variable across the SPRFMO Convention Area depending on the geomorphological attributes of each area and be taxon-specific (Rowden *et al*., 2024; Stephenson *et al*., 2022). Using historical fishing effort and benthic bycatch data carries other limitations other than catchability of VME indicator taxa, such as limited geolocation accuracy, particularly for the early years of the orange roughy fisheries in the high seas, when no specific regulatory measures and associated data reporting standards were in place (Tingley and Dunn, 2018). Modelled predictions of the distribution of VME indicator taxa are constrained by coarse-level taxonomic data, integration of data from multiple sources and multiple points in time (*e.g.*, fisheries bycatch, research surveys), limited coverage of data across geographical and environmental spaces, which combined are impeding the development of highly-accurate, fine-scale, species-specific predictions (Stephenson *et al*., 2021).

Despite the assumed uncertainties, the ERS requires consideration of the Deep-sea Fisheries Guidelines and the precautionary approach, meaning that not being in possession of highly certain and accurate information regarding location and extent of VMEs is not an impediment to implementing management actions (van Denderen *et al*., 2023).

Future improvements

The relationship between the biomass of benthic bycatch recorded on the surface and the biomass on the seafloor is poorly understood. Generally, bottom trawl gear is relatively inefficient at catching benthic invertebrates, including VME indicator taxa, so the amount of bycatch material landed on deck is unlikely to represent the scale of impact on the seafloor because some of the catch may be broken into small fragments and lost from the net before it is recovered to the surface for further examination (Stephenson *et al*., 2022). In SPRFMO bottom fisheries, it has been acknowledged that existing data on the catch efficiency of trawl gears for VME indicator taxa is broadly consistent and indicates that catchabilities are generally very low, meaning only a small fraction of VME indicator taxa on the seafloor are caught and retained by demersal fish trawls (Geange *et al*., 2019; Stephenson *et al*., 2022). Lack of data from the SPRFMO fishing grounds is a known impediment for determining density/biomass estimates of VME indicator taxa and the development of area-based and taxon-specific catchability estimates, both of which are ideally important inputs for determining thresholds for the VME encounter protocol and the ERS. To date, a pragmatic but data-informed approach has been used to develop candidate threshold weights (Geange *et al*., 2020), and the possibility of a research programme to allow the determination of more robust taxon-specific estimates of catchability has been explored (Stephenson *et al*., 2022), although its cost has been deemed too high and its benefits uncertain. The

North Pacific Fisheries Commission (NPFC) has recently undertaken work (Rooper *et al*., 2025) that builds on the approach adopted by SPRFMO and outlined in Geange *et al*. (2020). Subject to the availability of suitable data from within the SPRFMO Convention Area or adjacent fishing grounds (*e.g.*, parts of the New Zealand's EEZ), the approach developed by Rooper *et al*. (2025) could be trialled for a certain subset of VME indicator taxa. More robust thresholds would likely improve determination of likelihood of SAI on a VME and enhance the overall applicability of the ERS. While it is widely accepted that encounter thresholds should be data-informed and scientifically-driven, RFMO-specific bottom fisheries management considerations, such as spatial management arrangements, gear-specific restrictions, levels of observer coverage and move-on distances, may also inform the setting of thresholds (Reid, 2023). As of 2026, SPRFMO is the only deep-sea RFMO that has used context-specific bycatch data to develop a distinct set of threshold weights for VME indicator taxa designed to inform the biodiversity component of the encounter protocol. This component is triggered when the bycatch weight of at least three VME indicator taxa in one given tow reach or exceed the values set in Annex 6B of CMM03, as an indication that diverse seabed fauna may represent the presence of a VME (Watling and Auster, 2021).

Other potential improvements that have been identified but not addressed yet refer to the application of the dRBS, which is relevant to the BFIAS and the ERS, to determine likelihood of SAIs on VMEs. The lack of status thresholds to determine if a SAI on a VME has occurred (or likely occurred), and at which spatial scales these thresholds can be applied, are outstanding issues that remain to be addressed (Arkhipkin and Tablada, 2025). Progress is being made in the development of approaches to define SAIs quantitatively using the 'range of natural variation' approach (Hiddink *et al*., 2023). This approach defines a good state of an indicator, such as VME abundance or biomass, as an indicator value that falls within the long-term natural variation of that indicator in time-series from minimally impacted locations. Although very few time-series are likely to exist for VME indicator taxa, fitting general relationships between the threshold for good state and environmental (*e.g.* depth) and life-history (*e.g.* longevity) parameters is likely to allow the extrapolation of thresholds for VMEs in the SPRFMO Convention Area. These thresholds (relative to carrying capacity / long-term mean abundance in minimally impacted locations) are likely to be much higher for VME indicator taxa than those applicable to shallower water benthic communities (Hiddink *et al*., 2023).

Both the BFIAS and the ERS would benefit from having reference points in terms of relative benthic status and spatial scales that are of ecological relevance to VMEs, even more so if they were to be tailored for each VME indicator taxon.

While the ERS offers a degree of flexibility to accommodate each Member's capacity and resources to undertake encounter reviews, a comprehensive application of the ERS may require significant effort and time (New Zealand, 2025). All the possible enhancements to the ERS discussed above would likely result in efficiencies when reviewing potential encounters with VMEs. A more streamlined ERS would be desirable if SPRFMO bottom fisheries were to significantly expand (in terms of effort and/or spatially), as this could increase the number of encounters triggered in a fishing year.

Looking ahead

Detected deficiencies and limitations across the different RFMOs that require impact assessments of deep-sea fisheries on the ecosystem are due, at least in part, to elements and criteria that are missing from the Deep-sea Fisheries Guidelines (DOSI, 2022; Kaikkonen *et al*., 2024). Having a structured universal bottom fishing impact assessment standard could solve these deficiencies and allow for inter-comparability among RFMOs. Differences between RFMOs, such as data availability, scientific capacity, and the value of the fishery, should be considered, ensuring that a degree of flexibility is incorporated when designing such a standard. For example, data paucity on actual VMEs including connectivity, community composition and ecosystem function is the most critical impeding factor across RFMOs to provide appropriate baseline information in their respective benthic impact assessments (DOSI, 2022; Kaikkonen *et al*., 2024). While most RFMOs have opted to model predicted habitat suitability for VME indicator taxa as a proxy for VME occurrence (which misses the aforementioned aspects of connectivity, community composition and function), this is not evenly applied across RFMOs, due to the different RFMO-specific lists of VME indicator taxa (Baco *et al*., 2023). Some RFMOs have developed more comprehensive lists of VME indicator taxa than others (and often using different levels of taxonomic resolution), in part due to the topographic and morphological characteristics of each geographical area (Baco *et al*., 2023; Reid, 2023). Another critical difference to consider when designing an across-RFMO standard relates to fishery-independent surveys. While such surveys are routinely carried out in the NAFO Regulatory Area and the collected data is used in the multi-criteria approach designed to identify VMEs (Kenchington *et al*., 2026), other deep-sea RFMOs may not have the means to fund such surveys and lack the capacity to support such a time and data-consuming scientific process.

