BOTTOM FISHERY IMPACT ASSESSMENT STANDARD

for the South Pacific Regional Fisheries Management Organisation

Revised October 2019

South Pacific Regional Fisheries Management Organisation
PO Box 3797, Wellington 6140, New Zealand.
T: +64 4 499 9889 - F: +64 4 473 9579 – E: secretariat@sprfmo.int

Contents

SPRFMO Bottom Fishery Impact Assessment Standard

1. Bottom Fishery Impact Assessment sections

Supporting background information is given in Appendix A. Appendix B provides information relevant to the definition and distribution of vulnerable marine ecosystems (VMEs). Appendix C provides examples of different risk assessment approaches. Appendix D provides additional information relevant to new and exploratory fisheries.

Impact assessments for bottom fishing activities in the SPRFMO Convention Area shall provide information under the following sections.

1.1 Description of fishing activities

Assessments shall contain a detailed fishing plan, providing a quantified description of fishing activities, including:

- Details of the vessels used/to be used, providing all vessel data required consistent with CMM 05 (Record of Vessels) and confirmation that they appear on the list of approved SPRFMO vessels submitted by flag states to the SPRFMO Secretariat.
- Detailed description of fishing methods (trawls, hook and lines, traps/pots) used/to be used, including a description and gear plan, providing the information needed to evaluate potential impacts, such as net or bottom line types, net dimensions or bottom line lengths/number of hooks, trawl-door type, size and weight, footrope dimensions and type, ground gear (bobbins, rock-hopper gear, etc.), range in fishing height off bottom, net opening, soak times and any factors affecting gear selectivity.
- Seabed depth range fished/to be fished.
- Target species, and likely or potential by-catch species.
- Temporal aspects of fishing (e.g. years the fishery has been active/is anticipated to be active, seasonal aspects, periodicity and/or duration of trips, periodicity and/or duration of fishing operations).
- Effort indices: How many vessels, how many tows (cumulative effects), estimated tow durations or distance (ranges).
- Estimated total catch and discard quantities by target and bycatch species.

In instances where new or exploratory fisheries are being undertaken, assessments shall provide all of the information specified above, as well as information on any other requirements specified in CMM 13 (Exploratory Fisheries).

1.2 Mapping and description of fishing areas

Maps of the fishing areas in relation to available information on vulnerable marine ecosystems (VMEs) and seabed bathymetry should be presented including:

- Maps of the fishing areas by method and target species, at the appropriate resolution.
- Mapping of sample data and results of predictive habitat suitability models for VME indicator taxa occurring in the SPRFMO Convention Area, or topographic features likely to support such VME indicator taxa, including geospatial data available on actual or predicted distribution of VMEs and

topographic features.

- Mapping of all known VMEs, or evidence of potential VMEs, in the proposed fishing areas, in particular, all geospatial data on distributions of known VMEs or evidence of potential VMEs.
- Baseline data and description of the fishing areas, presenting any available information that might be useful to assessing the potential impacts of fishing, such as past history of fishing, seabed type, depth ranges, location/presence of any known seabed topographic features and VMEs, and also overlap with ranges of protected, rare, threatened or endangered species that might interact with the fishery.

Additional information on mapping fishing known or potential VME areas and bottom fishing effort is given in Appendix B.

1.3 Risk and impact assessment framework

A challenge with the implementation of an ecosystem approach to fisheries management is the scale and range of issues to be considered, all of which cannot necessarily be addressed at the same level of detail (Hobday et al. 2011). The typical sequence in addressing this complexity is to first undertake the risk assessment (or assessments) that highlights the activities and potential impacts that are the most important. These are then the subject of impact assessment that describes the situation, what and how various assets will be affected, determination of what can be avoided or mitigated, and identification of residual impacts that will remain. The final step in the framework is a management and monitoring plan, which focuses on residual impacts that need to be actively managed and monitored. The overall framework should be iterative and adaptive in that risks and impacts are periodically reassessed and management and monitoring plans are updated accordingly.

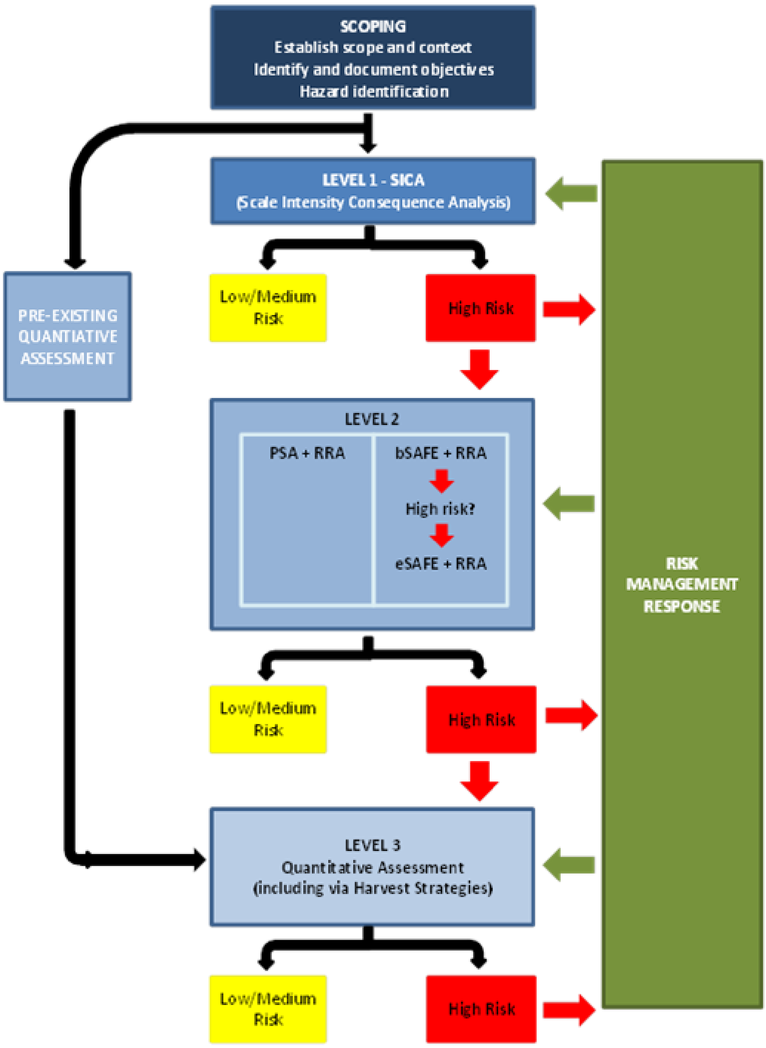
Consequently, this BFIAS is structured around the following components:

1. Identification of objectives, assets, hazards and risks using a hierarchical risk assessment approach
2. Identification and assessment of impacts
3. Identification of mitigation, management and monitoring measures relevant to impacts and residual risks
4. Iterative and adaptive review (i.e. periodic reassessment and improvement).

Risk should be assessed at each level of a hierarchy based on the uncertainty inherent in various types of assessments (e.g. benthic assessments, stock assessments, productivity-susceptibility analyses etc.). The Hobday et al. (2011) approach (Figure 1) is an ecological risk assessment approach that, in this context, is nested within the BFIAS framework of impact assessment, management of impacts, ongoing monitoring and iterative review.

The Hobday et al. (2011) risk assessment approach is structured around three tiers: the first is largely expert-based/qualitative assessment, the second is semi-quantitative and the third is fully quantitative estimates of status at various levels of detail. Within each tier there are various methods that can be adapted to fish stocks, other species of interest or concern, and benthic habitats and communities. Any hazard that cannot be demonstrated to be low risk with justification at a given tier needs to be assessed at the next level tier, or managed to reduce risk to low. Impacts, on the other hand, need to be actively managed and/or mitigated and monitored.

Figure 1. Structure of the three level hierarchical methodology for the Ecological Risk Assessment for the Effects of Fishing methodology. Indicative methods available at each tier are shown, e.g. SICA – Scale Intensity Consequence Analysis; PSA – Productivity-Susceptibility Analysis; SAFE -- Sustainability Assessment for Fishing Effects; RRA – Residual Risk Analysis. Modified from Hobday et al. (2011).



1.3.1 Scoping of objectives, assets and hazards

The initial step in an assessment is to identify objectives as well as all assets of value against all potential hazards the fisheries may pose. SPRFMO objectives are outlined in Annex B.

Key assets in any bottom fishing impact assessment will include:

- Target species
- Non-target (bycatch) species
- Seabirds, marine mammals, reptiles and other species of concern
- Benthic habitats, biodiversity and VMEs.

Hazards include:

- Fishing activity: this will need to be evaluated for each gear type used by all vessels (e.g. trawling, longlining, etc.) engaged in fishing
- Loss of bottom fishing gear, including the risk of ghost fishing and ongoing physical impact of lost gear
- Non-gear impacts, for example bird strikes with vessels, offal discharge, use of lights at night etc.

For each hazard to be evaluated a description of the impacts should be provided, in terms of what has been or may be affected and how. Any hazards that cannot be demonstrated to be low need to be assessed in more detail. Non-fishery related hazards that may result in cumulative risk and/or impacts should also be identified.

1.3.2 Information on status of the deepwater stocks to be fished

This section should provide information on the estimated status of the deepwater stocks of the intended target and by-catch species. For established and exploratory fisheries, such information should include:

- A list of the intended target and likely by-catch species.
- Tables of historic catches and catch trends of these species in the intended fishing area.
- Tables, figures of analyses of historic nominal and/or standardised CPUE trends in these species.
- Results of any surveys conducted on the stocks to be fished.
- Results of the most recent stock assessments that have been conducted for the stocks to be fished, if any such stock assessments have been conducted.
- Any other information relevant to understanding the status and sustainability of target and bycatch species.

If a robust stock assessment is available with relevant reference points, this would constitute a high standard of risk assessment (e.g. Level 3 in the Hobday et al. (2011) framework), where the outputs of the stock assessment relative to reference points indicates the risk to the stocks, and where the impacts of fishing on the stocks can be managed and monitored through, for example, a fishery harvest strategy. These elements should be worked towards for key stocks. Where information is not available to provide fully quantitative assessments, methods such as Productivity-Susceptibility Analysis (PSA, e.g. Stobutzki et al. 2002), Sustainability Assessment For Fishing Effects (SAFE, e.g. Zhou et al. 2008; Zhou et al. 2019) and Ecological Assessment of Sustainable Impacts of Fisheries (EASI-Fish, Griffiths et al. 2018) (see Appendix C for details of methods) could be applied to provide estimates of risk and/or status based on species' biological characteristics in relation to the spatial extent (and in some cases intensity) of fishing.

1.3.3 Interactions with marine mammals, reptiles, seabirds and other species of concern

This section should provide information on the estimated risk to, and/or status of seabirds, marine mammals, marine reptiles and other species of concern. Such information should include:

- A list of the likely by-catch species and any conservation status assigned to them.
- Tables of historic interactions with these species in the intended fishing area, including interaction types and life status.
- Results of (or reference to) any assessments or surveys conducted on these species.
- Any other information relevant to understanding the status and sustainability of these species.

