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Methods for deriving thresholds for VME encounter protocols for SPRFMO bottom fisheries

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Contents

1. Introduction

The paper presents an overview of the process and analyses used to develop threshold weights for a VME encounter protocol for bottom trawls within the SPRFMO Convention Area and includes three components:

Section 1 provides an overview of the key steps in the development of international resolutions, recommendations and guidelines relating to the protection of VMEs from significant adverse impacts on the high seas. This information is provided as background to the development of encounter protocols.

Section 2 summarises scientific information that we used to inform the number of VME indicator taxa and/or the weight of VME indicator taxa in benthic bycatch that might trigger a bottom trawl move-on-rule within the assessed area of the SPRFMO Area. However, although the scientific process provides information to inform the development of a bottom trawl encounter protocol, the development of a final encounter protocol is a management decision to be made in consultation with stakeholders.

Section 3 combines the first two and suggests a bottom trawl encounter protocol for the western SPRFMO Area based available scientific information.

1.1 International Context for conservation measures to protect VMEs in the high seas

Obligations to detect fishing encounters with vulnerable marine ecosystems in the high seas originated from the United Nations General Assembly (UNGA). In 2006 the UNGA included provisions for the protection of vulnerable marine ecosystems in the high seas into their annual resolution on sustainable fisheries. UNGA Resolution 61/105 called upon regional fisheries management organizations (RFMOs) to adopt conservation measures to protect vulnerable marine ecosystems (VMEs) from significant adverse impacts of bottom fishing activities, or to cease bottom fishing activities in areas where VMEs are likely to occur unless conservation and management measures have been established to prevent significant adverse impacts on VMEs. Resolution 61/105 is also the origin of requirements for bottom fishing vessels to cease fishing and move away from areas where VMEs are encountered. This has since become better known as the 'move-on rule'. The provisions of the resolution were non-binding and it was intended that implementation would primarily rely on RFMOs adopting conservation measures, binding upon their members, to prevent significant adverse impacts on VMEs, including through implementation of move-on rules. However, this is complicated by the fact that UNGA Resolution 61/105 offers no definition of VMEs (other than reference to "seamounts, hydrothermal vents and cold-water corals") or advice on how encounters with VMEs during high seas fishing operations should be detected. This leaves RFMOs to develop their own interim definitions of VMEs and their own criteria for detecting encounters with VMEs.

The UNGA has continued to re-emphasise and strengthen calls for implementation of measures to prevent significant adverse impacts of high seas bottom fisheries on VMEs. Subsequent resolutions have become increasingly explicit regarding the need to develop science-based protocols to define evidence of VMEs encountered during high seas bottom fishing operations. In 2009, UNGA Resolution 64/72 (UNGA 2010) concluded that further actions were needed to strengthen the implementation of

UNGA Resolution 61/105 and called upon RFMOs to establish and implement science-based protocols, including "*threshold levels and indicator species*", that would define evidence of an encounter with a VME.

The implementation of these measures by RFMOs was reviewed by the General Assembly in 2011 and, in response to the findings of that review, UNGA Resolution 66/68 (2012) called for further actions to strengthen procedures for carrying out and updating assessments and tasked the FAO with providing technical guidance on encounter protocols, including "*encounter thresholds and move-on distances*", as well as providing further guidance on applying criteria for identifying VMEs.

The guidelines for management of deep-sea fisheries in the high seas mandated by UNGA Resolution 61/105 were developed by the FAO in collaboration with members of the Committee on Fisheries (COFI) during two technical consultations in 2008. The resulting guidelines were adopted by COFI and published in 2009 (FAO 2009). These guidelines attempted to define VMEs in terms of the life history and vulnerability (to impacts of fisheries) characteristics of the component species of such ecosystems. The guidelines provide a list of characteristics that have served since then as the principle means of defining and identifying VME indicator species.

However, the FAO has not, as yet, provided any advice or technical guidance on what constitutes evidence on an encounter with a VME during bottom fishing operations. Participants in deep-sea fisheries in the high seas are therefore currently still in a position of having to determine for themselves, based on best available scientific information, what constitutes evidence of an encounter with a VME, and to feed the results of such work into the FAO process.

Rogers & Gianni (2010) reviewed the responses by RFMOs and CCAMLR to UNGA resolutions 61/105 and 64/72, including the development of measures to prevent significant adverse impacts on VMEs and the use of move-on rules. They concluded, for SPRFMO, that the move-on rules adopted by New Zealand and proposed by Spain, combined with closed areas, represented a serious attempt to implement the resolutions and the FAO Guidelines. However, they noted that areas remaining open to bottom trawl fishing by New Zealand vessels may contain significant areas of VMEs and that the move-on rule is only applied to a subset of the open areas within New Zealand's trawl footprint.

Kenchington (2011) assessed the application of move-on rules by RFMOs up to 2010 and inferred that these had not been intended as stand-alone measures to protect VMEs, rather they were "back stops" to complement long-term closures. At that time, move-on rules had been adopted only as interim measures, pending further development, and Kenchington (2011) considered that none could be said to be efficient or even effective. Hansen et al. (2013) reviewed developments up to 2013 and provided an excellent and detailed summary of move-on rules and protocols for various gear types in SPRFMO (as proposed or implemented by New Zealand, Australia, and the EU), CCAMLR, and three other RFMOs (see their Appendix A, updated and adapted from Kenchington (2011)). Although both Rogers & Gianni (2010) and Kenchington (2011) contended that move-on rules are not intended as stand-alone measures and should be complemented with spatial closures, it is clear from these three published reviews that wide variation and interpretation of the guidance described in section 2 exists (both in terms of the protocols around move-on rules, and whether they are complemented with spatial closures), even within a single RFMO or CMM.

In its report to the Commission in 2013, SC-01 endorsed the following characteristics of effective move-on rules:

- Lists of regionally specific VME indicator taxa should be identified for each fishery, using all available information on species occurrence and retention by fishing gears;
- VME indicator taxa should be specified at a level that facilitates rapid and accurate onboard visual identification by trained observers;
- Encounter thresholds indicating evidence of a VME should be based on analyses of historical bycatch data, taking account of the different retention rates of species by each gear type. Multiple species can be used to indicate higher biodiversity;
- Once evidence of a VME is encountered using an agreed protocol, move-on areas should be closed to fishing by all demersal fishing vessels until further analysis or evidence indicates that area does not contain VMEs;
- Move-on distances and area closures should encompass the area covered by typical fishing operations using that gear type.

However, SC-01 also **emphasized** in the following paragraph that:

Move-on rules should be considered to be temporary measures, providing precautionary protection for areas showing evidence of VMEs until objectively planned spatial closures can be implemented to protect known and highly bio-diverse VME areas.

Cryer & Nicol (2017) noted that this was a consistent theme through many documents and publications on move-on rules; they appear most useful as stop-gaps or temporary measures when information is almost non-existent and before well-designed spatial management areas can be put in place. Once well-designed spatial management is in place, their utility seems restricted to "back stops" or "insurance" to the main management measures in case these turn out to be deeply flawed. For instance, a move-on rule can put a quick stop to fishing in a place where large amounts of sensitive and structural benthic fauna are recovered when none or little was predicted by the VME habitat suitability models used to design the spatial management regime.

The UNGA conducted a review of bottom fishing in 2016. With ongoing concern about implementation of bottom fishing resolutions, the UNGA adopted resolution 71/123, which called for the application of the full set of criteria in the FAO Guidelines to identify where VMEs occur or are likely to occur as well as for assessing significant adverse impacts. It also noted a particular need to improve effective implementation of thresholds and move-on rules as well as the need to account for the impacts on VMEs of other human activities when managing deep-sea fisheries and protecting VMEs.

1.2 Existing bottom fishing measures to protect VMEs

The existing CMM-3-2018 for bottom fisheries sets out the requirements for Members wanting to pursue bottom fisheries to assess those fisheries against relevant international guidelines and the Bottom Fishery Impact Assessment Standard (BFIAS) (see paragraphs 10 to 15 of the CMM). The CMM is not specific about precisely how Members should implement the requirements, and New Zealand and Australia developed measures that were different in several respects.

New Zealand's implementation includes: definition of a historical bottom trawl fishing footprint (using 20 minute-of-arc blocks) over the reference years 2002-2006; development of a VME-Evidence Identification protocol; and a three-tiered system of spatial management areas whereby 41% of the footprint area is closed to fishing, 30% is open to fishing subject to a move-on rule if evidence of VMEs is encountered, and the remaining 29% of the footprint is open to fishing with no move-on rule. The open, move-on and closed areas are stratified between eight fishing areas constituting the total footprint. Within the move-on areas a rapid VME identification protocol[4] is used to assess evidence of VME. The VME identification protocol includes threshold weights (between 1 and 50 kg) for each of six VME indicator taxa (any one of which would trigger a move-on within the move-on areas) and an index of taxonomic diversity whereby the presence of any amount of any three specified high-level taxa would trigger a move-on (Parker et al. 2009, see also Table 1 of Cryer & Nicol 2017).