Recent independent reviews on the implementation of the ecosystem approach (Fletcher, 2020) and the Deep-sea Fisheries Guidelines (Thompson and Reid, 2024) by RFMOs have identified important achievements but also gaps. Specifically, Fletcher (2020) identified that the major gaps relate to ecological wellbeing (notably the lack of inclusion of climate change considerations, see subheading - Future improvements) and human wellbeing (missing economic and/or social aspects). Importantly, Fletcher (2020) noted that many of the assessed RFMOs engaging in deep-sea fisheries have tasked progressing the implementation of an ecosystem approach to a subsidiary scientific body (*e.g.*, SPRFMO Scientific Committee). However, the implementation of the ecosystem approach should be guided by an overarching strategy (FAO, 2012) and include long-term management plans with appropriate tracking and monitoring systems in place to assess progress, something that NAFO has begun to implement (Mariano Koen-Alonso *et al*., 2019) and, we believe, SPRFMO should consider. Fletcher *et al*. (2020) also noted that despite SPRFMO being one of the most recently established RFMOs, it has managed to consider half of the key components regarding implementation of an ecosystem approach to fisheries (FAO, 2012). Furthermore, it must be acknowledged that SPRFMO manages three fishery resources (jack mackerel, flying jumbo squid and orange roughy) that are ecologically and geographically distinct, and with a varying degree of involvement across membership, adding an extra layer of complexity and influencing the implementation of an ecosystem approach, which is variable across each fishery. In this regard, SPRFMO could consider diverse ways to implement an ecosystem approach based on the uniqueness of its fisheries, including the diverse requirements for assessments, capacity of engaged Members, availability of data and scientific knowledge and objectives (ICES, 2024).

Arguably the most comprehensive independent performance evaluation of RFMOs to date has identified that despite its recent establishment, SPRFMO (out of the 16 assessed RFMOs) ranked above average (Carmine *et al*., 2025). While Carmine *et al*. (2025) acknowledged the relative appropriateness of existing measures across SPRFMO managed fisheries (which by definition include the standards being discussed here, but also other aspects such as governance tools), this does not necessarily translate to achieving demonstrable results in terms of implementing the ecosystem approach (interpreted as management success). Significantly, none of the 16 assessed RFMOs reviewed by Carmine *et al*. (2025) achieved results deemed as best-practise, indicating that performance gaps are not unique but rather common, even among higher-performing RFMOs. Carmine *et al*. (2025) and similar publications understandably analyse RFMOs in their entirety and typically do not provide individual evaluations for each fishery, which may differ significantly.

Within the SPRFMO context of bottom fisheries, the BFIAS and the ERS acknowledge that there are important aspects that remain unresolved, including the lack of practical and operational definitions for VMEs and SAIs. However, many of these unresolved issues are common to other RFMOs and addressing them would improve the likelihood of generating universal standards for implementing ecosystem-based fisheries management in the high seas. For example, the spatial scales at which to identify, map, and assess impacts on VMEs (following the Deep-sea Fisheries Guidelines reference to "species groups, communities, habitats and features") need to be ecologically relevant. Providing clarity on SAIs and VMEs would have consequences for both the BFIAS and the ERS, as it could facilitate the development and adoption of operational thresholds to be included in quantitative assessments. The development and establishment of a data-driven, pragmatic approach to identify VMEs across the SPRFMO Convention Area would allow the population of the VME register (Annex 9 of CMM03), where locations of known VMEs within the SPRFMO Convention Area are listed, which as of 2026 remains empty. The empty register can be partly justified by the fact that, as already mentioned, SPRFMO relies on excluding a significant amount of the predicted suitable habitat for each VME indicator taxon within FMAs as a way to avoid SAIs on VMEs (SPRFMO, 2023), therefore postponing the issue of VME identification across large spatial scales (*e.g.*, FMAs) until availability of relevant data improves (Ardron *et al*., 2014). However, the application of the ERS may require undertaking identification of potential VMEs at relatively small spatial scales (*i.e.*, the area that results temporarily closed to fishing). These ad-hoc applications of the ERS may lead to the VME register being progressively populated, subject to the management outcomes of each assessed encounter as determined by the SPRFMO Commission.

The Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ Agreement) adopted in 2023 entered into force in January 2026. The BBNJ Agreement is likely to have consequences for RFMOs, particularly regarding the inclusion of impacts across multiple sectors in impact assessments for areas beyond national jurisdiction (Johnson *et al*., 2025). Sectors identified as being a priority for immediate inclusion in cumulative impacts assessment include biodiversity conservation, climate change, oil and gas, and deep-sea mining and renewable energy (Johnson *et al*., 2025). The BBNJ Agreement sets out the procedures for proposals for area-based management tools (*e.g.*, marine protected areas, fishery closures), which are expected to be formally assessed. These proposals are likely to include criteria for identifying areas of ecological significance and consideration of fishing impacts, alongside other anthropogenic pressures. Such criteria are likely to relate directly to VMEs and assessment of SAIs, respectively. Therefore, future impact assessments would benefit from a standardised framework (similar to, or based on the BFIAS, for example) and build on the significant progress SPRFMO has made in developing and implementing

Standards and Conservation and Management Measures intended to safeguard the marine ecosystems in which the fishing resources it manages occur. In this context, promoting increased cooperation at regional scales between established RFMOs such as SPRFMO and other inter-governmental organisations appears to be critical to achieve broader conservation and sustainability goals (Carmine *et al*., 2025; FAO, 2026; Johnson *et al*., 2025; Tian and Guo, 2025; Weiand *et al*., 2021).