This information should be used to describe impacts on these species. The same information should be provided in instances where new or exploratory fisheries are being undertaken (in accordance with CMM 13 (Exploratory Fisheries)).

Assessment approaches could include, for example, ecological risk assessment (e.g. Hobday et al. 2011, Ford et al. 2015; Richard et al. 2017, Georgeson et al. 2019, see Appendix C for details of methods) or simple extrapolation of bycatch (with the appropriate caveats). Given the rareness of interactions with many of these species in established SPRFMO bottom fisheries and various uncertainties in some ERAs (e.g. PSA), a qualitative expert-based assessment (e.g. Scale-Intensity-Consequence Analysis (SICA) as applied by Ford et al. (2015)) may be preferable.

1.3.4 Interactions with benthic habitats and VMEs

This section should specifically address the impacts of the fishing gear on potential VMEs or VME indicator taxa:

- What impacts on potential VMEs or VME indicator taxa are likely to result from the fishing gears to be used? All impacts should be identified, characterised and, if possible, quantified or ranked. All interactions of fishing gear with the seabed will have some impact, but the nature and severity will depend on the gear type and the species/habitat. Information on known or likely species and habitats in the proposed fishing area should be used to evaluate potential impacts of the fishing gears to be used.
- What will be the probability, likely extent (% of habitat targeted) and intensity of the interaction between the proposed fishing gear/targeting practices on potential VMEs or VME indicator taxa in the fishing areas?
- What are the characteristics of the habitats and benthic communities that may be impacted? Are the fished seabed features likely to support VMEs or VME indicator taxa? Do these areas include fragile or habitat-forming species? What proportion of the estimated distribution range of these potential VMEs or VME indicator taxa will the fishing activities impact? How widespread or localized are the potential VMEs/VME indicator taxa? How vulnerable are they to impact by the fishing gears?
- How diverse is the ecosystem in the proposed fishing areas, and will the fishing activity reduce biodiversity? Do the fishing areas contain species that do not occur elsewhere? What are the levels of endemism? Could fishing lead to localised/global extinctions?
- What is the likely spatial scale and duration of the impacts? Will impacts be cumulative with previous impacts in the area? The overall consequences of impact will be the product of spatial scale, duration and cumulative impact on potential VMEs/VME indicator taxa and other marine resources. Loss of substantial areas of habitat forming coral could have a prolonged impact on the ecosystem, including on target species, whereas consequences may be less for faunal groups that are able to recover quickly. To the extent possible, rates of recovery, regeneration and re-colonisation should be quantified or estimated.

In instances where new or exploratory fisheries are intended to be undertaken the assessment should include consideration of all aspects specified above, where appropriate.

1.3.5 Risk assessment for benthic habitats, biodiversity and VMEs

Determining the level of risk to benthic habitats, biodiversity and VMEs for each hazard should be based on quantifiable criteria where possible. Where quantitative risk assessment approaches are used (see Appendix C for examples), evaluations of interactions will be directly provided by those assessments.

Where qualitative criteria are used due to data gaps, qualitative judgements should be justified as far as possible by quantitative analyses, and sufficient documentation should be provided to enable the Scientific Committee to assess the threat as appropriate. Criteria that should be considered are:

Intensity – The intensity or severity of the impact. This will be influenced by the unit of analysis chosen for the assessment (i.e. the scale at which impact is assessed) and should, where possible, be based on quantitative measures derived from impact assessment methods that have been applied successfully elsewhere (e.g. Sharp et al. 2009, Ellis et al. 2014; Pitcher et al. 2016). Additional guidance on selection of units of analysis is given in Appendix B. Where quantitative approaches are not possible, intensity may be quantified by previous studies or an expert evaluation of the magnitude of the impact. For example:

- *None* (no detectable impact);
- *Low* (some physical damage to some taxa/colonies);
- *Medium* (substantial damage to a small proportion of colonies/taxa, or small damage to a large number of taxa at the site, likely to modify biological and ecological processes e.g. reproduction) or
- *High* (significant damage to a significant proportion, where ecological functions and processes are significantly altered such that they temporarily or permanently cease).

Duration – how long the effects of the impact may last.

Spatial extent – The spatial impact relative to the extent of VME indicator taxa (e.g. will fishing impact 5%, 30% or 80% of the VME indicator taxa distribution) and whether there may be offsite impacts (e.g. will reproduction be impacted at a broader spatial scale).

Cumulative impact – The frequency of the impact will influence the risk, with activities occurring repeatedly at a site likely to have a greater risk. This will depend on the amount of fishing effort and should be considered in relation to the recovery of the VMEs/taxa. Other potential cumulative impacts (e.g. non-fishing impacts) should also be considered.

Overall risk – The overall risk ranking of an activity is evaluated from the combination of the criteria used. The method for combining these criteria to assign low, medium or high risk to an activity—or preferably, to derive absolute estimates of status—should be detailed in the assessment report. If methods to derive absolute estimates of status are unable to be applied, the following risk categories apply:

Low: Where the impact will have a low or negligible influence on the environment and no active management or mitigation is required. This would be allocated to impacts of low intensity and duration, but could be allocated to impacts of any intensity, if they occur at a local scale and are of temporary duration.

Medium: Where the impact could have an influence on the environment, which will require active modification of the management approach and/or mitigation. This would be allocated to short to medium-term impacts of moderate intensity, locally to regionally, with possibility of cumulative impact.

High: Where the impact could have a significant negative impact on the environment, such that the activity(ies) causing the impact should not be permitted to proceed without active management and mitigation to reduce risks and impacts to acceptable levels. This would be allocated to impacts of high intensity that are local, but last for longer, and/or impacts which extend regionally and beyond, with high likelihood of cumulative impact.

Where there are data limitations a robust categorical scoring-based or expert-based risk assessment should be used which considers the criteria above, as well as more precautionary monitoring, management and mitigation measures.

Examples of different approaches relevant to the quantitative assessment of risks to VMEs, habitats and communities are included at Appendix C.

1.3.6 Mitigation, management and monitoring measures

Mitigation, management and monitoring measures must be identified and implemented to address the impacts identified in the assessment.

This section should document how the planned fishing activities will be managed to avoid or minimise the likelihood of significant adverse impacts on VMEs and species of concern, and ensure long term sustainability of deep-sea fish stocks. There should be a detailed description of the mitigation measures, management, and then monitoring measures that are currently in place or planned to be implemented to limit the residual impacts to acceptable levels.

Effective monitoring measures should be implemented to ensure the effectiveness of management and to detect any change in the degree of impact which would prompt the need for a re-assessment. In addition to proposed mitigation or management measures, the following monitoring measures should be implemented including the use of observers, as prescribed by the SPRFMO CMMs and include:

- CMM 06 (Commission VMS) provides details of VMS systems to be used on vessels, including to whom they report, polling frequency and positional accuracy.
- Details of catch and effort data collection and reporting systems to be used by the flag states concerned, and any additional systems implemented specifically for the proposed fishing activity. They should indicate how these data collection systems comply with CMM 02 (Data Standards). These monitoring systems must specifically address how retained and discarded by-catches are to be monitored and reported. There must also be a reporting system in place to record whether a VME indicator taxa has been encountered during fishing.
- Details of scientific observer coverage for the fishing activity, including levels of coverage, and how deployments will be designed to monitor fishing in accordance with CMM 02 (Data Standards).
- Description of the data that will be provided to the SPRFMO Secretariat for the fishing activity including, as a minimum, data required by CMM 02 (Data Standards) but also describing other information (e.g. seabed bathymetry or mapping, VME identification and characterization) that will be provided. Details regarding the reporting of all benthic bycatch to the SPRFMO Secretariat must be included.
- Where quantitative risk assessment approaches are used (e.g. Pitcher et al. 2016), these approaches should also be used to evaluate the effectiveness of proposed mitigation measures, by quantitatively evaluating the reduction in risk resulting from those mitigation measures.

This section should also describe any potential changes or additions to these management measures and the associated monitoring requirements.

1.3.7 High level assessment across all assets/objectives

The high level assessment should provide a summary statement of risks and impacts across all assets/objectives.

1.3.8 Uncertainties, next steps and research requirements

This section should explicitly detail the uncertainties inherent in the various assessments made. It should detail a plan for how these uncertainties will be addressed, including outlining any additional research and/or data collection requirements.

Appendix A – Background and supporting information

Bottom fishing impacts and the marine ecosystem

An ecosystem approach to fisheries management, as required by the SPRFMO Convention, requires consideration of fishing risks and impacts on all key levels of the affected ecosystem. In SPRFMO demersal fisheries, these are the benthic taxa and communities on the seafloor, the fish species that may be wholly or partly associated with these communities, and other animals distributed throughout the water column and in the air. These living marine resources are linked as part of the broader marine ecosystem. Maintaining diversity and populations of species within ecosystems maintains resilience (MacArthur 1953, Walker 1992) and means that the ecosystem is able to support impacts—for example, those from sustainable fisheries—while maintaining a healthy equilibrium state. Removal of species or large changes in abundance or species distribution due to impacts such as overfishing, the impact of fishing gears on the seafloor, seabed mining and climate change may alter the resilience of the ecosystem and result in shifts to different and potentially undesirable states (Möllmann & Diekmann 2012, Levin and Möllmann 2015).

Fishing gears that contact the seabed have the potential to negatively impact the abundance and diversity of benthic species (Clark et al. 2016). The most fragile and potentially vulnerable species to bottom fishing gear are those that form complex biogenic structures that other species use as habitat, food or shelter from predation (Auster 2005). Deepwater habitat-forming species are often concentrated on seamounts, creating areas of high biodiversity which are vulnerable to disturbance. These structure-forming organisms are typically slow growing and long lived, making them slow to recover and vulnerable to cumulative impacts from fishing (Clark et al. 2010). Benthic ecosystems that include organisms with these characteristics are referred to as 'vulnerable marine ecosystems' (VMEs) (UNGA 2007, FAO 2008).

Many deep-sea fish stocks have biological characteristics that result in low productivity (Norse et al. 2012), including late age-at-maturity, slow growth, long life expectancies, low natural mortality rates and intermittent recruitment success. Their low productivity means that they may not be able to sustain high exploitation rates and if depleted their populations may be slow to recover (Norse et al. 2012). There are also often limited fishery and biological data and information available to support management, which poses challenges for their sustainable utilization and exploitation (FAO 2008). Despite these challenges, sustainable and profitable fisheries for deepwater species such as orange roughy are achievable (FAO 2018) and, despite historical overfishing of a number of stocks globally, there are many examples of sustainable, well-managed stocks (e.g. Patterson et al. 2018, Cordue 2019).

Deep-sea fisheries also have the potential to interact with marine mammals, reptiles, seabirds and other species of concern. Interactions with these organisms are relatively rare—particularly if adequate mitigation measures are enacted—but cumulative impacts may cause sustainability concerns, particularly for low productivity species.