Australia's implementation includes: definition of a historical all-methods fishing footprint (using 20 m.o.a. blocks) over the reference years 2002-2006; development of a VME-Evidence Identification protocol; and spatial management areas whereby all fishing is subject to a move-on rule if evidence of VMEs is encountered. A rapid VME identification protocol is used to assess evidence of VME. The VME identification protocol includes a single threshold weight (50 kg) for either of two VME indicator taxa (either of which would trigger a move-on) (See Table 1 of Cryer & Nicol 2017).

Paragraph 8f of CMM-03-2018 provided for these different approaches and threshold weights: "*until the Scientific Committee has developed advice on SPRFMO threshold levels pursuant to paragraph 5(c) of this CMM, establish threshold levels for encounters with VMEs for vessels flying their flag, taking into account paragraph 68 of the FAO Deep-sea Fisheries Guidelines*;" (where paragraph 5c of the CMM requires the SC to "*develop and provide advice and recommendations to the Commission on criteria for what constitutes evidence of an encounter with a VME, in particular threshold levels and indicator species*;"). A consistent approach across all bottom fishing Members requires the development of a single set of indicator species and threshold weights if an encounter protocol is still required.

1.3 Proposed spatial management within the western SPRFMO Convention Area

A draft for a new conservation and management measure (CMM) for bottom fisheries within the western SPRFMO Convention Area (those parts of the Convention Area that are within the area starting at a point of 24°S latitude and 146°W, extending southward to latitude 57° 30S, then eastward to 150°E longitude, northward to 55°S, eastward to 143°E, northward to 24°S and eastward back to point of origin) was presented as an information paper at the SRFMO Commission meeting in Jan 2018. The proposed CMM is based on a spatial management approach and includes management areas in which bottom fishing may be conducted. Work to underpin the development of spatial management areas as part of the CMM included the mapping of VMEs and the use of spatial decision-support software to design open and closed areas that would prevent significant adverse impacts on VMEs and provide for a viable fishery.

[4] CMM-03-2018 requires that trawl fisheries have 100% observer coverage and these observers conduct the rapid assessments of whether a move-on is required and also collect comprehensive data on benthic bycatch, identified to the lowest possible taxon, from every tow.

Records of the location or density of VMEs or VME indicator taxa such as reef-forming corals within the SPRFMO Convention Area are sparse and inadequate to map the distribution of VMEs directly. This paucity of data meant that models using all available biological, physical and chemical information from depths between 200 and 3000 metres were used to predict habitat suitability (and the likely distribution) of a variety of VME indicator taxa. The modelled habitat suitability maps for VME indicator taxa and the reported distribution of fishing were used within spatial decision-support software to prioritise areas to be closed to fishing (to prevent significant adverse impacts on VMEs) and areas to be opened to fishing (to provide for a viable fishery), which were then finalized for inclusion in the draft CMM following feedback from various workshops and discussions with scientists, experts and officials COMM 6 - INF 05_rev1.

Within this process it is important to acknowledge that, although the spatial management measures were developed using the best available scientific information, there remains uncertainty in the modelled distributions of VME indicator taxa that drive prioritisation within the spatial decision-support software. In developing their proposals, therefore, New Zealand and Australia are proposing to complement the spatial management approach with a move-on rule as a "back stop" (as envisaged by SC-05) to reflect uncertainty in the effectiveness of spatial management measures based on modelled distributions of VME taxa.

1.4 SPRFMO Scientific Committee direction in the development of move-on rules to complement spatial management measures

The draft CMM for bottom fisheries within the western SPRFMO Convention Area, as proposed to the Commission in 2018 included a VME encounter protocol that applies a move-on rule if threshold weights for VME indicator taxa taken as bycatch are exceeded. These thresholds were derived from 2012-2017 catch records of New Zealand bottom trawlers fishing in the SPRFMO Convention Area by identifying the top 2-percentile catch weights for the most commonly-caught species, with data pooled across all fishing areas. As joint proposers of the new bottom fishing CMM, New Zealand and Australia agreed that the potential approaches to deriving move-on rules should be further explored with reference to the advice of the 2017 SPRFMO Scientific Committee in its report.

121. After considering the paper/presentation and ensuing discussion, the SC:

- ***noted*** *the diverse guidance on Conservation and Management Measures for bottom fisheries available from UNGA resolutions, FAO documents and guidelines, published reviews, the SPRFMO Convention, and the existing CMM;*
- ***noted*** *the progress on the development and testing of methods to model and map VMEs in the western part of the SPRFMO Area and on the application of software-based methods to design candidate spatial management areas to provide for sustainable use while preventing significant adverse impacts on VMEs;*
- ***noted*** *the application of such decision-support tools by Australia and New Zealand in multi-stakeholder workshops in July-August 2017;*
- *affirmed its agreement at SC-01, SC-02, SC-03, and SC-04 that a revised comprehensive CMM for bottom fisheries in the SPRFMO Area should be based on a spatial management approach;*

- ***agreed*** *that move-on rules should be viewed only as "back-stop" measures (if required) to complement spatial closures developed using decision-support software and designed to prevent significant adverse impacts on VMEs;*
- ***agreed*** *that the potential information gathering benefits of move-on rules can be better met using structured and mandatory collection and review of benthic bycatch in bottom fisheries;*
- ***agreed*** *that, should a move-on rule be implemented as part of the revised CMM for bottom fisheries, the threshold for triggering such a rule should be high. Ideally a move-on response should follow more than one encounter involving weights of bycatch of benthic fauna that would indicate the models used to predict the distribution of VME taxa are misleading*
- ***agreed*** *that future research could investigate the relationship between indicator taxa retained in nets compared to actual presence of VMEs and associated impacts, for example through the use of cameras*

Elements of move-on rules that could be further developed include:

- Refinement of VME indicator taxa
- Refinement of VME indicator taxa weight thresholds
- Refinement of biodiversity component of encounter protocols
- Refinement of encounter protocols

In reconsidering these elements of move-on rules, additional guidance came from discussions at the 2018 North Pacific Fisheries Commission (NPFC)/FAO Workshop on the Protection of Vulnerable Marine Ecosystems, attended by Ashley Rowden (NIWA) and Martin Cryer (MPI) on behalf of SPRFMO. The workshop agreed that thresholds should ideally be specific to area, gear type, and taxon, and discussed four broad approaches (in increasing order of complexity and data requirements) for determining VME indicator taxa weight thresholds:

1. *Completely arbitrary based on what "feels about right"*
2. *Arbitrary but based on actual historical catch records*
    a. *catch records could come from the fisheries for which a threshold is required, or from similar fisheries, and*
    b. *thresholds could be based on medians, percentiles, or other metrics*
3. *Combination of observed densities of VME indicator taxa, trawl tow distances, and estimated or imputed trawl catchabilities to estimate likely (or some precautionary percentile of) catch of given taxa within a VME*
4. *Comparison of observed catches with model predictions of (in order of preference) biomass, density, or habitat suitability for VME indicator taxa*

These approaches were subsequently discussed at meetings in New Zealand in May 2018 including officials and stakeholders from New Zealand and Australia. It was agreed that the second approach above was the most practical option given data availability and time constraints. In particular, the more sophisticated methods (3 and 4) were not considered feasible using existing data.

2. Evidence to inform a new VME encounter protocol

2.1 Overview

This section provides scientific information to inform the quantity and/or number of VME indicator taxa in benthic bycatch to trigger the bottom trawl move-on rule. Given it was not possible to implement more sophisticated methods based on VME abundance and trawl catchability, a more pragmatic "data-informed" method based on historical catch records from the fishery was used. We examined the distribution of bycatch weights for each VME indicator taxon encountered in bottom trawls and the number of VME taxa encountered per tow, and used this information to develop the proposed encounter protocol (comprising threshold weights for key taxa and a biodiversity component as in the current New Zealand encounter protocol).

2.2 VME indicator taxa used in the analysis

VME indicator taxa used in the analysis were those defined for the southwest Pacific Ocean by Parker et al (2009), as presented in Table 1.

2.3 Data used in analysis

Data used in the analysis relating to the VME indicator taxa retained, benthic bycatch weight distributions, numbers of taxa caught per tow and cumulative weight frequency distributions were extracted from the New Zealand's Centralized Observer Database (COD) (accessed 15 June 2018) and provided by Fisheries New Zealand. Data were restricted to New Zealand bottom trawl tows (including mid-water trawls) in the western high seas SPRFMO Area over the period 2008–18 (noting that the 2018 data does not cover a full fishing year) and included tow-by-tow observer data for all observed fishing events irrespective of whether or not VME indicator taxa were recorded as benthic bycatch. Bottom trawl data was restricted to tows targeting black oreo (*Allocyttus niger*) alfonsinos (*Beryx splendens* and *B. decadacylus*), cardinal fish (*Epigonus telescopus*), orange roughy (*Hoplostethus atlanticus*) and spiky oreo (*Neocyttus rhomboidalis*) (species codes BOE, BYS/BYX, CDL, ORH and SOR, respectively). These data had one record per benthic taxon encountered on each tow, and included trip number, tow number, fishing method, trawl type, benthic species code, common name, bycatch weight, method of weight analysis and information on whether the benthic material was encrusting anything or being encrusted by something else.