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References

Anderson, O., Charsley, A., Moore, B., Rowden, A., Bennion, M., Tablada, J., Geange, S., and Arkhipkin, A. 2024. Updated quantitative benthic impact assessment for New Zealand and Australian bottom fisheries. South Pacific Regional Fisheries Management Organisation, SC12-DW12. https://www.sprfmo.int/assets/Meetings/02-SC/12th-SC-2024/Deepwater/SC12-DW12_rev1-NZL-Updated-quantitative-benthic-impact-assessment-for-New-Zealand-and-Australian-bottom-fisheries.pdf

Anderson, O. F., Stephenson, F., Behrens, E., and Rowden, A. A. 2022. Predicting the effects of climate change on deep-water coral distribution around New Zealand—Will there be suitable refuges for protection at the end of the 21st century? *Global Change Biology*, **28**: 6556– 6576. https://doi.org/10.1111/gcb.16389

Anderson, J. L., Anderson, C. M., Chu, J., Meredith, J., Asche, F., Sylvia, G., Pinto da Silva, P., Tlusty, M., Garcia, E., Cleary, J., and Morrissey, M. T. 2015. The Fishery Performance Indicators: A management tool for triple bottom line outcomes. *PLOS ONE*, **10(5)**: e0122809. https://doi.org/10.1371/journal.pone.0122809

Ardron, J. A., Clark, M. R., Penney, A. J., Hourigan, T. F., Rowden, A. A., Dunstan, P. K., Watling, L., Shank, T. M., Tracey, D. M., Dunn, M. R., and Parker, S. J. 2014. A systematic approach towards the identification and protection of vulnerable marine ecosystems. *Marine Policy*, **49**: 146–154. https://doi.org/10.1016/j.marpol.2013.11.017

Arkhipkin, A., and Tablada, J. 2025. Revision of SPRFMO Bottom Fishing Impact Assessment Standard. South Pacific Regional Fisheries Management Organisation, SC13-DW11. https://www.sprfmo.int/assets/Meetings/02-SC/13th-SC-2025/Deepwater/SC13-DW11-Revision-of-SPRFMO-Bottom-Fishing-Impact-Assessment-Standard.pdf

Baco, A. R., Ross, R., Althaus, F., Amon, D., Bridges, A. E. H. Brix, S., Buhl-Mortensen, P., Colaco, A., Carreiro-Silva, M., Clark, M. R., Du Preez, C., Franken, M-L., Gianni, M., Gonzalez-Mirelis, G., Hourigan, T., Howell, K., Levin, L. A., Lindsay, D. J., Molodtsova, T. N., Morgan, N., Morato, T., Mejia-Mercado, B. E., O'Sullivan, D., Pearman, T., Price, D., Robert, K., Robson, L., Rowden, A. A., Taylor, J., Taylor, M., Victorero, L., Watling, L., Williams, A., Xavier, J. R., and Yesson, C. 2023. Towards a scientific community consensus on designating Vulnerable Marine Ecosystems from imagery. *PeerJ,* **11**: e16024 https://doi.org/10.7717/peerj.16024

Behrens, E., Williams, J., Morgenstern, O., Sutton, P., Rickard, G., and Williams, M. J. 2020. Local grid refinement in New Zealand's earth system model: Tasman Sea ocean circulation improvements and super-gyre circulation implications. *Journal of Advances in Modeling Earth Systems,* **12**: e2019MS001996. https://doi.org/10.1029/2019MS001996

Bennion, M., Anderson, O. F., Rowden, A. A., Bowden, D. A., Geange, S. W., and Stephenson, F. 2024. Evaluation of the full set of habitat suitability models for vulnerable marine ecosystem indicator taxa in the South Pacific high seas. *Fisheries Management and Ecology*, **31(4)**: e12700. https://doi.org/10.1111/fme.12700

Bennion, M., Rowden, A. A., Anderson, O. F., Bowden, D. A., Clark, M. R., Althaus, F., Williams, A., Geange, S. W., Tablada, J., and Stephenson, F. 2025a. The Use of Image-Based Data and Abundance Modelling Approaches for Predicting the Location of Vulnerable Marine Ecosystems in the South Pacific Ocean. *Fisheries Management and Ecology*, **32(1)**: e12751. https://doi.org/10.1111/fme.12751

Bennion, M., Rowden, A. A., Moore, B. R., Anderson, O. F., Tablada, J., Geange, S. W., and Stephenson, F. 2025b. Development of the South Pacific Vulnerable Marine Ecosystem bioregionalisation. *Frontiers in Ecology* *and Evolution*, **13**: 1670027. https://doi.org/10.3389/fevo.2025.1670027

Brough, T., Bennion, M., Leunissen, E., Hayden, M., and Behrens, E. 2025. Forecasting future habitat suitability of marine taxa to advance climate-smart marine spatial planning in Aotearoa New Zealand. NIWA CLIENT REPORT No: 2025186HN Prepared for the Department of Conservation. https://www.doc.govt.nz/globalassets/documents/conservation/marine-and-coastal/marine-protected-areas/forecasting-future-habitat-suitability-of-marine-taxa-to-advance-climate-smart-marine-spatial-planning.pdf

Carmine, G., Cronin, M. R., Barkley, C., Tuohy, C. L., Crespo, G.O., Österblom, H., Jacquet, J. and Halpin, P. N. 2025. An expanded evaluation of global fisheries management organizations on the high seas. *Environmental Research Letters*, **20(12)**: 123001. https://doi.org/10.1088/1748-9326/ae1b1e

Cerutti-Pereyra, F., Drenkard, E.J., Espinoza, M., Finucci, B., Galván-Magaña, F., Hacohen-Domené, A., Hearn, A., Hoyos-Padilla, M. E., Ketchum, J. T., Mejía-Falla, P. A. and Moya-Serrano, A. V. 2024. Vulnerability of Eastern Tropical Pacific chondrichthyan fish to climate change. *Global Change Biology*, **30(7)**: e17373. https://doi.org/10.1111/gcb.17373

Clark, M. R., and Roberts, C. D. 2008. Fish and invertebrate biodiversity on the Norfolk Ridge and Lord Howe Rise, Tasman Sea (NORFANZ voyage, 2003). *New Zealand Aquatic Environment and Biodiversity Report* **No. 28**. 131 p. https://webstatic.niwa.co.nz/library/NZAEBR28.pdf

Clark, M. R., Anderson, O. F., Bowden, D. A., Chin, C., George, S. G., Glasgow, D. A., Guinotte, J. M., Hererra, S., Osterhage, D. M., Pallentin, A., Parker, S. J., Rowden, A. A., Rowley, S. J., Stewart, R., Tracey, D. M., Wood, S. A., and Zeng, C. 2015. Vulnerable Marine Ecosystems of the Louisville Seamount Chain: voyage report of a survey to evaluate the efficacy of preliminary habitat suitability models. *New Zealand Aquatic Environment and Biodiversity Report* **No. 149**: 86 p. https://fs.fish.govt.nz/Doc/23779/AEBR_149_2848_SEA2013-01%20.pdf.ashx

Clark, M.R ., Wood, B., Mackay, K., Anderson, O. F., Hart, A., Rickard, G., and Rowden, A. A. 2022. Underwater Topographic Features in the New Zealand region: development of an updated 'SEAMOUNT' database and information on the extent and intensity of deep-sea trawl fisheries on them. *New Zealand Aquatic Environment and Biodiversity Report* **No. 291**: 28 p. https://fs.fish.govt.nz/Doc/25301/AEBR-291-Underwater-Topographic-Features-SEAMOUNT-Database-NZ-Region-4268.pdf.ashx