The extent and scale of bottom fishing impacts has been highly variable across global fisheries (Amoroso et al. 2018). Historically, benthic trawl fisheries have been the main source of fishing-related impact on deep-sea habitats, threatening deep-sea ecosystems by, for example, entirely removing habitat-forming organisms from the seafloor, penetrating and mixing upper layers of sediment, or modifying seabed morphology, leading to loss of biodiversity and habitat availability (e.g. Puig et al. 2012, Pusceddu et al. 2009). In recent years benthic longlines are increasingly used in deep-sea fisheries, which also damage these habitats primarily through shearing and hooking of organisms as the line gets retrieved, but also through the release of sediment plumes that can affect feeding of deep-sea corals (e.g. Pham et al. 2014, Ewing & Kilpatrick 2014, Welsford et al. 2014, Clark et al. 2016). The physical impact of longlines is acknowledged to be much lower than that of benthic trawls (e.g. Pham et al. 2014); however, with increased use of longlines in deep-sea environments, their impact also needs to be considered.

SPRFMO responses to international obligations

The United Nations General Assembly (UNGA) Resolution 61/105 set specific targets and deadlines for action by 31 December 2008, calling on States, either individually or through RFMO/As, to manage bottom fisheries on the high seas in order to sustainably manage fish stocks (Article 80) and prevent significant adverse impacts on VMEs (Article 83), among other things. Later Resolutions, such as 64/72 and 66/88, have called for further actions to protect VMEs from significant adverse impacts and ensure sustainable management of bottom fisheries.

Further, UNGA Resolutions 71/123 and 72/72 call upon RFMOs to use the full set of criteria in the FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO Deep-sea Fisheries Guidelines; FAO 2008) to identify where VMEs occur or are likely to occur as well as for assessing significant adverse impacts, to ensure that impact assessments, including for cumulative impacts of activities covered by the assessment, are conducted consistent with the FAO Deep-sea Fisheries Guidelines, are reviewed periodically and are revised whenever a substantial change in the fishery has occurred or there is relevant new information, and that, where such impact assessments have not been undertaken, they are carried out as a priority before authorising bottom fishing activities, and to ensure that CMMs are based on and updated on the basis of the best available scientific information, noting in particular the need to improve effective implementation of thresholds and move-on rules.

Since the adoption of the first interim SPRFMO Bottom Fishery Impact Assessment Standard (BFIAS) in 2011 by the 10th meeting of the Science Working Group in Vanuatu, the subject of significant adverse impacts of fishing gears on VMEs has received further attention and scientific investigation in both SPRFMO and the wider community. In response to the UNGA Resolutions and the implementation of the FAO Deep-sea Fisheries Guidelines, SPRFMO has adopted a spatial management approach through CMM 03 (Bottom Fishing) [1] that seeks to protect potential VME habitat across large areas of the South Pacific Ocean while still allowing for sustainable and profitable fisheries to occur. This approach is complemented by precautionary measures to protect potential VME habitats within areas that are open to fishing (i.e. an encounter protocol with VME indicator taxa thresholds, move-on rules and review of benthic bycatch), and also requires scientifically-based assessments of cumulative impacts of past and proposed bottom fishing. This BFIAS and resulting bottom fishing impact assessments form part of a suite of measures aimed at promoting sustainable and profitable fisheries that minimise harm to the marine ecosystem.

SPRFMO CMM 03 (Bottom Fishing) requires that:

> *20(a)* "Each Member or CNCP proposing to participate in bottom fishing activities shall submit to the Scientific Committee a proposed assessment that meets the SPRFMO Bottom Fishery Impact Assessment Standard (SPRFMO BFIAS2) with the best available data including consideration of cumulative impacts, not less than 60 days prior to the annual meeting of the Scientific Committee. These submissions shall also include the mitigation measures proposed by the Member or CNCP to prevent such impacts."

Following submission of these bottom fishery impact assessments:

> *20(b) The Scientific Committee shall undertake a review of the proposed assessment and provide advice to the Commission on:*
>
> - *whether the proposed bottom fishing would contribute to having significant adverse impacts on deep sea fish stocks for which no stock assessment has been completed, bycatch species and/or VMEs and, if so,*

[1] Note that full references to CMMs include the year of the most recent update. As these can and do change, CMMs referenced herein are denoted by the CMM number and the short title. Paragraph references are correct as of August 2020.

- *whether any proposed or additional mitigation measures would prevent such impacts.*

In addition to the requirements of CMM 03 (Bottom Fishing), a requirement of paragraph 5(b)viii of CMM 13 (Exploratory Fisheries) is that:

> *5. Any Member or CNCP seeking to permit a vessel that flies its flag to fish in an exploratory fishery, or to fish in an exploratory fishery with a gear type that has not been used in that fishery for the previous ten years; shall, not less than 60 days in advance of the next annual meeting of the Scientific Committee:*
>
> *b) prepare and submit a Fisheries Operation Plan to the Scientific Committee. The Fisheries Operation Plan shall include the following information, to the extent it is available:*
>
> *viii. if the proposed activity is bottom fishing, as defined in* CMM 03 (Bottom Fishing)*, the assessment of the impact of their flagged vessels' bottom fishing activities (*is to be*) prepared pursuant to paragraph 20(a) of* CMM 03 (Bottom Fishing)…(i.e. in accordance with the BFIAS).

Purpose of the BFIAS

The purpose of the BFIAS is to provide a standardized approach for assessing cumulative impacts of bottom fishing activities on VMEs, deep sea fish stocks and marine mammals, reptiles, seabirds and other species of concern within the SPRFMO Evaluated Area and associated 'Management areas' specified in CMM 03 (Bottom Fishing), as well as a standardized approach for assessing bottom fishing impacts of new and exploratory fisheries in accordance with CMM 13 (Exploratory Fisheries) paragraph 5(b)viii. This standard is intended to guide SPRFMO participants in preparing the required bottom fishery impact assessments, and to guide the Scientific Committee when reviewing these assessments.

The definitions and processes in the BFIAS contribute to achieving the overall objective of the SPRFMO Convention, being:

> *"…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 BFIAS is consistent with international principles for the management of deep-sea fisheries articulated in the FAO Deep-seas Fisheries Guidelines, which are to "*promote responsible fisheries that provide economic opportunities while ensuring the conservation of marine living resources and the protection of marine biodiversity, by*:

- *ensuring the long-term conservation and sustainable use of marine living resources* [with which bottom fisheries interact]*; and*
- *preventing significant adverse impacts on VMEs"* (FAO 2008).

The BFIAS aims to ensure that VMEs are protected from significant adverse impacts due to bottom fishing, that deep-sea fishery resources are not overfished, and that risks to other parts of the ecosystem are minimized, by ensuring that management decisions are informed by impact assessments that are based on the best data and methods available.

Review of the BFIAS

In accordance with CMM 03 (Bottom Fishing) paragraph 24, the Scientific Committee shall review the BFIAS in 2019 (this version) and every five years to ensure that it reflects best practice.

Review of the BFIAS should take into account any information relevant to the implementation of CMM 03 (Bottom Fishing) and CMM 13 (Exploratory Fisheries) and, as far as practicable, any scientific research or other information relevant to bottom fishing impact assessment.

Scope of application

The BFIAS applies to all bottom fishing across all fishable depths within the SPRFMO area.

This includes the Evaluated Area and associated 'Management Area(s)' specified in CMM 03 (Bottom Fishing). The BFIAS also applies to all proposed new and exploratory bottom fishing activities in accordance with paragraph 5(b)viii of CMM 13 (Exploratory Fisheries).

Bottom Fishery Impact Assessment process

The process for preparing, submitting, evaluating and reviewing bottom fishery impact assessments is outlined in CMM 03 (Bottom Fishing).

SPRFMO bottom fishery impact assessments and the Scientific Committee's review of such assessments are to be made publicly available on the SPRFMO website. Participants are required to update bottom fishery impact assessments (including cumulative bottom fishery impact assessments) at least every five years, and whenever a substantial change in the fishery occurs or is proposed, such that it is likely that the risk or impact of the fishery may change. Changes that might trigger a re-assessment would include changes in existing or intended fishing areas, fishing technique, management measures or the use of different types of vessels or gears. Many of these changes would also trigger the requirement for a new and exploratory fishing proposal in accordance with CMM 13 (Exploratory Fisheries).

The onus for updating bottom fishing impact assessments (including cumulative assessments) will be on the Member or Cooperating Non-Contracting Party whose fishing (or proposed fishing) has resulted or will result in a substantial change.

Appendix B – VMEs: scale, definitions and distribution

Unit of analysis

The choice of a unit (or units) of analysis will vary based on data availability. The unit of analysis for an impact assessment could be based on taxonomic groupings and/or spatial units (ideally both). Selection of a unit of analysis for taxonomic groupings (e.g. individual taxa to 'VMEs' as a group) may depend on the spatial and temporal scale of impacts. Additional information relevant to the selection of units of analysis is given in the section below on quantifying Significant adverse impacts. As more information becomes available (such as the location of known VMEs or VME indicator taxa) it may be appropriate to undertake impact assessments for particular benthic communities, assemblages or at a bioregional level.

In terms of spatial scale, FAO (2016) noted that:

> *"Management considerations require that delineated VMEs should be of an appropriate size. Whereas there is no lower or upper size limit for a VME, the smaller VMEs are currently around 10 km^2; for example, the VME Risk areas in the Southern Ocean are each 11 km^2. The three largest VMEs declared to date, the New England Seamounts (northwest Atlantic Ocean), the middle Mid-Atlantic Ridge (northeast Atlantic Ocean), and the Wüst Seamount (southeast Atlantic Ocean), are all over 200 000 km^2, but these include areas of abyssal plain that are far too deep for commercial fisheries."*

The unit of analysis for deep-sea fish stocks and other organisms with which bottom fisheries interact, including VMEs, should be the biological stock or population, although data limitations may constrain the unit of analysis to the species, resource assemblage, undersea feature, management unit level or some other spatially delineated unit. As more information becomes available it may be possible to update assessments to the biological stock level and/or at finer spatial scales.

Definitions

The BFIAS requires definitions of risk, VMEs and significant adverse impacts. Definitions for bottom fishing gear types are given in CMM 03 (Bottom Fishing). Common bottom fishing gear types not defined in CMM 03 (Bottom Fishing) may include traps or pots, defined as enclosures or devices that fish, crustaceans or molluscs enter voluntarily, or are entangled in, but from which they are prevented from escaping in some way (SAFS 2019).

Aspects of the FAO Deep-sea Fisheries Guidelines that are relevant to SPRFMO fisheries have been directly incorporated in the definitions below.

Risk

The definition of risk for an assessment needs to be based on SPRFMO objectives. The risk that is being assessed is the risk of not achieving those objectives.

The shared objective of CMM 03 (Bottom Fishing) and CMM 03a (Deepwater Species) is:

> *"through the application of the precautionary approach and an ecosystem approach to fisheries management, to ensure the long-term conservation and sustainable use of deep sea fishery resources, including target fish stocks as well as non-target or associated and dependent species, and, in doing so, to safeguard the marine ecosystems in which these resources occur, including inter alia the prevention of significant adverse impacts on vulnerable marine ecosystems."*

The objective of SPRFMO CMM 13 (Exploratory Fisheries) is to:

> *"ensure that sufficient information is available to evaluate the long term potential of new and exploratory fisheries, to assist the formulation of management advice, to evaluate the possible impacts on target stocks and non-target and associated and dependent species, to ensure new*

and exploratory fishery resources are developed on a precautionary and gradual basis and to promote the sustainable management of new and exploratory fisheries."