Australian data were not included in this analysis because benthic bycatch records are not captured in databases with the same precision and resolution as New Zealand benthic bycatch data. Inclusion of these lower-resolution data would degrade the usefulness of the existing New Zealand data. An analysis of Australian benthic bycatch data extracted from observer records has indicated that for line gears, the rates of interactions with benthic bycatch are similar to those in New Zealand fisheries. Preliminary analysis of benthic bycatch records for Australian trawl fisheries in SPRFMO indicates that rates of interaction are lower than for New Zealand fisheries. However, analysis of benthic bycatch in

Australian trawl data is not very informative due to the generally low and sporadic effort during the 2008–2018 period and the coarse resolution of the data.

Table 1: Rationale for taxonomic groups as potential indicators of VMEs (modified from Parker et al. 2009).

FAO Code	Taxon	Comments	Relationship to FAO listings
PFR	Porifera (Phylum) *Sponges*	Include both classes (Demospongiae and Hexactinellida). These are found in the deep sea, can form complex structures and are vulnerable to disturbance by fishing gears. Longevity and resilience of cold-water sponges is unknown.	Sponge dominated communities are specifically listed by the FAO guidelines as vulnerable ecosystem components to protect. Sponge fields and large colonies form complex structures and may provide habitat for many species.
GGW	Gorgonacea (Order) *Sea fans*	Gorgonacea (Sea fans) have been revised and subsumed into the Alcyonacea (soft corals) but are left separated here as important VME taxa that may be complex, large, fragile, and form complex biogenic structure.	Specifically listed by FAO guidelines as one of the main target taxonomic groups of the VME definition. This group includes several large structure-forming species that may provide habitat to other species.
AXT	Stylasteridae (Subclass or Family) *Hydrocorals*	Covers a wide range of taxa from small (cm scale) to massive *Macropora* reef, but if big enough to be caught by fishing gear, they are indicative of VME.	Specifically listed by FAO guidelines as one of the main target taxonomic groups of the VME definition. They can form very large complex, yet brittle structures.
CSS	Scleractinia (Order) *Stony corals*	Includes six complex branching, thicket or mound forming genera matching VME criteria: *Solenosmillia; Goniocorella; Oculina; Enallopsammia; Madrepora*, and *Lophelia*.	Specifically listed by FAO guidelines as one of the main target taxonomic groups of the VME definition. They are slow growing, structure-forming species vulnerable to disturbance by fishing gear, with unknown recovery rates. Accordingly, a high importance is given.
AQZ	Antipatharia (Order) *Black corals*	All taxa are structure forming, fragile and associated with habitats that tend to be more diverse (heterogeneous seabed with accelerated current flow).	Specifically listed by FAO guidelines as one of the main target taxonomic groups of the VME definition. They are low productivity, structure-forming species vulnerable to fishing gears.
ATX	Actiniaria (Order) *Anemones*	Anemones are not listed by FAO (2007) but can be large and are indicators of hard substrate and habitats that support corals, so are included as an indicator of vulnerable species.	As an indicator of other VME components.
AJZ	Alcyonacea (Order) *Soft corals*	Deep-sea species may be erect, large and branching, providing structural habitats and associated with other VME taxa.	Specifically listed by FAO guidelines as one of the main target taxonomic groups of the VME definition. If found in high densities, they would be vulnerable to fishing gear.
NTW	Pennatulacea (Order) *Sea pens*	They are typical of softer substrates but do provide complex structure, have been associated with fish species and are vulnerable to trawl gear because they can be tall and often live in trawlable habitat.	Specifically listed as VME examples by FAO guidelines, but do not indicate hard substrate or stony corals. They do, however, suggest a different type of VME. They are scored as an indicator of habitat containing vertical structure.
CWD	Crinoidea (Class) *Sea lillies*	All taxa are fragile and associated with habitats that tend to be more diverse (heterogeneous seabed with accelerated current flow)	Not specifically identified by FAO guidelines, but identified by Parker (2008) as a habitat indicator of VME taxa. Once detected, crinoids are an indicator of suitable VME substrate.
BHZ	Brisingida (Order) *'Armless' stars*	All taxa are fragile and associated with habitats that tend to be more diverse (Heterogeneous seabed with accelerated current flow)	Not specifically identified by FAO guidelines, but identified by Parker (2008) as a habitat indicator of VME taxa. Once detected, armless stars are an indicator of suitable VME substrate.

We checked some potential source of bias in the data extract. Of the total 13,390 benthic bycatch records in the New Zealand database, 109 had no or zero specified weight. Inspection revealed that these were either samples less than 0.1 kg in weight that could not be accurately weighed at sea, due to rounding error, or the observer simply recorded the presence of a taxon. Because it was found that zero weights were indicative of the presence of benthic taxa as bycatch, all records with zero weight were retained in the analysis. Similarly, of the 5,079 bycatch records that corresponded to the VME indicator taxa presented in Table 1, 23 included bycatch weights over 100 kg. For each of these records, the observer comments, bycatch forms and any available photographs were reviewed to verify that samples did include VME indicator taxa and weren't composite samples that also included non-VME indicator components, and that reported weights seemed reasonable. None of the records greater than 100 kg was recorded as encrusting something, and only four were recorded as being encrusted by something else. For all but three records (Porifera 1091 kg; Scleractinia 200 kg and 120 kg), all weights over 100 kg were estimated by eye. Because there was no compelling evidence in the forms or images that reported weights were incorrect or "punch errors", all records greater than 100 kg were retained in the analysis.

No other data checking or error correction, such as checking tow positions, was conducted and it is possible that there are other sources of bias in this extract for the purpose of designing and assessing the impact of an encounter protocol. For instance, New Zealand fishers say they actively avoid fishing in the move-on areas because of the risk of disruption of their operations by the need to move-on. Also, the proposed new management areas are different in several ways from the combined Australian and New Zealand footprints, so the distribution of fishing under a new measure will be different from the distribution of fishing between 2008 and 2018. This difference is likely to be increased by the reduction in catch limits for orange roughy in the Tasman Sea recommended by SC-05.

Of the total 8,850 individual bottom trawl tows, 2,820 (32%) included VME indicator taxa as benthic bycatch (Figure 1).

2.4 Allocation of benthic species to FAO VME taxa codes

Individual benthic species within the bycatch dataset were assigned to higher order taxonomic groups using taxonomic designations from the World Register of Marine Species (www.marinespecies.org, accessed 12 July 2018). Individual benthic species that met VME indicator taxa criteria were then aggregated up into higher taxonomic groups and allocated FAO VME indicator taxa codes (Table 2 and Appendix A), resulting in a final 5,079 individual aggregated taxa records across 2,820 bottom trawl tows. Based on advice from the Observer Programme, COU (unidentified coral) was interpreted to indicate stony coral (Scleractinia[5]), and ANT (anemone) was interpreted to indicate a mix of VME indicator taxa (Actinaria, Zoanthidea) and non-VME indicator taxa (Ceriantharia, Corallimorpharia), and was therefore the latter was not included as a VME indicator taxa.

To evaluate if bycatch weights have decreased over time (potentially as a result of historical fishing), which would suggest the calculation of threshold weights should be based on bycatch weights from more recent fishing events, we plotted VME indicator taxon-specific weights through time (Figure 2). Finding no consistent relationship between VME bycatch weight and year across the VME indicator taxa, the entire temporal dataset was included in all subsequent analyses.

[5] This too may introduce modest bias into our summary but we believe this allocation is defensible

Table 2: Allocation of benthic bycatch species to VME taxonomic groups.

FAO Code	Taxon	No. spp. codes	Fisheries New Zealand codes
PFR	Porifera (Phylum) *Sponges*	19	APU, CFU, CLS, DSO, ERE, FAR, GLS, GVE, HYA, ONG, PAZ, PHB, PHW, PLN, RHA, SLT, THN, TLD, TTL
GGW	Gorgonacea (Order) *Sea fans*	1	GOC
AXT	Stylasteridae (Subclass) *Hydrocorals*	4	COR, CRE, ERR, LPT
CSS	Scleractinia (Order) *Stony corals*	8	COU, DDI, ERO, GDU, MOC, OVI, SIA, SVA
AQZ	Antipatharia (Order) *Black corals*	11	ATP, BTP, COB, DDP, DEN, LEI, LIL, LSE, PTP, SLP, TDP
ATX	Actiniaria (Order) *Anemones*	5	ACS, ATR, BOC, HMT, LIP
AJZ	Alcyonacea (Order) *Soft corals*	14	ARO, BOO, CHR, CLL, CTP, IRI, ISI, LLE, MTL, PAB, PLE, PMN, PRI, THO
NTW	Pennatulacea (Order) *Sea pens*	7	ALF, DGR, FQU, GYS, PNN, PTU, SPN
CWD	Crinoidea (Class) *Sea lillies*	3	CMT, CRI, CRN
BHZ	Brisingida (Order) *'Armless' stars*	1	BRG

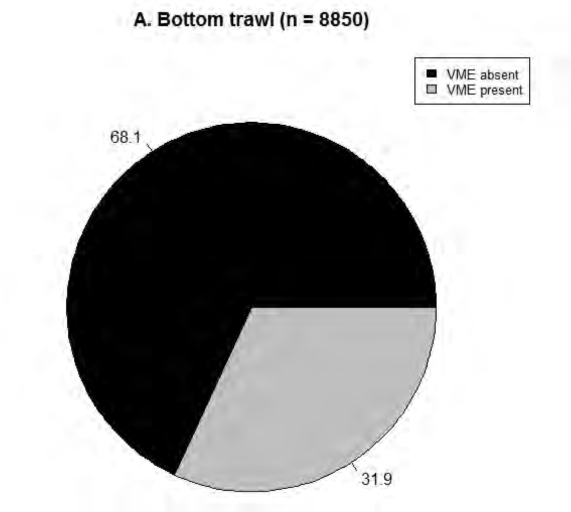

Figure 1: Percent of New Zealand bottom trawl tows within the western SPRFMO Convention Area catching at least one of the VME indicator taxa between 2008 and 2018.