Cooke, S. J., Fulton, E. A., Sauer, W. H. H., Lynch, A. J., Link, J. S., Koning, A. A., Jena, J., Silva, L. G. M., King, A. J., Kelly, R., Osborne, M., Nakamura, J., Preece, A. L., Hagiwara, A., Forsberg, K., Kellner, J. B., Coscia, I., Helyar, S., Barange, M., Nyboer, E., Williams, M. J., Chuenpagdee, R., Begg, G. A., and Gillanders, B. M. 2023. Towards vibrant fish populations and sustainable fisheries that benefit all: learning from the last 30 years to inform the next 30 years. *Rev. Fish. Biol. Fisheries,* **33**: 317–347. https://doi.org/10.1007/s11160-023-09765-8

Cryer, M., Geange, S. W., and Bock, T. 2018. Methods for Designing Spatial Management Areas Using Outputs from Zonation Software and Other Spatial Data. South Pacific Regional Fisheries Management Organisation, SC6-DW11. https://sprfmo.int/assets/Meetings/02-SC/2018-SC6/Meeting-Documents/SC6-DW11-Process-for-drawing-mgmt-areas.pdf

Cummings, V. J., Lundquist, C. J., Dunn, M. R, Francis, M., Horn, P., Law, C., Pinkerton, M. H., Sutton, P., Tracey, D., Hansen, L., and Mielbrecht, E. 2021. Assessment of potential effects of climate-related changes in coastal and offshore waters on New Zealand's seafood sector. *New Zealand Aquatic Environment and Biodiversity Report* **No. 261**: 153 p. https://fs.fish.govt.nz/Doc/24891/AEBR-261-Assessment-Of-Potential-Effects-Of-Climate-Change-On-Seafood-Sector-3389.pdf.ashx

Curtis, J. M., Rooper, C. N., and Warawa, D. R. 2020. A Framework for Identifying Vulnerable Marine Ecosystems in the North Pacific Ocean. North Pacific Fisheries Commission, BFME01-WP12. https://www.npfc.int/system/files/2020-11/NPFC-2020-SSC%20BFME01-WP12%20A%20Framework%20for%20Identifying%20Vulnerable%20Marine%20Ecosystems.pdf

Datta, S., Beran, H., and Rogers, A. 2024. The impacts of warming on shallow and deep-water fisheries in New Zealand. *Earth's Future*, **12(12)**: e2024EF004857. https://doi.org/10.1029/2024EF004857

De Clippele, L. H., Nozères, C., Xu, J., MacDonald, B., Lirette, C., Phelan, K., Staniford, C., Whoriskey, F., Wolff, G. A., Blackbird, S., Mohn, C. and Kenchington, E. 2025. Fish use of deep-sea sponge habitats evidenced by long-term high-resolution monitoring. *Scientific reports*, **15**: 17656. https://doi.org/10.1038/s41598-025-01822-5

De Clippele, L. H., Rovelli, L., Ramiro-Sánchez, B., Kazanidis, G., Vad, J., Turner, S., Glud, R. N., and Roberts, J. M. 2021. Mapping cold-water coral biomass: an approach to derive ecosystem functions. *Coral Reefs*, **40(1)**: 215–231. https://doi.org/10.1007/s00338-020-02030-5

Durán Muñoz, P., Abalo Morla, S., Palas Otero, S., Garrido Fernández, I., Baldó Martínez, F., Sacau Cuadrado, M. 2022. NEREIDA: Research in support of the reassessment of NAFO bottom fisheries in 2022, Project number 101074766. https://www.nafo.int/Portals/0/PDFs/NEREIDA/NEREIDA_Final_Report_with_Annexes.pdf

DOSI. 2022. Assessments for Deep-Sea Fisheries on the High Seas against the FAO Deep-Sea Fisheries Guidelines. *Deep Ocean Stewardship Initiative Report*. https://www.dosi-project.org/fisheries-review-2022

FAO. 2019. Deep-ocean climate change impacts on habitat, fish and fisheries, Lisa Levin, Maria Baker, and Anthony Thompson (Eds.). *FAO Fisheries and Aquaculture Technical Paper* **No. 638**: Rome, FAO. 186 p. https://openknowledge.fao.org/handle/20.500.14283/ca2528en

FAO. 2012. EAF Toolbox: The ecosystem approach to fisheries. Rome. 172 p. https://openknowledge.fao.org/handle/20.500.14283/cc6834en

FAO. 2026. Fisheries and the BBNJ Agreement – A guide. The Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable

Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ Agreement). Rome. https://doi.org/10.4060/cd7986en

FAO. 2009. International Guidelines for the Management of Deep- Sea Fisheries in the High-seas. Food and Agriculture Organisation of the United Nations, Rome, Italy, 73 p. https://openknowledge.fao.org/handle/20.500.14283/i0816t

Fletcher, W. J. 2020. A review of the application of the FAO ecosystem approach to fisheries (EAF) management within the areas beyond national jurisdiction (ABNJ). Rome, FAO. https://www.fao.org/3/cb1509en/CB1509EN.pdf

Free, C. M., Mangin, T., García Molinos, J., Ojea, E., Burden, M., Costello, C., and Gaines, S. D. 2020. Realistic fisheries management reforms could mitigate the impacts of climate change in most countries. *PLOS ONE*, **15(3)**: e0224347. https://doi.org/10.1371/journal.pone.0224347

Gammon, M. J., Tracey, D. M., Marriott, P. M., Cummings, V. J., and Davy, S. K. 2018. The physiological response of the deep-sea coral *Solenosmilia variabilis* to ocean acidification. *PeerJ,* **6**: e5236. https://doi.org/10.7717/peerj.5236

Garcia, S. M., and Cochrane, K. L. 2005. Ecosystem approach to fisheries: a review of implementation guidelines. *ICES Journal of Marine Science*, **62(3)**: 311–318. https://doi.org/10.1016/j.icesjms.2004.12.003

Geange, S. W., Rowden, A. A., Cryer, M., and Bock, T. D. 2019. Evaluating the availability of data to assess catchability of VME indicator taxa. South Pacific Regional Fisheries Management Organisation, SC7-DW14. https://www.sprfmo.int/assets/Meetings/SC/7th-SC-2019/SC7-DW14-Availability-of-Data-to-Assess-Catchability-of-VME-Indicator-Taxa.pdf

Geange, S. W., Rowden, A. A., Nicol, S., Bock, T., and Cryer, M. 2020. A data-informed approach for identifying move-on encounter thresholds for vulnerable marine ecosystem indicator taxa. *Frontiers in Marine Science*, **7**: 155 p. https://doi.org/10.3389/fmars.2020.00155