These objectives need to be operationalized so that they are measurable and the risk of not meeting the objectives can be assessed. Operationalizing these objectives requires identification of assets and hazards. This should be clarified in the impact assessment. The impact assessment must assess the risk of significant adverse impacts on VMEs, the risk of over-exploitation of deep sea fish stocks and the risks to other organisms with which bottom fisheries interact. In line with the precautionary principle—whereby greater uncertainty should result in a higher level of precaution—risk-based approaches must account for risks arising from limited data availability in attempting to quantify impacts.

Vulnerable Marine Ecosystems

For the purposes of the BFIAS, VMEs are defined as any marine ecosystem threatened by significant adverse impacts resulting from physical contact with bottom fishing gears during fishing operations, including, inter alia, reefs, seamounts, hydrothermal vents, corals, sponge beds and low productivity or vulnerable species. Assessment of significant adverse impacts to VMEs will be informed by the definitions and characteristics outlined below.

'Vulnerable marine ecosystem' (VME) means a marine ecosystem that has the characteristics referred to in paragraph 42 of, and elaborated in the Annex to, the FAO Deep-sea Fisheries Guidelines. These are:

"Uniqueness or rarity *– an area or ecosystem that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems. These include:*

- *habitats that contain endemic species;*
- *habitats of rare, threatened or endangered species that occur only in discrete areas; or*
- *nurseries or discrete feeding, breeding, or spawning areas.*

Functional significance of the habitat *– discrete areas or habitats that are necessary for the survival, function, spawning/reproduction or recovery of fish stocks, particular life-history stages (e.g. nursery grounds or rearing areas), or of rare, threatened or endangered marine species.*

Fragility *– an ecosystem that is highly susceptible to degradation by anthropogenic activities.*

Life-history traits of component species that make recovery difficult *– ecosystems that are characterized by populations or assemblages of species with one or more of the following characteristics:*

- *slow growth rates;*
- *late age of maturity;*
- *low or unpredictable recruitment; or*
- *long-lived.*

Structural complexity *– an ecosystem that is characterized by complex physical structures created by significant concentrations of biotic and abiotic features. In these ecosystems, ecological processes are usually highly dependent on these structured systems. Further, such ecosystems often have high diversity, which is dependent on the structuring organisms."*

A CCAMLR VME Workshop (CCAMLR 2009) expanded on the FAO Deep-sea Fisheries Guidelines to develop a set of criteria that characterise species constituting VMEs:

"Habitat-forming *– One of the main characteristics of the structural species within VMEs is the degree to which they create habitat that could be used by other organisms. Organisms that are large, with a strong three-dimensional shape, or which create a complex surface by clustering in* *high densities, or changing the character of the substratum (e.g. sponge spicule mats), create habitats for other organisms.*

Longevity *– Mortality of long-lived organisms can result in long recovery periods to regenerate unfished age structure, from decades to centuries. Vulnerability of these species is proportional to longevity.*

Slow growth *– Organisms which grow slowly will take a longer time to attain a large size or reproductive maturity. Slow growth rates of organisms are correlated with high longevity, but independent of age, slow growth requires longer times to generate maximum size.*

Fragility *– The potential for damage or mortality resulting from physical disturbance from bottom fishing gear.*

Larval dispersal potential *– The range of dispersal by larvae and propagules influences the ability of a species to recolonise impacted areas. Species which brood larvae, or otherwise have limited dispersal abilities, are less resilient to fishing disturbance because new recruits may not be available from a nearby source, and recruitment, recolonisation and recovery could be delayed. Organisms with high dispersal potential have a higher probability of supplying larvae to a disturbed area and are therefore more resilient.*

Lack of adult motility *– Motility in itself should not exclude taxa from being vulnerable or less resilient to bottom fishing gear, as organisms which can move to some degree may still meet all the other criteria of vulnerability. However, the lack of motility does add some degree of vulnerability and decreases resilience because as adults those organisms cannot redistribute themselves in response to a direct disturbance, adjust their position if altered in some way, or move into a disturbed area to recolonise.*

Rare or unique populations *– Vulnerable taxa containing species that create dense, isolated populations are intrinsically vulnerable because they have a more limited potential for recovery. This criterion also indicates vulnerability to physical disturbance and is independent of the habitat-forming characteristics of the taxon."* (CCAMLR 2009)

Taxonomic groups that meet the above criteria, and that have been encountered in bottom trawl fisheries in the SPRFMO Area have been compiled by Parker et al. (2009). Taxa such as bryozoans and feathery hydroids were excluded from this list because they are generally not retained by bottom fishing gears.

Annex 1 of the FAO Deep-sea Fisheries Guidelines provides a list of examples of potentially vulnerable species groups, communities and habitats, as well as features that potentially support VME indicator taxa:

> *"The following examples of species groups, communities, habitats and features often display characteristics consistent with possible VMEs. Merely detecting the presence of an element itself is not sufficient to identify a VME.*
>
> *Examples of species groups, communities and habitat forming species that are documented or considered sensitive and potentially vulnerable to DSFs* [Deep Sea Fisheries] *in the high-seas, and which many contribute to forming VMEs* [include]*:*
>
> - *certain coldwater corals and hydroids, e.g. reef builders and coral forest including: stony corals (Scleractinia), alcyonaceans and gorgonians (Octocorallia), black corals (Antipatharia) and hydrocorals (Stylasteridae);*
> - *some types of sponge dominated communities;*
> - *communities composed of dense emergent fauna where large sessile protozoans (xenophyophores) and invertebrates (e.g. hydroids and bryozoans) form an important*

structural component of habitat; and

- *seep and vent communities comprised of invertebrate and microbial species found nowhere else (i.e. endemic).*

Examples of topographical, hydrophysical or geological features, including fragile geological structures, that potentially support the species groups or communities, referred to above [may include but are not limited to]*:*

- *submerged edges and slopes (e.g. corals and sponges);*
- *summits and flanks of seamounts, guyots, banks, knolls, and hills (e.g. corals, sponges, xenophyphores);*
- *canyons and trenches (e.g. burrowed clay outcrops, corals); hydrothermal vents (e.g. microbial communities and endemic invertebrates); and*
- *cold seeps (e.g. mud volcanoes for microbes, hard substrates for sessile invertebrates)"* (FAO 2008).

The FAO Deep-sea Fisheries Guidelines provide the following characteristics in relation to defining vulnerability:

> *"14. Vulnerability is related to the likelihood that a population, community, or habitat will experience substantial alteration from short-term or chronic disturbance, and the likelihood that it would recover and in what time frame. These are, in turn, related to the characteristics of the ecosystems themselves, especially biological and structural aspects. VME features may be physically or functionally fragile. The most vulnerable ecosystems are those that are both easily disturbed and very slow to recover, or may never recover.*
>
> *15. The vulnerability of populations, communities and habitats must be assessed relative to specific threats. Some features, particularly those that are physically fragile or inherently rare, may be vulnerable to most forms of disturbance, but the vulnerability of some populations, communities and habitats may vary greatly depending on the type of fishing gear used or the kind of disturbance experienced.*
>
> *16. The risks to a marine ecosystem are determined by its vulnerability, the probability of a threat occurring and the mitigation means applied to the threat."*

The above characteristics have been used to develop lists of specific taxa (orders, families, genera or species) which are considered to be indicators of VMEs in the SPRFMO Area, recognising that additional taxa may meet FAO criteria for identifying VME but which do not make good operational indicators (for example, due to poor retention by fishing gear). Annex 5 of SPRFMO CMM 03 (Bottom Fishing) contains the SPRFMO VME bycatch indicator taxa list. This list should be reviewed periodically and updated if necessary.

Significant Adverse Impacts

The FAO Deep-sea Fisheries Guidelines provide guidance on what constitutes significant adverse impacts on VMEs:

> *"Significant adverse impacts are those that compromise ecosystem integrity (i.e. ecosystem structure or function) in a manner that: (i) impairs the ability of affected populations to replace themselves; (ii) degrades the long-term natural productivity of habitats; or (iii) causes, on more than a temporary basis, significant loss of species richness, habitat or community types. Impacts should be evaluated individually, in combination and cumulatively.*
>
> *When determining the scale and significance of an impact, the following six factors should be considered:*

- *the intensity or severity of the impact at the specific site being affected;*
- *the spatial extent of the impact relative to the availability of the habitat type affected;*
- *the sensitivity/vulnerability of the ecosystem to the impact;*
- *the ability of an ecosystem to recover from harm, and the rate of such recovery;*
- *the extent to which ecosystem functions may be altered by the impact; and*
- *the timing and duration of the impact relative to the period in which a species needs the habitat during one or more of its life-history stages.*

Temporary impacts are those that are limited in duration and that allow the particular ecosystem to recover over an acceptable time frame. Such time frames should be decided on a case-by-case basis and should be in the order of 5-20 years, taking into account the specific features of the populations and ecosystems.

In determining whether an impact is temporary, both the duration and the frequency at which an impact is repeated should be considered. If the interval between the expected disturbance of a habitat is shorter than the recovery time, the impact should be considered more than temporary. In circumstances of limited information, States and RFMO/As should apply the precautionary approach in their determinations regarding the nature and duration of impacts."

The above factors should all be considered—and where possible, quantified—when evaluating the potential significance of adverse impacts of bottom fishing activities in the SPRFMO Convention Area. Assessments should evaluate the impact that each type of fishing gear is likely to have on areas likely to contain VMEs, both on a per set/tow basis and cumulatively.

Each bottom fishery impact assessment shall detail how the above factors were used to develop a definition of 'significance' for the purposes of the assessment. This should include at a minimum the following criteria:

- The severity of the impact at the specific site affected (i.e. are entire colonies/habitats destroyed, or just a few branches broken); this will be gear specific and will also depend on fishing intensity;
- The ecological consequence of a given impact (which depends on the distribution, density, and recovery potential of the organisms in question), including estimation of past impacts and/or future likelihood of interaction;
- The spatial extent of the impact relative to the extent of the VME and whether there may be offsite impacts (for example, a reduction in the capacity of organisms to recover or reproduce in other areas due to the impact at a specific site);
- The frequency of the impact and the cumulative fishing and non-fishing impacts. The rate of impact (on a temporal and geographical scale) in relation to rates of recovery of taxa needs to be considered.

Considerable progress has been made towards the development of methods to quantitatively assess these criteria (e.g. Sharp et al. 2008, Ellis et al. 2014, Pitcher et al. 2017). Nonetheless, many of these criteria can be difficult to measure directly for deepwater fisheries and so assumptions may need to be based on expert input or studies conducted elsewhere. All assumptions must be clearly documented in the impact assessments to ensure transparency.