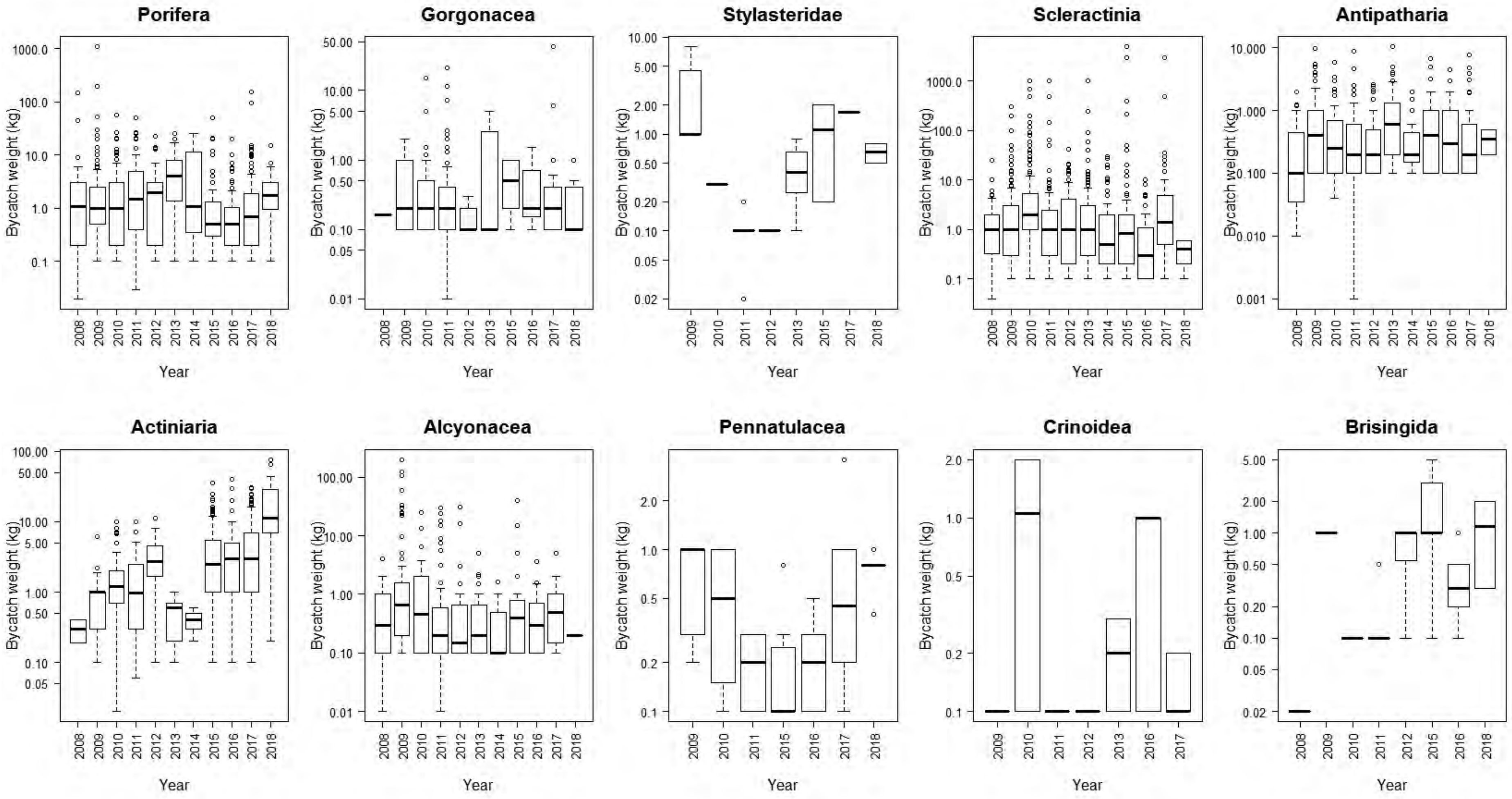

Figure 2: Weight (kg) of VME indicator taxa bycatch in New Zealand bottom trawls within the western SPRFMO Area as reported by observers for the 2008-2018 period. Within each boxplot the line indicates the 50th percentile (median), and the box encompasses 50% of the data, from the 25th to the 75th percentile. The dashed vertical lines extend to 1.5 times the interquartile range, with circles indicating "outliers". Note that the y-axis differs between panels, and the years that each taxon was observed as bycatch are shown.

2.5 Informing the weight thresholds of a bottom trawl encounter protocol

The FAO guidelines recommend that VME indicator taxa weight thresholds should ideally be specific to area and taxon. Although the western part of the SPRFMO Area can be divided into two distinct geographic areas, the Louisville Seamount Chain to the east of New Zealand, and various Tasman Sea fisheries to the west of New Zealand, there were insufficient data for many taxa within each area to enable the generation of area-specific weight thresholds (Table 3). Therefore, VME indicator taxon-specific weight thresholds were generated for the entire western SPRFMO Area combined. It should be noted that this may lead to inaccurate estimates of the potential impact of the proposed encounter protocol on fishing activity if the location of fishing shifts substantially (we test this empirically with a sensitivity analysis in Section 4).

Table 3: The number of fishing events including bycatch per VME indicator taxon (n), and the range in bycatch weight (kg) for all FMAs, the Louisville Seamount Chain (New Zealand observer code LOUR), and the Tasman Sea fisheries (CET, SOET, TKET, WANB).

		ALL Areas		Louisville		Tasman Sea	
FAO Code	**Taxon**	**n**	**Range**	**n**	**Range**	**n**	**Range**
PFR	Porifera (Phylum) *Sponges*	811	0 – 1,091.2	44	0 – 13.9	767	0 – 1,091.2
GGW	Gorgonacea (Order) *Sea fans*	235	0 – 42.7	31	0 – 42.7	204	0 – 21.3
AXT	Stylasteridae (Subclass) *Hydrocorals*	22	0 – 8.0	9	0 – 1.7	13	0.02 – 8.0
CSS	Scleractinia (Order) *Stony corals*	1,257	0 – 5,000.0	550	0 – 5,000.0	707	0 – 1,000.0
AQZ	Antipatharia (Order) *Black corals*	636	0 – 10.4	61	0 – 8.9	575	0 – 10.4
ATX	Actiniaria (Order) *Anemones*	774	0.02 – 77.0	5	0.2 – 2.0	769	0.02 – 77.0
AJZ	Alcyonacea (Order) *Soft corals*	383	0 – 200.0	35	0 – 13.2	348	0 – 200.0
NTW	Pennatulacea (Order) *Sea pens*	78	0 – 3.6	5	0.1 – 1.0	73	0 – 3.6
CWD	Crinoidea (Class) *Sea lilies*	31	0 -2.0	0	-	31	0 – 2.0
BHZ	Brisingida (Order) *'Armless' stars*	28	0.02 – 5.0	12	0.1 – 1.0	16	0.02 – 5.0

To inform the choice of potential threshold weights, we calculated the 80th, 90th, 95th, 97th, 98th, 99th and 99.5th percentiles of the ordered values[6] for each of the VME indicator taxa (Table 4) and plotted cumulative distributions of catch weights from all bottom trawls for which observers reported VME indicator taxa (Figure 3). The choice of threshold weights within an encounter threshold should also informed by the advice of the SPRFMO Scientific Committee that the threshold for triggering the move-on rule should be high and triggered by rare and large catches of VME taxa that suggest the models used to predict the distribution of VME taxa are misleading.