Georgeson, L., and Cryer, M. 2019. Revision of the SPRFMO Bottom Fishery Impact Assessment Standard. South Pacific Regional Fisheries Management Organisation, SC7-DW19. https://www.sprfmo.int/assets/Meetings/SC/7th-SC-2019/SC7-DW19-Revision-of-SPRFMO-Bottom-Fishing-Impact-Assessment-Standard.pdf

Georgeson, L., Nicol, S., Cryer, M., and Bock, T. 2018. Review of the SPRFMO Bottom Fishery Impact Assessment Standard. South Pacific Regional Fisheries Management Organisation, SC6-DW13. https://www.sprfmo.int/assets/Meetings/02-SC/2018-SC6/Meeting-Documents/SC6-DW13-SPRFMO-BFIAS-review.pdf

Grantham, H., Adams, V., and The IUCN WCPA Taskforce on Spatial Planning. 2024. An overview of Participatory, Integrated, and Biodiversity-Inclusive Spatial Planning and Target 1 under the Convention on Biological Diversity Kunming-Montreal Global Biodiversity Framework, *IUCN WCPA Issues Paper Series,* **No. 4**, Gland, Switzerland: IUCN. https://iucn.org/sites/default/files/2024-10/iucn-wcpa-issues-paper-4.pdf

Hiddink, J. G., Valanko, S., Delargy, A. J., and van Denderen, P. D. 2023. Setting thresholds for good ecosystem state in marine seabed systems and beyond. *ICES Journal of Marine Science*, **80**: 698–709. https://doi.org/10.1093/icesjms/fsad035

Hitt, N. T., Sinclair, D. J., Fallon, S. J., Neil, H. L., Tracey, D. M., Komugabe-Dixson, A., and Marriott, P. 2020. Growth and longevity of New Zealand black corals. *Deep Sea Research Part I: Oceanographic Research Papers*, **162**: 103298. https://doi.org/10.1016/j.dsr.2020.103298

Hobday, A. J., Smith, A. D. M, Stobutzki, I. C., Bulman, C., Daley, R., Dambacher, J. M., Deng, R. A., Dowdney, J., Fuller, M., Furlani, D., Griffiths, S. P., Johnson, D., Kenyon, R., Knuckey, I. A., Ling, S. D., Pitcher, R., Sainsbury, K. J., Sporcic, M., Smith, T., Turnbull, C., Walker, T. I., Wayte, S. E., Webb, H., Williams, A., Wise, B. S., and Zhou, S. 2011. Ecological risk assessment for the effects of fishing. *Fisheries Research*. Volume **108: Issues 2–3**. https://doi.org/10.1016/j.fishres.2011.01.013

Hobday, A. J., J. Dowdney, C. Bulman, M. Sporcic, M. Fuller, M. Goodspeed, and E. Hutchinson. 2007. Ecological Risk Assessment for the Effects of Fishing: Bass Strait Central Zone Scallop Sub-Fishery. Report for the Australian Fisheries Management Authority, Canberra. https://www.fish.gov.au/Archived-Reports/2014/Documents/2014_refs/Hobday%20et%20al%202007%20ERA.pdf

ICES. 2022. Benchmark Workshop on the occurrence and protection of VMEs (vulnerable marine ecosystems) (WKVMEBM). *ICES Scientific Reports*. **4:55**. 99 p. http://doi.org/10.17895/ices.pub.20101637

ICES. 2024. NEAFC request on Ecosystem Approaches to Fisheries Management. ICES Advice: Special Requests. Report. https://doi.org/10.17895/ices.advice.27052372.v1

Johnson, D. E., Turner, P. J., and Barrio Froján, C. 2025. Report on cross-sectoral impacts on deep-sea fisheries in the high seas. Rome, FAO. https://doi.org/10.4060/cd3781en

Judah, A. B., Mull, C. G., Dulvy, N. K., Finucci, B., Assad, V. E., and Drazen, J. C. 2025. Deep-sea mining risks for sharks, rays, and chimaeras. *Current Biology*, **35(21)**: 5353–5362. https://doi.org/10.1016/j.cub.2025.09.019

Kaikkonen, L., Amaro, T., Auster, P.J., Bailey, D. M., Bell, J. B., Brandt, A., Clark, M. R., Drazen, J. C., Du Preez, C., Escobar-Briones, E., Giacomello, E., Gianni, M., Johnson, A. F., Levin, L. A., Milligan, R. J., Oduware, S., Pearman, T. R. R., Pham, C. K., Ramalho, S. P., Rowden, A. A., Sutton, T. T., Taylor, M. L., Watling, L., and Victorero, L. 2024. Improving impact assessments to reduce impacts of deep-sea fisheries on vulnerable marine ecosystems. *Marine Policy*, Volume **167**: 106281. https://doi.org/10.1016/j.marpol.2024.106281

Keller, K, Emery, T, Timmiss, T., Hartog, J., and Fuller, M. 2025. Updated SPRFMO ecological risk assessment for teleost and deepwater chondrichthyans. South Pacific Regional Fisheries Management Organisation, SC13-DW03. https://www.sprfmo.int/assets/Meetings/02-SC/13th-SC-2025/Deepwater/SC13-DW03-Ecological-Risk-Assessment-for-Deepwater-fisheries.pdf

Kenchington, E., Lirette, C., Sacau, M., Murillo, F. J., and Wang, Z. 2026. Vulnerable marine ecosystems in the NAFO regulatory area: Updated Kernel Density analyses of vulnerable marine ecosystem indicators. *NAFO SCR Doc.*, **25/047**, Serial No. N7693. https://doi.org/10.13140/RG.2.2.10484.00649

Kenny, A. J., Pepin, P., Bell, J., Downie, A., Kenchington, E., Koen-Alonso, M., Lirette, C., Barrio Froján, C., Ollerhead, Neil., Murillo, F. J., Sacau, M., Fuller, S. and Diz, D. 2025. Reference points for assessing significant adverse impacts on deep sea vulnerable marine ecosystems. *Ecological Indicators*, **172**: 113296. https://doi.org/10.1016/j.ecolind.2025.113296

Kirby, D. S., and Ward, P. 2014. Standards for the effective management of fisheries bycatch. *Marine Policy*, **44**: 419–426. https://doi.org/10.1016/j.marpol.2013.10.008

Koen-Alonso, M., Pepin, P., Fogarty, M. J., Kenny, A., and Kenchington, E. 2019. The Northwest Atlantic Fisheries Organization Roadmap for the development and implementation of an Ecosystem Approach to Fisheries: structure, state of development, and challenges. *Marine Policy*, **100**: 342–352. https://doi.org/10.1016/j.marpol.2018.11.025