Predictive habitat modelling, seabed depth range and topography

Records of the location or density of VME indicator taxa such as reef-forming corals within the SPRFMO Convention Area are sparse and inadequate to directly map the distribution of VMEs (Cryer et al. 2018). Global habitat prediction models for deep sea scleractinian corals and other species (Tittensor et al 2009, Davies & Guinotte 2011) have enabled the coarse-scale identification of areas where VMEs may occur. Higher resolution predictive habitat suitability models (e.g. Rowden et al. 2013, Anderson et al. 2016a, Anderson et al. 2016b, Rowden et al. 2017, Georgian et al. 2019) have been used in the western SPRFMO Convention Area to identify areas where VME indicator taxa are likely to occur. This modelling will contribute to the quantitative evaluation of the risk of significant adverse impacts and the effectiveness of any proposed management and mitigation measures.

Seabed depth range and topography can be good indicators of seabed geology, and therefore of substratum suitability for supporting VME species. Global predictive habitat modelling could be used in the absence of high resolution habitat suitability modelling. These global models rely on proxy indicators including depth and analysis of topography, particularly depth range, slope, rugosity and specific topographic features, as indicators of habitat likely to support VMEs.

Differences in bottom fishing impacts by different gears

Benthic ecosystems are differentially vulnerable to the impacts of different bottom fishing gears (e.g. Chuenpagdee et al. 2003, Pham et al. 2014). Gear type and how the gear is to be fished is an important component of any impact assessment. Gear impact should be considered cumulatively and evaluated as a product of the typical seabed impact footprint per set/tow of the gear type to be used, the past and/or planned number of all fishing events irrespective of gear type (to provide an estimate of the overall extent of physical impact), the likelihood of encountering vulnerable species in proposed fishing areas (including the proportion of planned deployments occurring in new areas, if applicable), the potential for recovery of vulnerable species over time and the expected degree of impact by each gear type used.

Distribution of Vulnerable Marine Ecosystems

In accordance with Annex 5 of CMM 03 (Bottom Fishing), a list of species or higher level taxa known or likely to indicate the presence of potential VMEs in the South Pacific, and the catching of which could indicate evidence of such VMEs, has been developed. Habitat suitability modelling (Georgian et al. 2019) has been used in the western SPRFMO Area to indicate the existence of areas likely to contain VMEs, with this modelling underpinning the spatial management approach embedded within CMM 03 (Bottom Fishing).

Implementation of CMM 03 (Bottom Fishing) requires a definition of potential ‘evidence of a VME’ to trigger the move-on provisions. Accordingly, a protocol to determine potential ‘evidence of a VME’ has been developed to enable an immediate management response (i.e. a move-on rule) during fishing operations at sea, to limit immediate impact on areas which appear to demonstrate unexpectedly high quantities of VME taxa based on the habitat suitability modelling that underpins CMM 03 (Bottom Fishing).

The move-on rule under SPRFMO CMM 03 (Bottom Fishing) applies in cases of any interactions that trigger the specified threshold weights of VME indicator taxa during fishing operations. For new and exploratory fisheries, encounter protocols should be sufficiently precautionary to account for a likely paucity of information on the distribution and characteristics of potential VMEs.

In contrast, ‘designating a VME’ requires a scientific and deliberative analysis to integrate data from individual or cumulative encounters and assess information on occurrence of VMEs across larger spatial scales, in order to identify, map and designate areas which are considered to constitute actual VMEs. This is to be undertaken in accordance with CMM 03 (Bottom Fishing) paragraphs 32-36.

Procedures for mapping known or likely VMEs and bottom fishing effort are described below.

Mapping and designation of VMEs

Mapping of known or likely vulnerable marine ecosystems is an important prerequisite for impact assessment and development of management and mitigation measures to prevent significant adverse impacts in such areas. Information and data on gear interactions with VME indicator taxa, predictive analyses of habitat suitability and results of seabed biodiversity surveys have formed and should continue to form the basis for mapping and designation of areas known or likely to support VMEs within the SPRFMO Convention Area.

Annex 1 of the FAO Deep-sea Fisheries Guidelines recognise that *"Merely detecting the presence of an element itself is not sufficient to identify a VME"* (FAO 2008). Single encounters with VME indicator taxa indicate the presence of a vulnerable species or taxa at some point in the area fished during the tow or set, but may not indicate the presence of a vulnerable ecosystem. Further data and analyses may be required to designate areas known to support VME indicator taxa based on repetitive encounters in a particular area, prediction of areas that may support VMEs based on information on habitat suitability models for vulnerable deepwater benthic species, or seabed biodiversity surveys.

Areas known or likely to support VMEs should be defined and mapped using all potential sources of information, including:

- Mapping of fishing positions observed to contain 'evidence of VMEs', as defined in the encounter protocol in CMM 03 (Bottom Fishing), and of scientific observer data on bycatches of VME indicator taxa.
- Distribution of predicted habitat suitability derived from predictive habitat models for vulnerable marine taxa (Rowden et al. 2013, Pitcher et al. 2015, Anderson et al. 2016a, Anderson et al. 2016b, Rowden et al. 2017, Georgian et al. 2019), or from other physical data/surrogates, used to inform habitat-suitability analyses (Hirzel et al. 2002, Clark et al. 2006, Davies et al. 2008).
- Mapping of known or predicted underwater topographic features, particularly seamounts, which may support VME indicator taxa.
- Data from scientific seabed biodiversity surveys which should be integrated into, or used to inform, habitat suitability analyses (Pitcher et al. 2007a,b, Williams et al. 2009, Anderson et al. 2011; Pitcher et al. 2016b, Anderson et al. 2016).

Repetitive encounters with taxa listed as vulnerable

Mapping of all sites found to contain evidence of VMEs is an essential step towards subsequent analysis of repetitive encounters with vulnerable species in a particular area, which may lead to that area then being designated as a VME. Management measures for designated VMEs have not yet been established but could include, for example, effort or gear limits, more precautionary thresholds and move-on rules, or full closures. Data on encounters with evidence of VMEs must be reported to the SPRFMO Secretariat immediately in accordance with CMM 03 (Bottom Fishing). Data for each encounter should include:

- Date of the fishing event
- Fishing gear type
- Exact location of the encounter (position of start of haul of the fishing gear in latitude/longitude to the nearest 1/10th degree)
- Depth of fishing event (start of haul)
- Details of the VME evidence encountered, listing each taxonomic group recorded under the VME evidence protocol, with quantitative estimates (weight or volume) of bycatch of each taxon.

In accordance with CMM 03 (Bottom Fishing), all detailed scientific observer data on benthic by-catch observed while monitoring bottom fishing operations must also be reported to the Secretariat in a similar format to the above evidence data, but with benthic species identified to the lowest taxon possible, and by-catches of each taxon quantified by weight or volume.

While any encounter with VME indicator taxa at a single site (either above or below the thresholds specified in CMM 03 (Bottom Fishing)) may not indicate presence of an actual VME, multiple or repetitive encounters with such evidence in an area indicate an increasing likelihood that the area does support a benthic VME. Data on evidence of VMEs gathered during fishing operations shall be regularly analysed in accordance with CMM 03 (Bottom Fishing) to identify areas in which multiple or repetitive encounters with VME species are found. Guidelines on what constitutes repetitive encounters with taxa indicating the presence of a VME will need to be developed as part of a protocol for the Scientific Committee's review of these data.

Seabed biodiversity surveys

The most reliable data on benthic biodiversity and presence of VMEs will be provided by scientific seabed biodiversity surveys, either using seabed sampling equipment designed to quantitatively sample the fauna concerned (such as benthic sampling sleds), or using photographic or video imagery along planned survey transects. Where feasible, efforts should be made to conduct such sampling in areas of particular interest or concern, such as those within bottom trawl management areas with high probability of VME indicator taxa habitat suitability.

Particular efforts should be made to survey areas proposed for long-term and large-scale spatial closures, to ensure that such areas do contain substantial and biodiverse communities, and that they are representative (in terms of actual or predicted biodiversity and VME abundance) of areas to be left open to possible fishing. Such surveys could be conducted as internationally collaborative surveys between SPRFMO participants.

Where scientific surveys are not considered to be cost effective, fishing vessels may be suitable platforms for conducting seabed imaging using drop cameras or net-mounted video systems. Simultaneous collection of seabed images and benthic bycatch recording by scientific observers would provide a particularly useful data set for improving understanding of the relationship between seabed biodiversity and benthic bycatches by various fishing gears.

Prediction of habitat suitability and likelihood of VMEs

Data on seabed biodiversity are lacking for most deep sea benthic areas, except for a few specifically surveyed seamount systems, and seabed biodiversity surveys are likely to remain unaffordable for all but a few areas of particular interest. In the absence of such data, biologically important physical factors (Clark 2008, Williams et al. 2009) can be used to indicate suitability of specific areas for vulnerable benthic species, and to stratify measures such as spatial closures to protect such areas.

Seabed topography can be combined with physical/chemical factors such as temperature, salinity, depth, chlorophyll, oxygen, currents, productivity and water chemistry using habitat suitability models (Tittensor et al. 2009, Davies & Guinotte 2011, Rowden et al. 2017, Georgian et al. 2019) to predict suitability of particular areas or features as habitats for VME species. Various analyses of this type have been conducted for the South Pacific region. Clark et al. (2006) classified the original Kitchingman and Lai (2004) seamounts in terms of suitability as habitats for coldwater corals, and Allain et al. (2008) classified South Pacific seamounts in terms of depth suitability for various deepwater fish species. Tittensor et al. (2009) and Davies & Guinotte (2011) developed global predictive habitat suitability models for coldwater scleractinian corals. Anderson et al. (2016) described results of habitat suitability models using presence data and a suite of environmental predictor variables for deep-sea reef-forming coral species across a large region of the South Pacific Ocean, and attempted to validate model predictions using photographic surveys. Rowden et al. (2017) built on the sampling and design methodology and results of Anderson et al. (2016) to produce very high resolution (25x25m) habitat suitability maps for VME indicator taxa and VME habitat on the Louisville Seamount Chain. Georgian et al. (2019) generated broad-scale, high resolution (1x1km) models for ten VME indicator taxa within the New Zealand Exclusive Economic Zone and a portion of the SPRFMO area, with these results underpinning the spatial management approach embedded within SPRFMO CMM 03 (Bottom Fishing).

Global seamount databases have been updated using the high-resolution (30 arc-second) GEBCO bathymetric data (Yesson et al. 2011) and habitat suitability of these seamounts has been classified using the habitat suitability results of Davies & Guinotte (2011). Taxonomic distinctness indices (Warwick and Clark 1998, Clark and Warwick 1998, 2001) can be used to evaluate comparative uniqueness, and therefore potential vulnerability, of communities on different features.

In addition to data on interactions with evidence of a VME, SPRFMO participants should collect and contribute sample and/or observations data on VME indicator taxa that are potentially useful to habitat suitability analyses. These data could include high-resolution or multi-beam bathymetry, VME indicator taxa by-catch data or seabed imagery, and should be used in periodic analyses overseen by the Scientific Committee to develop and refine habitat suitability models or contribute to other relevant work.