[6] The estimated percentiles were not very sensitive to the choice of estimation method

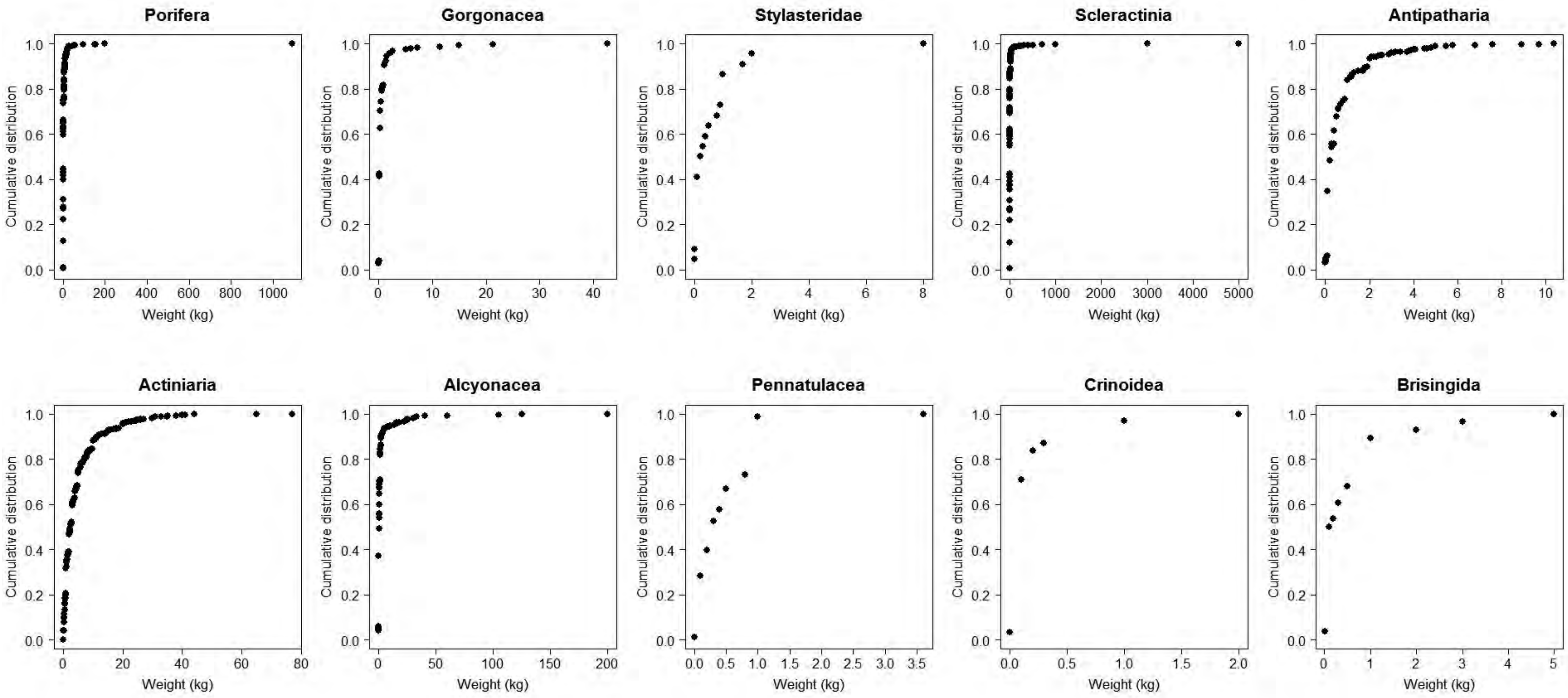

Figure 3: Cumulative distribution of bottom trawl catch weights (kg) for ten VME indicator taxa. NB: the x-axis scale differs between panels.

Table 4: The number of bottom trawl tows including bycatch (n), range in bycatch weight (kg), and percentiles in bycatch weight per VME indicator taxon. Percentiles are calculated using ordered values. Bycatch data is from all New Zealand bottom trawls within the western SPRFMO Convention Area between 2008 and 2018.

				Percentiles (kg)						
FAO Code	Taxon	n	Range	0.8	0.9	0.95	0.97	0.98	0.99	0.995
PFR	Porifera (Phylum) *Sponges*	811	0 – 1091.2	3.3	7.8	13.9	20	25	50	95
GGW	Gorgonacea (Order) *Sea fans*	235	0 – 42.7	0.6	1	2	5	7.2	15	21.3
AXT	Stylasteridae (Subclass) *Hydrocorals*	22	0 – 8.0	1	1.7	2	-	-	-	-
CSS	Scleractinia (Order) *Stony corals*	1257	0 – 5000.0	5	10	20	40	60	250	700
AQZ	Antipatharia (Order) *Black corals*	636	0 – 10.4	1	2	2.9	3.9	4.8	5.5	7.6
ATX	Actiniaria (Order) *Anemones*	774	0.02 – 77.0	7.24	12	20	24.5	30	38	41
AJZ	Alcyonacea (Order) *Soft corals*	383	0 – 200.0	1	2.3	13.2	24.1	30	60	125.1
NTW	Pennatulacea (Order) *Sea pens*	78	0 – 3.6	1	1	1	1	1	-	-
CWD	Crinoidea (Class) *Sea lillies*	31	0 -2.0	0.2	1	1	-	-	-	-
BHZ	Brisingida (Order) *'Armless' stars*	28	0.02 – 5.0	1	2	3	-	-	-	-

2.6 Informing a biodiversity component of an encounter protocol

Most often, VME indicator taxa are caught at weights less than their taxon-specific threshold and so do not trigger a move-on. Although the presence of a small amount of a single VME indicator taxon is unlikely to indicate an encounter with a VME, the presence of several VME indicator taxa in a single tow may indicate that the fishing event has encountered an area with a diverse seabed fauna, potentially constituting evidence of a VME (Parker 2008; Penny 2014). We believe that the assessment of "Evidence of a VME" should therefore also incorporate information on the number of VME indicator taxa caught within a single fishing event.

The inclusion of a biodiversity component within a move-on rule should however, include not only information on the number of taxa, but also the amount of those taxa within the catch. For example, we consider the presence of tiny amounts (say, <0.1 kg) of multiple VME indicator taxa within a trawl as poor evidence for the presence of a VME. However, the presence of substantial amounts of several taxa (but less than the threshold weight for any one taxon) constitutes much stronger evidence of the presence of a VME. To inform the consideration of how many VME indicator taxa should be required to constitute evidence of a VME, we explored the number of VME indicator taxa caught per fishing event with weights above the taxon-specific 80th and 90th percentiles (see Table 4) and calculated the number and percent of all fishing events reporting different numbers of VME indicator taxa above the taxon-specific biodiversity qualifying weights (Table 5).

Table 5: Number and percent of all fishing events recording 0 to >4 VME indicator taxon groups as benthic bycatch.

		Number of VME Indicator taxon groups per fishing event					
Percentile	Metric	0	1	2	3	4	>4
0.8	Number of fishing events	8,018	709	106	12	5	0
0.8	Percent of all fishing events	90.60%	8.01%	1.20%	0.14%	0.06%	0.00%
0.9	Number of fishing events	8,402	393	46	7	2	0
0.8	Percent of all fishing events	94.94%	4.44%	0.52%	0.08%	0.02%	0.00%

2.7 Reference points for selection threshold and biodiversity weights

To help inform the systematic selection of threshold and biodiversity qualifying weights, patterns in the cumulative catch curves were examined to determine the point at which taxon-specific cumulative catch curves begin to flatten toward the asymptote, potentially indicating a naturally occurring or ecologically relevant reference point. Thresholds indicating unexpectedly large catches should ideally fall to the right of such points, whereas qualifying weights for the biodiversity component of a rule indicating increasing numbers of taxa in a single tow at weights below the threshold trigger might also occur to the left. For the six taxa that could be assigned threshold weights using ordered percentiles, three-parameter segmented (or broken-line) relationships between bycatch weight and the cumulative distribution were fit using the *Segmented* package in R. A segmented relationship is defined by the slope parameters and the break-points where the linear relationship changes. Point estimates for the third break-point were taken as reference points (Figure 4).

Table 6: Relationship between reference points calculated from where cumulative distribution curves begin to flatten towards the asymptote and percentiles in bycatch weight for six VME taxa with sample size large enough to have the 90th percentile calculated. Green and orange values indicate catch weights below and above the threshold value, respectively.

			Percentiles (kg)						
FAO Code	Taxon	Reference point (kg)	0.8	0.9	0.95	0.97	0.98	0.99	0.995
PFR	Porifera (Phylum) *Sponges*	9.70	3.3	7.8	13.9	20	25	50	95
GGW	Gorgonacea (Order) *Sea fans*	2.66	0.6	1	2	5	7.2	15	21.3
CSS	Scleractinia (Order) *Stony corals*	7.97	5	10	20	40	60	250	700
AQZ	Antipatharia (Order) *Black corals*	2.58	1	2	2.9	3.9	4.8	5.5	7.6
ATX	Actiniaria (Order) *Anemones*	11.58	7.24	12	20	24.5	30	38	41
AJZ	Alcyonacea (Order) *Soft corals*	5.65	1	2.3	13.2	24.1	30	60	125.1