Maier, S. R., Kutti, T., Bannister, R. J., Fang, J. K. H., van Breugel, P., van Rijswijk, P., and Van Oevelen, D. 2020. Recycling pathways in cold-water coral reefs: Use of dissolved organic matter and bacteria by key suspension feeding taxa. *Scientific reports*, **10(1)**: 9942. https://doi.org/10.1038/s41598-020-66463-2

Marine Stewardship Council 2024. MSC Fisheries Standard Version 3.1. https://www.msc.org/standards-and-certification/fisheries-standard/version-3

McCay, B. J., and Jentoft, S. 1996. From the bottom up: Participatory issues in fisheries management. *Society & Natural Resources*, **9(3)**: 237–250. https://doi.org/10.1080/08941929609380969

Morato, T., Pham, C. K., Pinto, C., Golding, N., Ardron, J. A., Durán Muñoz, P., and Neat, F. 2018. A multi criteria assessment method for identifying vulnerable marine ecosystems in the North-East Atlantic. *Frontiers in Marine Science*, **5**:460. https://doi.org/10.3389/fmars.2018.00460

Milardi, M., and Geange, S. W. 2021. Design of a review process for VME encounters in bottom fisheries in the SPRFMO Area. South Pacific Regional Fisheries Management Organisation, SC9-DW08. https://www.sprfmo.int/assets/Meetings/SC/9th-SC-2021/deepwater-wg/SC9-DW08-Design-of-a-review-process-for-VME-encounters-in-bottom-fisheries-in-the-SPRFMO-area.pdf

NAFO. 2020. Report of the 13th Meeting of the NAFO Scientific Council Working Group on Ecosystem Science and Assessment (WG-ESA). *NAFO SCS Doc.* **20/23**, Serial No. 7148. https://www.nafo.int/Portals/0/PDFs/sc/2020/scs20-23.pdf

New Zealand. 2025. New Zealand 2024 VME Encounter Review. South Pacific Regional Fisheries Management Organisation, SC13-DW09. https://www.sprfmo.int/assets/Meetings/02-SC/13th-SC-2025/Deepwater/SC13-DW09-New-Zealand-2024-VME-Encounter-Review.pdf .

Peixoto, U. I., Sporcic, M., Hobday, A. J., Bentes, B., Passarone, R., Fredou, F. L., and Isaac, V. J. 2025. Ecological risk assessment of marine resources caught as bycatch in industrial bottom trawl shrimp fishery in the Amazon Continental Shelf. *Frontiers in Marine Science*, **12**: 1490894. https://doi.org/10.3389/fmars.2025.1490894

Penney, A. J. 2014. Review of the biodiversity component of the New Zealand Vulnerable Marine Ecosystem Evidence Process. *New Zealand Aquatic Environment and Biodiversity Report* **No. 135**. 40 p. https://www.mpi.govt.nz/dmsdocument/4723/direct/

Pentz, B., Klenk, N., Ogle, S., and Fisher, J. A. 2018. Can regional fisheries management organizations (RFMOs) manage resources effectively during climate change?. *Marine Policy*, **92**: 13–20. https://doi.org/10.1016/j.marpol.2018.01.011

Pinkerton, M. H. 2017. Impacts of Climate Change on New Zealand Fisheries and Aquaculture. *In* Climate Change Impacts on Fisheries and Aquaculture (Eds. B. F. Phillips and M. Pérez-Ramírez). https://doi.org/10.1002/9781119154051.ch5

Pitcher, C. R., Ellis, N., Jennings, S., Hiddink, J. G., Mazor, T., Kaiser, M. J., Kangas, M. I., McConnaughey, R. A., Parma, A. M., and Rijnsdorp, A. D. 2017. Estimating the sustainability of towed fishing-gear impacts on seabed habitats: a simple quantitative risk assessment method applicable to data- limited fisheries. *Methods in Ecology and Evolution*, **8(4)**: 472–480. https://doi.org/10.1111/2041-210X.12705

Reid, K. 2023. A review of the basis by which RFMOs have determined VME encounter thresholds by taxa and gear-types. North Pacific Fisheries Commission, 4th Small Scientific Committee on Bottom Fish and Marine Ecosystems (SSC BF-ME) meeting. https://www.npfc.int/system/files/2023-11/NPFC-2023-SSC%20BFME04-WP06%20VME%20encounter%20thresholds.pdf

Rooper, C. N., Somers, K., Goddard, P., and Campbell, G. 2025. Estimating quantitative gear and taxa specific encounter thresholds for commercial fisheries bycatch of vulnerable marine ecosystem indicator taxa. *Deep Sea Research Part II: Topical Studies in Oceanography*, **219**: 105448. https://doi.org/10.1016/j.dsr2.2024.105448

Rowden, A. A., Anderson, O. F., Stephenson, F., Geange, S. W., and Milardi, M. 2025. Determination of optimal move-on distance for trawl encounters with vulnerable marine ecosystems. *ICES Journal of Marine Science*, **82(2)**: fsae173. https://doi.org/10.1093/icesjms/fsae173

Rowden, A. A., Stephenson, F., Cryer, M., Lundquist, C. J., Anderson, O. F., Bennion, M., Biggerstaff, A., Bock, T., Brough, T., Georgeson, L., Macdonald, A., Milardi, M., Nicol, S., Pitcher, R., Tablada, J., Timmiss, T. A., Magsig, R. M., and Geange, S. W. 2026. Implementing area-based management of vulnerable marine ecosystems in areas beyond national jurisdiction: A South Pacific case study. Ocean & Coastal Management, 280, 108267. https://doi.org/10.1016/j.ocecoaman.2026.108267

Rowden, A., Tablada, J., and Arkhipkin, A. 2024. A review of information to assist in defining thresholds for significant adverse impact on vulnerable marine ecosystems. South Pacific Regional Fisheries Management Organisation, SC12-DW07_rev1. https://www.sprfmo.int/assets/Meetings/02-SC/12th-SC-2024/Deepwater/SC12-DW07_rev1-NZL-A-review-of-information-to-assist-in-defining-thresholds-for-SIAs-on-VMEs.pdf

Sharp, B. R., Parker, S. J. and Smith, N. 2009. An impact assessment framework for bottom fishing methods in the CAMLR Convention Area. *CCAMLR Science*, **16**: 195–210. https://www.ccamlr.org/en/system/files/science_journal_papers/10sharp-et-al.pdf

SPRFMO. 2025a. Conservation and Management Measure for the Management of Bottom Fishing in the SPRFMO Convention Area (CMM 03-2025). South Pacific Regional Fisheries Management Organisation. https://www.sprfmo.int/assets/Fisheries/Conservation-and-Management-Measures/2025-CMMs/CMM-03-2025-Bottom-Fishing.pdf