Mapping of Underwater Topographic Features

UNGA Resolutions 61/105 and 64/72 both identify seamounts as areas of particular concern regarding potential impact of fishing on VMEs which may occur on such features. Annex 1 of the FAO Deep-sea Fisheries Guidelines extend this to list a number of underwater topographic features or habitats that may contain VMEs, including summits and flanks of seamounts, submerged edges and slopes, guyots, banks, knolls, hills, canyons, trenches, hydrothermal vents and cold seeps (FAO 2008).

Mapping of bottom fishing effort

Bottom fishing effort distribution maps are to be prepared using available tow-by-tow or set-by-set data or, if available, Vessel Monitoring System (VMS) data (noting that confidentiality restrictions need to be considered in accordance with CMM 02 (Data Standards)). Confidentiality requirements will influence the level of resolution at which the maps can be displayed. The historic effort data underlying those maps will also be submitted to the Secretariat in accordance with the SPRFMO CMM 02 (Data Standards).

Areas below fishable depth (currently about 2000m depth for bottom trawl fishing in the SPRFMO Convention Area) should be excluded in maps of fishing effort distribution. Estimates of actual seabed swept area for bottom trawl fisheries should be based on actual trawl tracks, geospatially buffered with appropriate estimates of trawl swept width. Accurate estimates of seabed swept area at 1kmx1km resolution or finer are required for quantitative risk assessment of seabed impact areas, probability of interaction with VME indicator taxa and discounting of biodiversity in previously fished areas (Penney & Guinotte 2013, Pitcher et al. 2016).

Given the differences in impacts of bottom fishing by different bottom fishing gears (see, for example, Chuenpagdee et al. 2003, Hiddink et al. 2017), effort distribution should therefore be considered and mapped separately for each of the main bottom fishing methods: trawling, lining, potting and trap fishing. Consideration should also be given to fishing effort distribution for different periods of years, so that the Scientific Committee can evaluate both the cumulative duration of fishing impacts in various areas, and also the recovery time for areas fished in the past.

Appendix C - Examples of different risk assessment approaches

Examples of different approaches relevant to the assessment of risks to VMEs, habitats and communities include:

- Impact assessment framework for bottom fishing methods: This a method for estimating the cumulative bottom footprint and gear impact of past bottom fishing based on an approach presented in CCAMLR (Sharp et al. 2009; Sharp 2010; Webber and McKinlay 2011; Webber 2012). The method assumes there is no benthic recovery following fishing impact. It has been applied in SPRFMO (Mormede et al 2017, Cryer et al. 2018).
- Relative Benthic Status (RBS) assessment: RBS is quantitative method based on the Schaefer (1954)-type logistic population-growth equation, as commonly used for stock assessments, with an additional term to describe the direct impacts of trawling on seabed benthos, consistent with previous dynamic-modelling approaches seabed assessment (Ellis et al. 2014, Pitcher et al. 2015, Pitcher et al. 2016). To enable application to the typically data-limited circumstances of seabed assessment, RBS is a simpler approach, such that in habitats subject to chronic trawling, the long-term relative abundance of biota, as a fraction of carrying capacity can be estimated by the equilibrium solution of the logistic. Estimating RBS requires maps of fishing intensity and habitat distributions – and parameters for trawl impact and recovery rates. The aggregate status of habitats in an assessed region is indicated by the mean and distribution of RBS values for the region. The status of trawled habitats and their RBS value depend on impact rate (depletion per trawl), recovery rate and exposure to trawling (Pitcher et al. 2017). Impact in RBS shares similarities with the impact method described above, but also accounts for future trawling and recovery potential.
- ICES: ICES have developed a series of approaches and indicators for evaluating physical disturbance pressures from bottom fishing gears and their impacts on seabed habitats and sea-floor integrity (e.g. ICES 2016a,b, ICES 2017a,b,c). These methods sit within an assessment framework that consists of three main components: fishing pressure (footprint), benthic habitat sensitivity and the resulting benthic impact (ICES 2019).
- SASI: The Swept Area Seabed Impact (SASI) model allows for understanding of the nature of fishing gear impacts on benthic habitats, the spatial distribution of benthic habitat vulnerability to particular fishing gears and the spatial and temporal distribution of realized adverse effects from fishing activities on benthic habitats (NEMFC 2011).

Examples of approaches relevant to the assessment of risks to species and populations include:

- Ecological Risk Assessment (ERA): ERA enables consideration of the risk or vulnerability of species to fishery interactions. ERA approaches to assessing risks from fishing fit broadly into three tiers. Level 1 is a qualitative, expert-based risk assessment and includes methods such as Scale-Intensity-Consequence Analysis (e.g. Ford et al. 2015). Level 2 is a semi-quantitative risk assessment and include methods such as Productivity-Susceptibility Analysis (PSA) (Stobutzki et al., 2002), which considers risk to species as a function of their biological productivity and their susceptibility to fishing using various gears (Patrick et al., 2010; Hobday et al., 2011). PSA is considered useful for evaluating the vulnerability of many data-limited species by providing simple results that are easily interpreted by fisheries managers and policy makers (Griffiths et al., 2017; Williams et al., 2018). More quantitative ERA tools such as Sustainability Assessment for Fishing Effects (SAFE) (Zhou et al., 2007; Zhou et al., 2012; Zhou et al., 2016; Zhou et al., 2019) and Ecological Assessment of Sustainable Impacts of Fisheries (EASI-Fish; Griffiths et al., 2018) extend the PSA concept and derive a proxy for fishing mortality based on the susceptibility of species in relation to productivity. Both of these tools are also capable of quantifying cumulative impacts across multiple fisheries (Griffiths et al., 2018; Zhou et al., 2019). PSA and SAFE methods have been applied in SPRFMO to evaluate vulnerability of teleost and chondrichthyan species to different fishing gears (Georgeson et al. 2019, Georgeson et al. unpublished). Level 3 of the ecological risk assessment framework describes fully quantitative risk assessments and includes traditional integrated stock assessments.

- Spatially Explicit Risk Assessment Framework (SEFRA): SEFRA is a Potential Biological Removal (PBR) type approach whereby catches are estimated and compared to population sustainability thresholds, and the results can be disaggregated or aggregated readily to the desired scale. It has the advantage of being fully quantitative: the ratio is a direct comparison between animals killed and the number of animals that can be produced by the population. Following this method, the risk ratio (RR) is estimated as the ratio of bycatch in fisheries (specifically referred to here as annual potential fatalities, APF) in relation to a measure of the population productivity, the population sustainability threshold (PST) (see, for example, Richard and Abraham 2013, Richard et al. 2017, Sharp et al. 2013, Sharp 2016).

Appendix D - New and exploratory fisheries

New and exploratory fisheries in the SPRFMO Convention Area are managed in accordance with CMM 13 (Exploratory Fisheries). For the purposes of CMM 13 (Exploratory Fisheries), "*a fishery is an 'exploratory fishery':*

a) if it has not been subject to fishing in the previous ten years; or

b) for the purposes of fishing with a particular gear type or technique, if it has not been subject to fishing by that particular gear type or technique in the previous ten years; or

c) if fishing in that fishery has been undertaken in the previous ten years pursuant to this CMM, and a decision has not yet been taken in accordance with paragraph 23 or 24 of this CMM to either close or manage the fishery as an established fishery; or

d) if it is of a kind listed in paragraph 15 of CMM 03 (Bottom Fishing).*"*

CMM 13 (Exploratory Fisheries) paragraph 5(b)viii requires that the Fisheries Operation Plan for an exploratory bottom fishery should be prepared pursuant to paragraph 20(a) of CMM 03 (Bottom Fishing).

Consequently, BFIA for exploratory fisheries shall be undertaken in accordance with this BFIAS and the requirements of CMM 13 (Exploratory Fisheries). The bottom fishing impact assessment for new and exploratory fisheries shall consider all the elements of Section 1, except where differences have been identified. The following section describes these differences.

Description of the proposed fishing activities

Estimates of catch and discard quantities may not be available given the nature of the fisheries and so estimates of factors such as fishing duration, number of tows and potential catch rates should be provided. Once information is available from the new or exploratory fishery the impact assessment would be updated using this data.

Mapping and description of fishing areas

Maps of the proposed fishing areas should be provided. These maps should display seabed type, depth, bathymetry and, if available, any information on the location of known VMEs or the likelihood of VMEs or VME indicator taxa in the areas to be fished. Appendix A provides additional information on mapping.

Impact assessment

Where little information is available, predictive approaches should be used to evaluate the likelihood of interaction with, and potential impact on, VMEs or VME indicator taxa. All assumptions used in the impact assessment should be clearly stated and evaluated. This section should describe the conditions for when a new assessment should be undertaken.

Information on status of the deepwater stocks to be fished and on marine mammals, reptiles, seabirds and other species of concern

Approaches such as ecological risk assessment could be used to inform the assessment of impact on deepwater stocks to be fished and on marine mammals, reptiles, seabirds and other species of concern with which the fishery will interact. Additionally, literature review and information from other fisheries should also be used to assist in evaluating potential impacts.

Monitoring, management and mitigation measures

Monitoring, management and mitigation measures are critical in situations where new or exploratory fisheries are being undertaken. As outlined in the FAO Deep-sea Fisheries Guidelines:

"Precautionary conservation and management measures, including catch and effort controls, are essential during the exploratory phase of a DSF, and should be a major component of the management of an established DSF. They should include measures to manage the impact of the fishery on low-productivity species, non-target species and sensitive habitat features. Implementation of a precautionary approach to sustainable exploitation of DSFs should include the following measures:

- *precautionary effort limits, particularly where reliable assessments of sustainable exploitation rates of target and main by-catch species are not available;*
- *precautionary measures, including precautionary spatial catch limits where appropriate, to prevent serial depletion of low-productivity stocks;*
- *regular review of appropriate indices of stock status and revision downwards of the limits listed above when significant declines are detected;*
- *measures to prevent significant adverse impacts on vulnerable marine ecosystems; and*
- *comprehensive monitoring of all fishing effort, capture of all species and interactions with VMEs."* (FAO 2008)

Therefore, assessments for new or exploratory fisheries must include a description of the monitoring, mitigation and precautionary management measures that will be in place, as outlined above. Details regarding the reporting of evidence of a VME to the SPRFMO Secretariat should be included.

References

Allain, V. J-A. Kerandel, M. Clark 2008, Potential seamount location in the South Pacific RFMO area: prerequisite for fisheries management and conservation in the high seas. *Paper presented to the SPRFMO 5 Science Working Group Meeting, SPRFMO-V-SWG-05*, 18 pp.

Anderson, O.F., Guinotte, J.M., Rowden, A.A., Clark, M.R., Mormede, S., Davies, A.J., Bowden, D.A. 2016a, Field validation of habitat suitability models for vulnerable marine ecosystems in the South Pacific Ocean: implications for the use of broad-scale models in fisheries management. *Ocean Coast. Manage.* 120, 110–126.

Anderson, O.F., Guinotte, J.M., Rowden, A.A., Tracey, D.M., Mackay, K.A., Clark, M.R. 2016b. Habitat suitability models for predicting the occurrence of vulnerable marine ecosystems in the seas around New Zealand. *Deep-Sea Res.* Pt. I 115, 265–292.