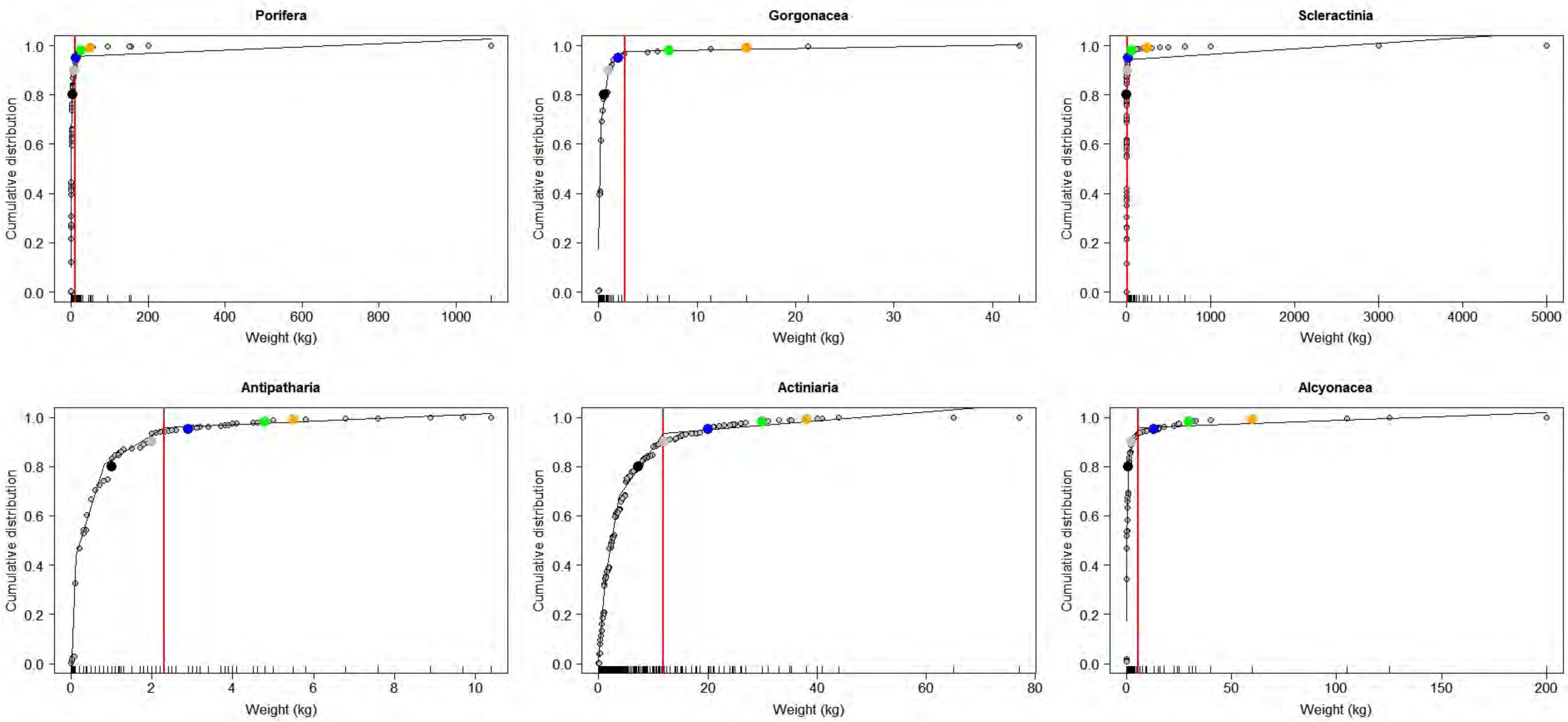

Figure 4: Cumulative distribution of bottom trawl catch weights (kg) for six VME indicator taxa showing reference points for where curves begin to flatten toward the asymptote (red vertical line), and the points of the 80th (black points), 90th (grey points), 95th (blue points), 98th (green points) and 99t percentiles (orange points). NB: the x-axis scale differs between panels.

3. A proposed VME encounter protocol

3.1 Overview

New Zealand and Australia convened several working groups with scientists, experts and officials in Wellington in June, July, and August 2018 to review the summarized bottom trawl bycatch distributions presented above and to guide the development of the VME encounter protocol, including the critical components relating to weight and biodiversity thresholds. The final structure of the VME encounter protocol presented here is a science-and data-informed management decision that carefully weighs issues raised during discussions with stakeholders. However, given that conservation and commercial objectives are often conflicting, we acknowledge that we have not been able to address all the issues raised by stakeholders, particularly in regards to minimizing uncertainty for the fishing industry in how frequently a move-on rule might be triggered, or the impact that any given weight threshold will have on the benthic environment given uncertainty around the catchability of different VME taxa. Australia and New Zealand will continue to work through these issues as proposals for a revised bottom fishing measure are developed.

3.2 Weight thresholds for VME indicator taxa

Data on benthic bycatch in deep-sea trawl fisheries suffers from unknown catchability, limited historical identification of taxa and limited spatial extent of samples. With these constraints in mind, a threshold weight was determined for each VME indicator taxa based on the cumulative distribution of bycatch weights observed during tows by the New Zealand bottom trawl fishery operating within the western SPRFMO Convention Area in the period 2008-2018. These bycatch distributions show that most catches were of small amounts, with many fewer large catches. It is not known what bycatch level is biologically significant without further study of the catchability of key taxa and how catches relate to the presence of habitats that constitute VMEs. These uncertainties led us to a pragmatic approach that sets thresholds for triggering a move-on rule relatively high such that they might suggest that the models used to predict the habitat suitability for VME taxa are misleading. We therefore propose using the 99th percentiles of the distributions of positive historical catch records in New Zealand databases for the six most commonly-caught high-level VME indicator taxa as threshold weights for an encounter protocol (Table 7). The four less commonly-caught taxa (for which there are insufficient data) are included within a “biodiversity component” of our proposed encounter protocol.

3.3 Biodiversity component of a move-on rule

Bottom trawls are inefficient at sampling fragile organisms such as corals and retain only a small proportion of the benthos impacted (Wassenberg et al. 2002, Mortensen et al. 2008). This means that an increasing number of VME indicator taxa within a tow may indicate a greater likelihood that the fishing event encountered a VME (Parker 2008; Penny 2014). The biodiversity component in the existing New Zealand protocol requires only very small amounts of three different high-level taxonomic groups to trigger a move-on and this was considered to be too sensitive an approach for a protocol designed to respond to very unusual events that suggest the models used to underpin the design of spatial management areas are misleading. We therefore propose using the 80th percentile of the distributions of positive historical catch records in New Zealand databases for all ten high-level VME indicator taxa as qualifying weights for the inclusion of any particular high-level taxon in the biodiversity component of our proposed move-on rule, with three or more VME indicator taxa exceeding these qualifying weights as the trigger.

Table 7: Proposed single-taxon threshold weights (kg) and qualifying weights (kg) for a biodiversity component of a move-on rule, equivalent, respectively, to the 99th and 80th percentiles of the distribution of positive records 2008–2018 for each of ten VME indicator taxa for the western South Pacific.

FAO Code	VME indicator taxa	Single-taxon threshold weight (kg)	Qualifying weight for the biodiversity component (kg)
PFR	Porifera (Phylum) *Sponges*	50	5
GGW	Gorgonacea (Order) *Sea fans*	15	1
CSS	Scleractinia (Order) *Stony corals*	250	5
AQZ	Antipatharia (Order) *Black corals*	5	1
ATX	Actiniaria (Order) *Anemones*	30	5
AJZ	Alcyonacea (Order) *Soft corals*	60	1
ATX	Stylasteridae (Family) Hydrocorals	–	1
NTW	Pennatulacea (Order) Sea pens	–	1
CWD	Crinoidea (Class) Sea lilies	–	1
BHZ	Brisingida (Order) ‘Armless’ stars	–	1

3.4 Vulnerable marine ecosystem evidence process

For real-time use at sea, a simple rapid assessment form could be used by observers to check whether the bycatch in a particular tow triggered the move-on rule. In Figure 5, we have adapted the form originally developed by the New Zealand Ministry of Fisheries, 2008, and currently in use by New Zealand observers. Observers would also complete more comprehensive Observer Benthic Materials Forms to record all benthic invertebrates in the bycatch. The rapid assessment form should include the threshold weights for each VME indicator taxon and allows the move-on rule to be triggered either by a single very large catch of a VME indicator taxon, or the presence of three VME indicator taxa above their respective biodiversity threshold weights.

In practice, observers would assess the total weights of all organisms whether dead or alive in each relevant VME indicator taxa group and record the weight. If the weight of a taxonomic group is greater than the threshold weight, a score of three for that taxonomic group is recorded. If a taxonomic group is present, but the weight is less than the threshold weight but greater than the biodiversity qualifying weight, a score of one is recorded for that taxonomic group. If the weight of a taxonomic group is less than the qualifying weight for the biodiversity component, a score of 0 is recorded. Finally, scores are summed across all taxonomic groups and, if the score is three or greater, the move-on rule would be triggered.

Figure 5: Example rapid assessment tool (Vulnerable Marine Ecosystem Evidence Process form) that could be used by observers on board bottom trawl vessels.

1.Trip, tow and vessel information

Trip number	Tow number	Observer/s		Name of vessel master
		.	.	

2. Date, time and position that hauling of the gear commenced

Date dd/mm/yy	Time 24-hr clock	Latitude Degrees, Minutes	Longitude Degrees, Minutes, E/W
/ /	:	° . ' S	° . '

3. Instructions

- Assess the total weights of all organisms whether dead or alive in each relevant taxonomic group and record in Section 4.
- If the Observed Weight of a taxonomic group is **greater than** (not equal to) the Threshold Weight, write the VME Indicator Score for that group in the "Score" Column.
- If a taxonomic group is present, but the Observed Weight is **less** than the Threshold Weight, but **greater** than the Biodiversity qualifying weight, write the Biodiversity score for that group in the Score column.
- Sum the scores and record the total at the bottom of the score column as the Total VME Indicator Score.
- **If the Total VME Indicator Score is 3 or greater, the area is considered to have Evidence of a Vulnerable Marine Ecosystem.**
- The Taxonomic groups recorded on this form may not be a complete record of all benthic material present in the tow.