SPRFMO. 2025b. Conservation and Management Measure on Standards for the Collection, Reporting, Verification and Exchange of Data (CMM 02-2025). South Pacific Regional Fisheries Management Organisation. https://www.sprfmo.int/assets/Fisheries/Conservation-and-Management-Measures/2019-CMMs/031708aaea/CMM-03-2019-5Mar2019.pdf

SPRFMO. 2025c. 13th Scientific Committee meeting report 180 p. Wellington, New Zealand 2025. South Pacific Regional Fisheries Management Organisation, SC13. https://www.sprfmo.int/assets/Meetings/02-SC/13th-SC-2025/SC13-REPORT-ADOPTED-13SEPT2025b.pdf

SPRFMO. 2024. Encounter Review Standard for the South Pacific Regional Fisheries Management Organisation. South Pacific Regional Fisheries Management Organisation. https://sprfmo.int/assets/Meetings/02-SC/12th-SC-2024/Deepwater/SC12-DW10-NZL-Encounter-Review-Standard-for-the-SPRFMO.pdf

SPRFMO. 2023. Cumulative Bottom Fishery Impact Assessment for Australian and New Zealand bottom fisheries, 2023. Prepared by Australia and New Zealand. South Pacific Regional Fisheries Management Organisation, SC11 – DW01_rev1. https://www.sprfmo.int/assets/Meetings/02-SC/11th-SC-2023/Deepwater/SC11-DW01_rev1-Cumulative-Bottom-Fishery-Impact-Assessment-for-AUS-and-NZL-bottom-fisheries-2023.pdf

SPRFMO. 2019a. Bottom Fishery Impact Assessment Standard for the South Pacific Regional Fisheries Management Organisation. South Pacific Regional Fisheries Management Organisation. https://www.sprfmo.int/assets/Fisheries/Science/SPRFMO-Bottom-Fishery-Impact-Assessment-Standard-2019.pdf

SPRFMO. 2019b. Conservation and Management Measure for the Management of Bottom Fishing in the SPRFMO Convention Area (CMM 03-2019). South Pacific Regional Fisheries Management Organisation. https://www.sprfmo.int/assets/Fisheries/Conservation-and-Management-Measures/2019-CMMs/031708aaea/CMM-03-2019-5Mar2019.pdf

SPRFMO. 2022. Convention on the Conservation and Management of High Seas Fishery Resources in the South Pacific Ocean. South Pacific Regional Fisheries Management Organisation. https://www.sprfmo.int/assets/Basic-Documents/Convention-and-Final-Act/SPRFMO-Convention-2023-update-12May2023.pdf

SPRFMO. 2014. Conservation and Management Measure for the Management of Bottom Fishing in the SPRFMO Convention Area (CMM 2.03). South Pacific Regional Fisheries Management Organisation. https://www.sprfmo.int/assets/Meetings/Archived-Meetings/Meetings-2013-plus/Commission-Meetings/2nd-Commission-Meeting-2014-Manta-Ecuador/Annex-M-CMM-2.03-CMM-for-Bottom-Fishing.pdf

SPRFMO. 2012. Bottom Fishery Impact Assessment Standard. South Pacific Regional Fisheries Management Organisation. https://www.sprfmo.int/assets/Meetings/Meetings-before-2013/Scientific-Working-Group/SWG-06-2008/a-Miscellaneous-Documents/4daf89abbe/SPRFMO-Bottom-Fishing-Impact-Assessment-Standardagreed-Vanuatu-Fri23Sep2011-1140am.pdf

SPRFMO. 2009a. Revised Draft Bottom Fishery Impact Assessment Standard (SP-08-SWG-DW-01). South Pacific Regional Fisheries Management Organisation, SWG-08-DW01. https://www.sprfmo.int/assets/Meetings/Meetings-before-2013/Scientific-Working-Group/SWG-08-2009/6829ec9d63/SP-08-SWG-DW-01-Revised-draft-SPRFMO-Bottom-Fishing-Impact-Assessment-Standard.doc.pdf

SPRFMO. 2009b. Standards for the collection, reporting, verification and exchange of data. South Pacific Regional Fisheries Management Organisation. https://sprfmo.int/assets/Fisheries/Old-Interim-Measures-Reporting/35a811a40b/2009May18-SPRFMO7-Annex-DConsolidated-Data-Standards-Amended-Peru.pdf

SPRFMO. 2008. Bottom Fishery Impact Assessment Bottom Fishing Activities by New Zealand Vessels Fishing in the High Seas in the SPRFMO Area during 2008 and 2009. South Pacific Regional Fisheries Management Organisation. https://www.sprfmo.int/assets/Meetings/Meetings-before-2013/Scientific-Working-Group/SWG-06-2008/a-Miscellaneous-Documents/c072db6780/New-Zealand-Bottom-Fishery-Impact-Assessment-v1.3-2009-05-13.pdf

Stephenson, F., Zelli, E., Bennion, M., Rowden, A. A., Anderson, O. F., Clark, M. R., Tablada, J., Hiddink, J. G., Kaikkonen, L., Finucci, B. and Tracey, D.M., and Geange, S. W. 2025. Large-scale assessments of bottom trawling effects on Vulnerable Marine Ecosystems can significantly under-represent impacts. *Journal of Environmental Management,* **395**, 127672. https://doi.org/10.1016/j.jenvman.2025.127672

Stephenson, F., Rowden, A. A., Anderson, O. F., Ellis, J. I., Geange, S.W., Brough, T., Behrens, E., Hewitt, J.E., Clark, M. R., Tracey, D. M. and Goode, S. L., 2023. Implications for the conservation of deep-water corals in the face of multiple stressors: A case study from the New Zealand region. *Journal of Environmental Management*, **346**: 118938. https://doi.org/10.1016/j.jenvman.2023.118938

Stephenson, F., Geange, S., Rowden, A., Charsley, A., Anderson, O., and Biggerstaff, A. 2022. Further analysis of the catchability of VME indicator taxa and the design of a related research programme. South Pacific Regional Fisheries Management Organisation, SC10-DW04. https://www.sprfmo.int/assets/Meetings/SC/10th-SC-2022/SC10-DW04-Further-analysis-of-VME-indicator-taxa-catchability-and-the-design-of-a-related-research-programme-NZ.pdf

Stephenson, F., Rowden, A. A., Anderson, O. F., Pitcher, C. R., Pinkerton, M. H., Petersen, G., and Bowden, D. A. 2021. Presence-only habitat suitability models for vulnerable marine ecosystem indicator taxa in the South Pacific have reached their predictive limit. *ICES Journal of Marine Science*, **78(8)**: 2830–2843. https://doi.org/10.1093/icesjms/fsab162