Anderson, T.J., S.L. Nichol, C. Syms, R. Przeslawski and P.T. Harris 2011, Deep-sea bio-physical variables as surrogates for biological assemblages, an example from the Lord Howe Rise. *Deep-Sea Research II*, 58: 979 – 991.

Auster, P.J. 2005, Are deep-water corals important habitats for fishes? *In*: Freiwald A, Roberts JM (eds) *Cold-Water Corals and Ecosystems*, Springer-Verlag, Berlin-Heidelberg, 747-760.

Bailey, D.M., M.A. Collins, J.D.M. Gordon, A.F. Zuur and I.G. Priede 2009, Long-term changes in deep-water fish populations in the northeast Atlantic: a deeper reaching effect of fisheries? *Proceedings of the Royal Society B*, (doi:10.1098/rspb.2009.0098)

CCAMLR 2007, Conservation Measure 22-06. Schedule of Conservation Measures in Force 2007/08, Hobart (Australia).

CCAMLR 2009, Report of the workshop on vulnerable marine ecosystems. La Jolla, CA, USA, 3 to 7 August 2009. SC-CAMLR-XXVIII/10, 17 pp.

Chuenpagdee R., L.E. Morgan, S.M. Maxwell, E.A. Norse, and D. Pauly 2003, Shifting gears: assessing collateral impacts of fishing methods in US waters. *Frontiers in Ecology and the Environment*, 1(10): 517-524.

Clark M.R., Koslow J.A. 2007, Impacts of fishing on seamounts. In: Seamounts: Ecology Fisheries and Conservation (eds T.J. Pitcher, P.J.B. Hart, T. Morato, R. Santos, M. Clark), Blackwell *Fisheries and Aquatic Resources Series*, Blackwell Scientific.

Clark, M.R. 2008, Report from the PEW workshop on design of marine protected areas for specific seamounts systems in international waters, 27 - 29 May 2008, 11pp.

Clark, M.R., D. Tittensor, A.D. Rogers, P. Brewin, T. Schlacher, A. Rowden, K. Stocks and M Consalvey 2006, Seamounts, deep-sea corals and fisheries: vulnerability of deep-sea corals to fishing on seamounts beyond areas of national jurisdiction. UNEP-WCMC, Cambridge, UK. 80 pp.

Clark, M.R., M. Dunn and O. Anderson 2010, Development of estimates of biomass and sustainable catches for orange roughy fisheries in the New Zealand region outside the EEZ: CPUE analyses, and application of the "seamount meta-analysis" approach. *New Zealand Fishery Assessment Report*, 2010/19: 46 pp.

Clark, M.R., Althaus, F, Schlacher, T, Williams, A, Bowden, D, Rowden, A.A. 2016, The impacts of deep-sea fisheries on benthic communities: a review. *ICES Journal of Marine Science* 73 (Suppl.1): 51-69. doi: 10.1093/icesjms/fsv123

Clark, M.R., Rowden, A.A., Schlacher, T., Williams, A., Consalvey, M., Stocks, K.I., Rogers, A.D., O'Hara, T.D., White, M., Shank, T.M., Hall-Spencer, J. 2010, The ecology of seamounts: structure, function, and human impacts. *Annual Review of Marine Science* 2: 253–278

Clarke K.R. and R.M. Warwick 1998, A taxonomic distinctness index and its statistical properties. *Journal of Applied Ecology*, 35:523–531

Clarke, K.R. and R.M. Warwick 2001, A further biodiversity index applicable to species lists: variation in taxonomic distinctness. *Marine Ecology Progress Series*, 216: 265-278.

Constable, A. and R. Holt 2007, Bottom fishing in high seas areas of CCAMLR. SC-CAMLR-XXVI/10. 17p.

Cryer, M., T. Bock and S. Geange 2018, Methods for designing spatial management of areas using outputs from Zonation software and other spatial data. 6th meeting of the SPRFMO Scientific Committee, Puerto Varas, Chile, 9–14 September 2018.

Davies, A.J. and J.M. Guinotte 2011, Global habitat suitability for framework-forming cold-water corals. *Plos ONE*, 6(4): 1-15.

Ellis, N., Pantus, F.J., Pitcher, C.R., 2014, Scaling up experimental trawl impact results to fishery management scales—a modelling approach for a 'hot time'. *CJFAS* 71,1-14

FAO 2008, International Guidelines for the Management of Deep-Sea Fisheries in the High Seas: Annex F of the Report of the Technical Consultation on International Guidelines for the Management of Deep-sea Fisheries in the High Seas. Rome, 4–8 February and 25-29 August 2008.

FAO 2018, Global review of orange roughy (*Hoplostethus atlanticus*), their fisheries, biology and management, by Geoffrey Tingley and Matthew Dunn. FAO Fisheries and Aquaculture Technical Paper No. 622. Rome, Italy.

Ford, R.B.; Galland, A.; Clark, M.R.; Crozier, P.; Duffy, C.A.J.; Dunn, M.; Francis, M.P.; Wells, R. (2015). Qualitative (Level 1) risk assessment of the impact of commercial fishing on New Zealand chondrichthyans. New Zealand Aquatic Environment and Biodiversity Report No. 157. 111 p.

Georgeson, L., C. L. Rigby, T. J. Emery, M. Fuller, J. Hartog, A. J. Williams, A. J. Hobday, C. A. J. Duffy, C. A. Simpfendorfer, T. Okuda, S. J. Nicol (unpublished), Ecological risks of demersal fishing on deepwater chondrichthyan populations in the Southern Indian and South Pacific oceans.

Georgeson, L, Emery, T, Williams, A, Nicol, S, Hobday, A, Hartog, J, Fuller, M, Cryer, M 2019, Ecological risk assessment for teleosts in SPRFMO demersal trawl, midwater trawl and demersal longline fisheries. 7th meeting of the SPRFMO Scientific Committee, La Havana, Cuba, 7-12 October 2019.

Georgian, S.E., O.F. Anderson and A.A. Rowden 2019, Ensemble habitat suitability modelling of vulnerable marine ecosystem indicator taxa to inform deep-sea fisheries management in the South Pacific Ocean. *Fisheries Research*. 211:256–274.

Griffiths, S., Duffy, L., and Aires-da-Silva, A. 2017. A preliminary ecological risk assessment of the large-scale tuna longline fishery in the eastern Pacific Ocean using productivity-susceptibility analysis. In IATTC - 8th Meeting of the Scientific Advisory Committee. IATTC-SAC-08-07d, La Jolla, California.

Griffiths, S., Kesner-Reyes, K., Garilao, C., Duffy, L., and Roman, M. 2018, Development of a flexible ecological risk assessment (ERA) approach for quantifying the cumulative impacts of fisheries on bycatch species in the eastern Pacific Ocean. In Inter-American Tropical Tuna Commission, Scientific Advisory Committee, 9th Meeting. IATTC, La Jolla, California.

Hiddink, J.G., Jennings, S., Sciberras, M., Szostek, C.L., Hughes, K.M., Ellis, N., Rijnsdorp, A.D., McConnaughey, R.A., Mazor, T., Hilborn, R., Collie, J.S., Pitcher, C.R., Amoroso, R.O., Parma, A.M., P. Suuronen, Kaiser, M.J. 2017, Global analysis of depletion and recovery of seabed biota following bottom trawling disturbance. *PNAS* 114, 8301-8306

Hirzel, A.H., J. Hausser, D. Chessel and N. Perrin 2002, Ecological-niche factor analysis: how to compute habitat-suitability maps without absence data? *Ecology*, 83: 2027 - 2036.

Hobday, A.J., A. Smith, H. Webb, R. Daley, S. Wayte, C. Bulman, J. Dowdney, A. Williams, M. Sporcic, J. Dambacher, M. Fuller and T. Walker 2007, Ecological Risk Assessment for the Effects of Fishing: Methodology. Report R04/1072 for the Australian Fisheries Management Authority, Canberra.

Hobday, A.J., A.D.M. Smith, I.C. Stobutzki, C. Bulman, R. Daley, J.M. Dambacher, R.A. Deng, J. Dowdney, M. Fuller, D. Furlani, S.P. Griffiths, D. Johnson, R. Kenyon, I.A. Knuckey, S.D. Ling, R. Pitcher, K.J. Sainsbury, M. Sporcic, T. Smith, C. Turnbull, T.I. Walker, S.E. Wayte, H. Webb, A. Williams, B.S. Wise and S. Zhou 2011, Ecological risk assessment for the effects of fishing. *Fisheries Research*, 108 (2-3): 372-384.

ICES 2016a, EU request for guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats. In Report of the ICES Advisory Committee, 2016. ICES Advice 2016, Book 1, Section 1.6.2.4. 5 pp.

ICES 2016b, OSPAR request for further development of fishing intensity and pressure mapping. In Report of the ICES Advisory Committee, 2016. ICES Advice 2016, Book 1, Section 1.6.6.4. 27 pp.

ICES 2017a, Report of the Workshop to evaluate regional benthic pressure and impact indicator(s) from bottom fishing (WKBENTH), 28 February–3 March 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:40. 233 pp.

ICES 2017b, Report of the Workshop to evaluate trade-offs between the impact on seafloor habitats and provisions of catch/value (WKTRADE), 28–31 March 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:42. 109 pp.

ICES 2017c, Report of the Workshop on scoping stakeholders on production of operational guidance on assessment of benthic pressure and impact from bottom fishing (WKSTAKE), 23 March 2017, ICES Headquarters, Copenhagen, Denmark. ICES CM 2017/ACOM:41. 31 pp.

ICES 2019, Interim Report of the Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT), 12–16 November 2018, ICES Headquarters, Copenhagen, Denmark. ICES CM 2018/HAPISG:21. 74 pp.

Kitchingman A. and S. Lai 2004, Inferences on potential seamount locations from mid-resolution bathymetric data. In: Seamounts: Biodiversity and Fisheries (eds T Morato, D Pauly) UBC Fisheries Centre, 78, pp. 261, Vancouver, B.C.

Koslow J.A., K. Gowlett-Holmes, J.K. Lowry, T. O'Hara, G.C.B. Poore, A. Williams 2001, Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. *Marine Ecology Progress Series*, 213: 111-125.

Levin P.S. and Möllmann, C. 2015. Marine ecosystem regime shifts: challenges and opportunities for ecosystem-based management. 370 .*Phil. Trans. R. Soc. B*.

MacArthur R. 1955, Fluctuations of animal populations and a measure of community stability *Ecology*. 36(3):533–6.

Ministry of Fisheries 2008, Bottom Fishing Activities by New Zealand Vessels Fishing in the High Seas in the SPRFMO Area during 2008 and 2009. Bottom Fishery Impact Assessment, New Zealand Ministry of Fisheries, 107 pp.

Möllmann C& Diekmann R. 2012, Marine ecosystem regime shifts induced by climate and overfishing: a review for the Northern Hemisphere. *Adv. Ecol. Res.* 47, 303–347.