4. Relevant taxonomic groups, weights, and scores

FAO Code	Taxonomic Group	Method of Weighting	Photo taken (y/n)	Observed Weight (kg)	Threshold Weight (kg)	Threshold Score	Biodiversity qualifying weight (kg)	Biodiversity Score	Score
PFR	Porifera *Sponges*			.	50	3	5	1	
GGW	Gorgonacea *Sea fans*			.	15	3	1	1	
AXT	Stylasteridae *Hydrocorals*			.		-	1	1	
CSS	Scleractinia *Stony corals*			.	250	3	5	1	
AQZ	Antipatharia *Black corals*			.	5	3	1	1	
ATX	Actiniaria *Anemones*			.	30	3	5	1	
AJZ	Alcyonacea *Soft corals*			.	60	3	1	1	
NTW	Pennatulacea *Sea pens*			.	-	-	1	1	
CWD	Crinoidea *Sea lillies*			.	-	-	1	1	
BHZ	Brisingida *'Armless' stars*			.	-	-	1	1	
Photo of all benthic bycatch taken (y/n)				Total VME Indicator Score: Sum of scores =					

5. Vessel notification

As soon as the form is completed for any tow provide a copy to the person in charge of the vessel.

Name (if not vessel master)	Received by person in charge (signature)	Date received dd/mm/yy	Time received 24-hr clock
		/ /	:

4. Implications of the proposed encounter protocol for fishers

The analyses presented in this paper show the ranges in the weight of VME indicator taxa weights, and in number of retained VME indicator taxa, per bottom trawl tow in the western SPRFMO Area since 2008. Applying the protocol (see **Error! Reference source not found.**) directly to the 8,850 bottom trawl tows conducted by New Zealand-flagged vessels between 2008 and 2018 suggests that, had the protocol been in place in all areas, the move-on rule would have been triggered 56 times (0.63% of trawls), almost always as a result of individual taxa exceeding their threshold weight(s). This result was not very sensitive to whether fishing occurred on the Louisville (0.69% of tows would have triggered the proposed move-on rule) or in the Tasman Sea (0.62%). The VME taxa most often exceeding their respective threshold weights were Porifera, Scleractinia, Antipatharia and Actinaria (Table B5). The biodiversity component of the proposed protocol would have been triggered only rarely, and only for one tow would the biodiversity component have led to a move-on when no individual threshold weight was exceeded. In future, if New Zealand flagged-vessels conduct the average number (from 2008–18) of trawls in a year, 805 trawls, it can be expected that the move-on rule might be triggered about 5 times each year (Appendix B). Substantial shifts in fishing effort relative to the patterns between 2008 and 2018 may mean more or fewer triggers.

5. Future Work

5.1 Review of VME indicator taxa

The VME indicator taxa included in this analysis were identified by Parker (2008 & 2009) as being vulnerable groups or indicator taxa in the SPRFMO Area based on the following rationale:

- Any taxonomic group specifically listed by FAO as examples of VME inhabitants is included if retained in New Zealand bottom trawl tows and identifiable to group. Some groups mentioned by FAO are not included because they are not encountered in deep-sea fisheries, not retained by fishing gear, or are difficult to identify (e.g. shallow water sponges, xenophyophores).
- Taxonomic groupings that are known to be associated with hard substrata in deep water are included, but only as indicators of suitable habitat.

Parker (2008) noted that data used in the analyses were chosen to try to obtain "adequate sample sizes for categories of the most representative tows". Compared with the thousands of observed tows available from within the EEZ, there were only hundreds of observed tows in the high seas. This led Parker et al to use data from both inside and outside the EEZ, and to use all observed tows over the period 1998 to 2002, providing 1,603 tows in their dataset.

Ten years on we have a much bigger high seas dataset that can be used to predict the catch distributions of VME indicator taxa during fishing in the western SPRFMO Area. To inform the need for a review of the VME indicator taxa for the SPRFMO Area, the bycatch dataset was queried to identify any taxonomic groups specifically listed by the FAO or CCAMLR as examples of VME indicator taxa that were not used in this analysis. The VME indicator taxa identified by the query are those that have been encountered as benthic bycatch by bottom trawl or bottom longline in the western SPRFMO Convention Area in the 2008-2018 fishing period, retained by fishing gear, and are able to be identified onboard by scientific observers. In addition to the ten VME indicator taxa used in the analyses above, the query identified an additional six taxa that could qualify as VME indicator taxa (**Error! Reference source not found.**), conditional on their physical structure within the western parts of the SPRFMO Area.

Table 8: The number of bottom trawl tows including bycatch (n) and the range in bycatch weight (kg) for six potential VME indicator taxa identified in bycatch data from all New Zealand bottom trawls within the western SPRFMO Convention Area between 2008 and 2018.

FAO Code	Taxon	n	Range (kg)
ZOT	Zoantharia (Order)	513	0.1 – 114.0
SSX	Ascidiacea (Class) *Sea squirts*	6	0.1 – 10.0
BZN	Bryozoan (Phylum) *Lace corals*	1	4.0 – 4.0
BRQ	Brachiopoda (Phylum) *Lamp shells*	1	1.0 -1.0
OEQ	Euryalida (Order) *Basket and snake stars*	62	0 – 30.0
CVD	Cidaroida (Order) *Pencil spine urchins*	8	0 – 1.4

An evaluation of these taxa should include a review of existing information, including photographic and video evidence, of their rarity, functional significance, structural complexity and species associations within the SPRFMO Area to determine if they meet the FAO (2009) designated characteristics of VME taxa in the SPRFMO context (

). For each identified VME indicator taxon, data should also be collected to relate their density and distribution on the seafloor to what appears on deck as bycatch, which will aid in the determination of species-specific catchability and an assessment of the appropriateness of the threshold weights selected for each VME indicator taxa.

Table 9: List of characteristics that should be used as criteria in the identification of VMEs as identified by the FAO (2009).

Characteristic	Definition
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.

5.2 Collection of data to verify models

It is important to acknowledge that the move-on rule presented here is intended as a “back stop” (as envisaged by SC-05) to reflect uncertainty in the effectiveness of spatial management measures based on modelled distributions of habitat suitability for VME indicator taxa. Increasing confidence that spatial management measures are effective in preventing significant adverse impacts on VMEs would imply decreasing need for move-on rules as a supporting measure. Ongoing collection of benthic bycatch data by observers (who record all benthic bycatch to the lowest possible taxonomic level for each tow) will contribute to such appraisal of the habitat suitability models. However, the limited spatial extent of fishing relative to the predicted distributions of VME indicator taxa means that more targeted data collection may also be required. Discussions with stakeholders highlighted the need for a more formalized data collection plan to test and validate the habitat suitability models over time. This could potentially include the collection of photographic and acoustic data as well as information on benthic bycatch.

5.3 Review of evidence process

The VME evidence process proposed here would represent a substantial change from the current VME evidence processes employed in Australia and New Zealand bottom trawl fisheries, both in terms of the contribution of threshold weights and the biodiversity component in triggering a move-on event. Although historical catch data can be used to explore the implications of the proposed VME encounter process for both fisheries and conservation values, stakeholder consultation highlighted the need for a review of the evidence process following its implementation to determine how effective it is in meeting its objectives.

5.4 Review of spatial management areas

The encounter protocol proposed here is intended to define when a move-on rule is triggered, either by a single very large catch of a VME indicator taxon above its threshold weight or by the presence of three or more VME indicator taxa above a biodiversity qualifying weight. It is important to note, however, that several other components of a management measure will contribute to the prevention of significant adverse impacts on VMEs and the move-on rule should not be considered in isolation. It is beyond the scope of this paper to consider these in detail, but we identify some other aspects here as context.

The triggering by empirical evidence of an interaction with VME indicator taxa, does not in itself mean the actual presence of a VME. Stakeholder consultation highlighted the need for a formalized process for the review of move-on events, closed areas and VME designation, and related management actions. It is important to highlight the difference between a move-on rule that offers a quick, short-term conservation intervention to limit the immediate impact on areas that may support important VME areas despite the model predictions, and VME designation process, which is a deliberate, long-term assessment, incorporating all available scientific information, followed by appropriate management responses.

Once a move-on rule is triggered and an area closed to fishing, there are (at least) two possible approaches to future treatment of the area. First, the area could be automatically re-opened to fishing unless the purportedly surprising evidence of VMEs (notwithstanding the model predictions) was reviewed and found (by SC) to be genuinely surprising and, in fact, suggested that the VME habitat suitability models were misleading. This broad approach is currently used by both Australia and New Zealand for their SPRFMO bottom fisheries, although the implementation details differ. Alternatively, an area could remain closed until such time as a review concluded that the area did not contain unexpected areas of VMEs. We think that, because of the presumption of continuing closure, this approach would require SC to recommend re-opening particular areas to the Commission. This broad approach is applied by CCAMLR after move-ons are triggered. Choosing between these approaches is not a science issue, but SC-06 might like to discuss the practicality and operational feasibility of different approaches.