Susini, I., Van Audenhaege, L., Price, D. M., Pearman, T. R., Mitchell, E. G., and Huvenne, V. A. 2025. Fine-scale spatial organisation of deep-sea sea pens in a NE Atlantic submarine canyon conservation area. *Scientific Reports*, **15(1)**: 29332. https://doi.org/10.1038/s41598-025-13327-2

Tablada, J., Geange, S., and Stephenson, F. 2022. Development of a process to review all recent and historical benthic bycatch data. South Pacific Regional Fisheries Management Organisation, SC10-DW03. https://www.sprfmo.int/assets/Meetings/SC/10th-SC-2022/SC10-DW03-Development-of-a-process-to-review-all-recent-and-historical-benthic-bycatch-data-NZ.pdf

Tablada, J., Jefferson, T., Tunley, K., and Geange, S. 2023. Development of a process to review all recent and historical benthic VME bycatch data. South Pacific Regional Fisheries Management Organisation, SC11-DW10. https://www.sprfmo.int/assets/Meetings/02-SC/11th-SC-2023/Deepwater/SC11-DW10-NZL-Development-of-a-process-to-review-all-recent-and-historical-benthic-VME-bycatch-data.pdf

Thompson, A. B., and Reid, K. 2024. Review of the implementation of the International Guidelines for the Management of Deep-sea Fisheries in the High Seas. *FAO Fisheries and Aquaculture Technical Paper*, **No. 703**. Rome, FAO. https://doi.org/10.4060/ca7692en

Tian, H., and Guo, J. 2025. The potential interactions between the BBNJ Agreement and RFMOs in the establishment of ABMTs: Implications for RFMOs. *Marine Policy*, **171**: 106477. https://doi.org/10.1016/j.marpol.2024.106477

Tingley, G., and Dunn, M. 2018. Global review of orange roughy (*Hoplostethus atlanticus*), their fisheries, biology and management. FAO. https://openknowledge.fao.org/handle/20.500.14283/ca1870en

Tracey, D. M., Marriott, P., Hitt, N., Neil, H., and Clark, M. R. 2024. Age and growth of a habitat-forming deep-sea coral *Solenosmilia variabilis* in the New Zealand region: implications for fisheries management. *New Zealand Journal of Marine and Freshwater Research*, **59(5)**: 997–1019. https://doi.org/10.1080/00288330.2024.2398779

Turschwell, M. P., Brown, C. J., Lacharité, M., Melbourne-Thomas J., Hayes, K. R., Bustamante, R. H., Dambacher, J. M., Evans, K., Fidelman, P., MacDonald, D. H., Van Putten, I., Wood, G., Abdussamie, N., Bates, M., Blackwell, D., D'Alessandro, S., Dutton, I., Ericson, J. A., Frid, C. L. J., McDougall, C.,Lea, M.-A., Rissik, D., Trebilco, R., and Fulton, E. A. 2023. Co-designing a multi-criteria approach to ranking hazards to and from Australia's emerging offshore blue economy. *Environmental Science & Policy*, **147**: 154–168. https://doi.org/10.1016/j.envsci.2023.06.008

van Denderen, P. D., Holah, H., Robson, L. M., Hiddink, J. G., Menot, L., Pedreschi, D., Kazanidis, G., Llope, M., Turner, P. J., Stirling, D., Murillo, F. J., Kenny, A., Campbell, N., Allcock, A. L., Braga-Henriques, A., González-Irusta, J. M., Johnston, G., Orejas, C., Serrano, A., Xavier, J. R., Hopkins, P., Kenchington, E., Nixon, E., and Valanko, S. A. 2022. Policy-based framework for the determination of management options to protect vulnerable marine ecosystems under the EU deep-sea access regulations. *ICES Journal of Marine Science*, **79**: 34–49. https://doi.org/10.1093/icesjms/fsab237

Vad, J., Cleland, J., De Clippele, L. H., de Froe, E., Kazanidis, G., Blackbird, S., Van Oevelen, D., Head, E., Yashayaev, I., Kenchington, E., de Moura Neves, Edinger, E., Coté, D., B., and Roberts, J. M. 2025. Drivers of Coral and Sponge Community Composition and Size Structure Revealed with Cumulative Abundance Profiles. *Marine Ecology*, **46(5)**: e70030. https://doi.org/10.1111/maec.70030

Vanegas-Cantarero, M. M., Pennock, S., Bloise-Thomaz, T., Jeffrey, H., and Dickson, M. J. 2022. Beyond LCOE: A multi-criteria evaluation framework for offshore renewable energy projects. *Renewable and Sustainable Energy Reviews*, **161**: 112307. https://doi.org/10.1016/j.rser.2022.112307

Watling, L., and Auster, P. J. 2021. Vulnerable marine ecosystems, communities, and indicator species: confusing concepts for conservation of seamounts. *Frontiers in Marine Science*, **8**: 622586. https://doi.org/10.3389/fmars.2021.622586

Warawa, D., Curtis, J., Rooper, C., Nephin, J., Georgian, S., Chu, J. W. F., Dudas, S., and Knudby, A. 2025. Identification of Vulnerable Marine Ecosystems on Seamounts in the North Pacific Fisheries Commission Convention Area using Visual Surveys and Distribution Models. *DFO Can. Sci. Advis. Sec. Res. Doc.* **2025/014**. vi + 42 p. https://publications.gc.ca/site/archivee-archived.html?url=https://publications.gc.ca/collections/collection_2025/mpo-dfo/fs70-5/Fs70-5-2025-014-eng.pdf

Weiand, L., Unger, S., Rochette, J., Müller, A., and Neumann, B. 2021. Advancing ocean governance in marine regions through stakeholder dialogue processes. *Frontiers in Marine Science*, **8**: 645576. https://doi.org/10.3389/fmars.2021.645576

Williams, A. 2011. Bottom Fishery Impact Assessment Australian report for the South Pacific Regional Fisheries Management Organisation (SPRFMO). South Pacific Regional Fisheries Management Organisation. https://www.afma.gov.au/sites/default/files/2023-02/bottom_fishery_impact_assessment_sprfmo.pdf

Zhou, S., and Griffiths, S. P. 2008. Sustainability Assessment for Fishing Effects (SAFE): A new quantitative ecological risk assessment method and its application to elasmobranch bycatch in an Australian trawl fishery. *Fisheries Research*, **91(1)**: 56–68. https://doi.org/10.1016/j.fishres.2007.11.007

Zelli, E., Ellis, J., Pilditch, C., Rowden, A. A., Anderson, O. F., Geange, S. W., Bowden, D. A., and Stephenson, F. 2025. Identifying climate refugia for vulnerable marine ecosystem indicator taxa under future climate change scenarios. *Journal of Environmental Management*, **373**: 122635. https://doi.org/10.1016/j.jenvman.2024.122635