NEMFC 2011, Essential fish habitat (EFH) omnibus amendment, The Swept Area Seabed Impact (SASI) model: A tool for analyzing the effects of fishing on essential fish habitat, New England Fishery Management Council, Massachusetts.

Norse, E.A, Sandra Brooke, William W.L. Cheung, Malcolm R. Clark, Ivar Ekeland, Rainer Froese, Kristina M. Gjerde, Richard L. Haedrich, Selina S. Heppell, Telmo Morato, Lance E. Morgan, Daniel Pauly, Rashid Sumaila, Reg Watson, 2012, Sustainability of deep-sea fisheries, *Marine Policy*, Volume 36, Issue 2, 2012, Pages 307-320, ISSN 0308-597X.

Orejas, C., A. Gori, C. Lo Iacono, P. Puig, J.M. Gili and M.R. Dale 2009, Cold-water corals in the Cap de Creus canyon, northwestern Mediterranean: spatial distribution, density and anthropogenic impact. *MEPS*. 397:37–51.

Parker, S.J, A.J. Penney and M.R. Clark 2009, Detection criteria for managing trawl impacts to Vulnerable Marine Ecosystems in high seas fisheries of the South Pacific Ocean. *Marine Ecology Progress Series,* 397, 309-317.

Parker, S.J. 2008, Development of a New Zealand High Seas Bottom Trawling Bottom Fishery Impact Assessment Standard for Evaluation of Fishing Impacts to Vulnerable Marine Ecosystems in the South Pacific Ocean. *Fisheries Research Report*, IFA2007-02, Ministry of Fisheries, Wellington, New Zealand.

Parker, S.J., R.G. Cole and S.M. Hanchet 2010, Further analysis of spatial patterns of benthic invertebrate habitats from fishery bycatch in the Ross Sea region. *CCAMLR Science*, WG-FSA 10/30, 22 pp.

Patrick , W. S., Spencer, P., Link, J., Cope, J., Field, J., Kobayashi, D., Lawson, P., et al. 2010, Using productivity and susceptibility indices to assess the vulnerability of United States fish stocks to overfishing. *Fishery Bulletin*, 108: 305-322.

Patterson, H, Larcombe, J, Nicol, S and Curtotti, R 2018, *Fishery status reports 2018*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. CC BY 4.0.

Penney A.J., S.J. Parker and J.H. Brown 2009, New Zealand Implementation of protection measures for vulnerable marine ecosystems in the South Pacific Ocean. *Marine Ecology Progress Series*, 397: 341–354.

Penney, A.J. and J.M. Guinotte 2013, Evaluation of New Zealand's high-seas bottom trawl spatial closures using predictive habitat models and quantitative risk assessment. *PLOS One*. 8(12).

Pitcher, C.R., Doherty, P., Arnold, P., Hooper, J., Gribble, N., and 55 others 2007, Seabed Biodiversity on the Continental Shelf of the Great Barrier Reef World Heritage Area. AIMS/CSIRO/QM/QDPI Final Report to CRC Reef Research. 320 pp.

Pitcher, C.R., Ellis, N., Althaus, F., Williams, A., McLeod, I. 2015, Predicting benthic impacts & recovery to support biodiversity management in the South-east Marine Region. Pages 24–25 in Bax, N.J. & Hedge, P. [Eds.]. 2015. Marine Biodiversity Hub, National Environmental Research Program, Final report 2011–2015. Report to Department of the Environment. Canberra, Australia.

Pitcher, C.R., Haywood, M., Hooper, J., Coles, R., and 30 others 2007, Mapping and Characterisation of Key Biotic & Physical Attributes of the Torres Strait Ecosystem. CSIRO/QM/QDPI Task Final Report to CRC Torres Strait. 142pp.

Pitcher, C.R., N. Ellis, W.N. Venables, T.J. Wassenberg, C.Y. Burridge, G. P. Smith, M. Browne, F. Pantus, I.R. Poiner, P.J. Doherty, J.N.A. Hooper and N Gribble 2016a, Effects of trawling on sessile megabenthos in the Great Barrier Reef and evaluation of the efficacy of management strategies. *ICES Journal of Marine Science* 73(1):115–126.

Pitcher, C.R., Miller, M., Morello, E., Fry, G., and 26 others 2016b, Environmental Pressures: Regional Biodiversity — Pilbara Seabed Biodiversity Mapping & Characterisation. Final report to PCMP, CSIRO Oceans & Atmosphere, 61 p.

Pitcher, C.R., N. Ellis, S. Jennings, J.G. Hiddink, T. Mazor, M.J. Kaiser, M.I. Kangas, R.A. McConnaughey, A.M. Parma, A.D. Rijnsdorp, P. Surronen, J.S. Collie, R. Amoroso, K.M. Hughes and R. Hilborn 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*. 8:472–480.

Puig, P., M. Canals, J. Martin, D. Lastras, A. Palanques, and A.M. Calafat 2012, Ploughing the deep sea floor. *Nature*. 489(7415):286–289.

Pusceddu, A., S. Bianchelli, J. Martin, P. Puig, A. Palanques, P. Masque and R. Danovaro 2014, Chronic and intensive bottom trawling impairs deep-sea biodiversity and ecosystem functioning. *PNAS*. 111(24):8861–8866.

Richard, Y. & Abraham, E. R. 2013, Application of Potential Biological Removal methods to seabird populations. New Zealand Aquatic Environment and Biodiversity Report No. 108. Ministry for Primary Industries, Wellington, New Zealand.

Richard, Y., E.R. Abraham, K. Berkenbusch 2017, Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2014–15. Draft Aquatic Environment and Biodiversity Report. Ministry for Primary Industries, Wellington.

Richer de Forges B., J.A. Koslow and G.C.B. Poore 2000, Diversity and endemism of the benthic seamount fauna in the southwest Pacific. *Nature*, 405, 944-947.

Rogers, A.D., M.R. Clark, J.M. Hall-Spencer and K.M. Gjerde 2008, The science behind the guidelines: A scientific guide to the FAO draft international guidelines (December 2007) for the management of deep-sea fisheries in high seas and examples of how the guidelines may be practically implemented. IUCN, Switzerland, 2008.

Rowden, A.A., J.M. Guinotte, S.J. Baird, D.M. Tracey, K.A. Mackay and S. Wadhwa 2013, Developing predictive models for the distribution of vulnerable marine ecosystems in the South Pacific Ocean region. New Zealand Aquatic Environment and Biodiversity Report No. 120. Ministry for Primary Industries.

Rowden, A.A., O.F. Anderson, S.E Georgian, D.A. Bowden, M.R. Clark, A. Pallentin and A. Miller 2017, High-Resolution Habitat Suitability Models for the Conservation and Management of Vulnerable Marine

Ecosystems on the Louisville Seamount Chain, South Pacific Ocean. *Frontiers in Marine Science*. 4(355): 1–19.

SAFS 2018, Traps and Pots. Status of Australian Fish Stocks. Fisheries Research and Development Corporation. https://www.fish.gov.au/Fishing-Methods/Traps-and-pots, accessed 8 July 2019.

Sharp, B. R. 2016, Spatially Explicit Fisheries Risk Assessment (SEFRA): A framework for quantifying and managing incidental commercial fisheries impacts on non-target species and habitats. Unpublished report, Ministry for Primary Industries, Wellington, New Zealand.

Sharp, B. R., Cryer, M., Richard, Y., & Abraham, E. R. 2013, New Zealand's approach to assessment of risk to seabirds associated with fishing-related mortality. 5th meeting of the Seabird Bycatch Working Group, La Rochelle, France, 1-3 May 2013.

Sharp, B., S.J. Parker and N. Smith. 2008, Methods for implementing conservation measure 22-06: An impact assessment framework for bottom impacting fishing methods in the CCAMLR area. CCAMLR, WSA-08/53.

Stobutzki, I. C., Miller, M. J., Heales, D. S., and Brewer, D. T. 2002, Sustainability of elasmobranchs caught as bycatch in a tropical prawn (shrimp) trawl fishery. *Fishery Bulletin*, 100: 800-821.

Tittensor, D.P., A.R. Baco, P.E. Brewin, M.R. Clark, M. Consalvey, J. Hall-Spencer, A.A. Rowden, T. Schlacher, K.I. Stocks and A.D. Rogers 2009, Predicting global habitat suitability for stony corals on seamounts. *J. Biogeogr.*, 36: 1111–1128.

Tracey, D.M., S.J. Parker, E. Mackay and K. Ramm 2008, A quick identification guide to "Vulnerable Marine Ecosystem" indicator taxa. Observer Programme, Ministry of Fisheries, Wellington, New Zealand.

Tyler-Walters, H., K. Hiscock, D.B. Lear and A. Jackson 2001, Identifying species and ecosystem sensitivities. *Report to the Department for Environment, Food and Rural Affairs from the Marine Life Information Network (MarLIN)*. Marine Biological Association of the United Kingdom, Plymouth

UNGA 2007, Resolution 61/105 Sustainable fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and related instruments. UNGA A/RES/61/105 Available at: http://www.un.org/Depts/los/general_assembly/general_assembly_reports.htm, 21pp.

UNGA 2009, Resolution 64/72 Sustainable fisheries, Sustainable fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and related instruments. UNGA A/RES/64/72. Available at: http://www.un.org/depts/dhl/resguide/r64.shtml. 26 pp.

Walker BH 1992, Biodiversity and ecological redundancy, *Conservation biology*. 6(1):18–23.

Warwick R.M. and K.R. Clarke 1998, Taxonomic distinctness and environmental assessment. *Journal of Applied Ecology*, 35: 532–543.

Welsford, D., C., G. P. Ewing, A. J. Constable, T. Hibberd & R. Kilpatrick 2014 (eds.), Demersal fishing interactions with marine benthos in the Australian EEZ of the southern ocean: an assessment of the vulnerability of benthic habitats to impact by demersal gears, final report to the Fisheries Research and Development Corporation, FRDC Report 2006/042, The Department of the Environment, Australian Antarctic Division and the FRDC.

Williams, A., Georgeson, L., Summerson, R., Hobday, A., Hartog, J., Fuller, M., Swimmer, Y., et al. 2018. Assessment of the vulnerability of sea turtles to IOTC tuna fisheries. IOTC-2018-WPEB14-40.

Williams, A., J. Dowdney, A.D.M. Smith, A.J. Hobday and M. Fuller (in press). Evaluating impacts of fishing on benthic habitats: A risk assessment framework applied to Australian fisheries. *Fisheries Research* (in press).

Yesson, C., M.R. Clark, M.L. Taylor and A.D. Rogers 2011, The global distribution of seamounts based on 30 arc seconds bathymetry data. *Deep Sea Research I*, 58: 442 – 453.

Zezina, O. 1997, Biogeography of the bathyal zone. *Advances in Marine Biology*, 32: 389–426.

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: 56-68.

Zhou, S., Hobday, A. J., Bulman, C. M., Fuller, M., and Daley, R. M. 2019, A data-limited method for assessing cumulative fishing risk on bycatch. *ICES Journal of Marine Science*. 76:4:837-847.