However, responses to individual move-on events are handled, we suggest that SC reviews new information on the bycatch of benthic fauna each year. This will give the SC a qualitative “finger on the pulse” regarding potential impacts on VMEs, but also provide information on the extent to which bycatch is consistent with model predictions. If the nature and extent of benthic bycatch and VME indicator taxa was largely consistent with the predictions of the habitat suitability models, this lends support to the idea that the design of the spatial management areas is preventing SAIs on VMEs. Conversely, if benthic bycatch and VME indicator taxa are frequently inconsistent with the predictions of the habitat suitability models, then this provides an impetus to update the models that underpin the spatial management regime quite urgently. Even without such strong evidence that the habitat suitability models may be misleading, we think it would be good practice to review the models periodically to include new data, test sensitivities, and, if there are significant conservation and/or utilisation gains to be had, to fine-tune the spatial management areas.

6. Recommendations

We propose that the Scientific Committee:

- **Note** that a pragmatic, data-informed approach has been used to develop thresholds to support a proposed move-on rule for bottom trawls that can work as a "back stop" together with spatial management areas to prevent SAIs on VMEs;
- **Note** that insufficient data on VME distribution and density and on trawl catchability exist to apply more sophisticated methods;
- **Note** that insufficient data from bottom longline fisheries exists to develop a data-informed move-on rule for that method;
- **Note** that it is proposed that a move-on rule for bottom trawl would include two thresholds, exceeding either of which would require the vessel to move away from the location:
    - a catch of any one of the six most commonly-caught VME taxa over a taxon-specific threshold weight (based on the 99th percentile of the distribution of historical positive catch weights); OR
    - a catch of three or more VME taxa over a taxon-specific qualifying weight (based on the 80th percentile of the distribution of historical positive catch weights);
- **Agree** that the scientific methods used to develop thresholds for the proposed move-on rule for bottom trawl to work as a "back stop" together with spatial management areas to prevent SAIs on VMEs are appropriate;
- **Agree** that benthic bycatch data and all move-on events should be reviewed annually by SC;
- **Agree** that models underpinning spatial management approaches should be reviewed periodically (perhaps every 5 years) or when evidence suggests those models are misleading, and to include these in suggested SC workplans for consideration by the Commission.

7. Acknowledgements

This paper has been greatly improved by several discussions and the invaluable input of the scientists, experts and officials who attended a number of working group meetings to guide the development of the VME encounter protocol.

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Appendix A: Benthic taxonomic code used by scientific observers

Table A1: Assignment of benthic bycatch taxa to higher order VME groups, where NZ Code is the benthic taxonomic code used by scientific observers to report benthic bycatch in the SPRFMO Convention Area, and the FAO Code is the corresponding FAO 3-alpha code.

NZ Code	Common Name	Phylum	Class	Order	Family	Genus	Species	VME Group	FAO Code
BOC	Deepsea anemones	Cnidaria	Anthozoa	Actiniaria	Actiniidae	*Bolocera*		Stylasteridae	**ATX**
ACS	Smooth deepsea anemones	Cnidaria	Anthozoa	Actiniaria	Actinostolidae			Stylasteridae	**ATX**
HMT	Warty deepsea anemones	Cnidaria	Anthozoa	Actiniaria	Hormathiidae			Stylasteridae	**ATX**
LIP	Deepsea anemones	Cnidaria	Anthozoa	Actiniaria	Liponematidae	*Liponema*		Stylasteridae	**ATX**
ATR	Sea anemones	Cnidaria	Anthozoa	Actiniaria				Stylasteridae	**ATX**
ARO	Gigantic coral	Cnidaria	Anthozoa	Alcyonacea	Alcyoniidae	*Anthomastus*	*robustum*	Alcyonacea	**AJZ**
CHR	Golden corals	Cnidaria	Anthozoa	Alcyonacea	Chrysogorgiidae	*Chrysogorgia*		Alcyonacea	**AJZ**
IRI	Iridescent coral	Cnidaria	Anthozoa	Alcyonacea	Chrysogorgiidae	*Iridogorgia*		Alcyonacea	**AJZ**
MTL	Metallic coral	Cnidaria	Anthozoa	Alcyonacea	Chrysogorgiidae	*Metallogorgia*		Alcyonacea	**AJZ**
CLL	Precious corals	Cnidaria	Anthozoa	Alcyonacea	Coralliidae	*Corallium*		Alcyonacea	**AJZ**
BOO	Branching bamboo coral	Cnidaria	Anthozoa	Alcyonacea	Isididae	*Keratoisis*		Alcyonacea	**AJZ**
LLE	Bamboo coral	Cnidaria	Anthozoa	Alcyonacea	Isididae	*Lepidsis*		Alcyonacea	**AJZ**
ISI	Bamboo corals	Cnidaria	Anthozoa	Alcyonacea	Isididae			Alcyonacea	**AJZ**
PAB	Bubblegum coral	Cnidaria	Anthozoa	Alcyonacea	Paragorgiidae	*Paragorgia*	*arborea*	Alcyonacea	**AJZ**
PLE	Plexaurid sea fans	Cnidaria	Anthozoa	Alcyonacea	Plexauridae			Alcyonacea	**AJZ**
CTP	Calyptrophora spp.	Cnidaria	Anthozoa	Alcyonacea	Primnoidae	*Calyptrophora*		Alcyonacea	**AJZ**
PMN	Primnoa sea fans	Cnidaria	Anthozoa	Alcyonacea	Primnoidae	*Primnoa*		Alcyonacea	**AJZ**
THO	Bottlebrush coral	Cnidaria	Anthozoa	Alcyonacea	Primnoidae	*Thouarella*		Alcyonacea	**AJZ**
PRI	Primnoid sea fans	Cnidaria	Anthozoa	Alcyonacea	Primnoidae			Alcyonacea	**AJZ**
ATP	Antipathes spp.	Cnidaria	Anthozoa	Antipatharia	Antipathidae	*Antipathes*		Antipatharia	**AQZ**
LSE	Black coral	Cnidaria	Anthozoa	Antipatharia	Leiopathidae	*Leiopathes*	*secunda*	Antipatharia	**AQZ**
LEI	Leiopathes spp.	Cnidaria	Anthozoa	Antipatharia	Leiopathidae	*Leiopathes*		Antipatharia	**AQZ**
BTP	Bathypathes spp.	Cnidaria	Anthozoa	Antipatharia	Schizopathidae	*Bathypathes*		Antipatharia	**AQZ**
DEN	Dendrobathypathes spp.	Cnidaria	Anthozoa	Antipatharia	Schizopathidae	*Dendrobathypathes*		Antipatharia	**AQZ**
DDP	Black coral	Cnidaria	Anthozoa	Antipatharia	Schizopathidae	*Dendropathes*		Antipatharia	**AQZ**
LIL	Lillipathes spp.	Cnidaria	Anthozoa	Antipatharia	Schizopathidae	*Lillipathes*		Antipatharia	**AQZ**
PTP	Parantipathes spp.	Cnidaria	Anthozoa	Antipatharia	Schizopathidae	*Parantipathes*		Antipatharia	**AQZ**

NZ Code	Common Name	Phylum	Class	Order	Family	Genus	Species	VME Group	FAO Code
SLP	Black coral	Cnidaria	Anthozoa	Antipatharia	Stylopathidae	*Stylopathes*		Antipatharia	**AQZ**
TDP	Black coral	Cnidaria	Anthozoa	Antipatharia	Stylopathidae	*Triadopathes*		Antipatharia	**AQZ**
COB	Black corals	Cnidaria	Anthozoa	Antipatharia				Antipatharia	**AQZ**
GOC	Gorgonian coral	Cnidaria	Anthozoa	Gongonacea				Gorgonacea	**GGW**
FQU	Rope-like sea pen	Cnidaria	Anthozoa	Pennatulacea	Funiculinidae	*Funiculina*	*quadrangularis*	Pennatulacea	**NTW**
GYS	Siboga sea pen	Cnidaria	Anthozoa	Pennatulacea	Pennatulidae	*Gyrophyllum*	*sibogae*	Pennatulacea	**NTW**
PNN	Purple sea pen	Cnidaria	Anthozoa	Pennatulacea	Pennatulidae	*Pennatula*		Pennatulacea	**NTW**
DGR	Two-lined sea pen	Cnidaria	Anthozoa	Pennatulacea	Protoptilidae	*Distichoptilum*	*gracile*	Pennatulacea	**NTW**
ALF	Long-leaf sea pen	Cnidaria	Anthozoa	Pennatulacea	Virgulariidae	*Acanthoptilum*	*longifolium*	Pennatulacea	**NTW**
PTU	Sea pens	Cnidaria	Anthozoa	Pennatulacea				Pennatulacea	**NTW**
SPN	Sea pen	Cnidaria	Anthozoa	Pennatulacea				Pennatulacea	**NTW**
CAY	Carnation cup coral	Cnidaria	Anthozoa	Scleractinia	Caryophylliidae	*Caryophyllia*		Scleractinia	**CSS**
DDI	Crested cup coral	Cnidaria	Anthozoa	Scleractinia	Caryophylliidae	*Desmophyllum*	*dianthus*	Scleractinia	**CSS**
GDU	Bushy hard coral	Cnidaria	Anthozoa	Scleractinia	Caryophylliidae	*Goniocorella*	*dumosa*	Scleractinia	**CSS**
SVA	Deepwater branching coral	Cnidaria	Anthozoa	Scleractinia	Caryophylliidae	*Solenosmilia*	*variabilis*	Scleractinia	**CSS**
STP	Solitary bowl coral	Cnidaria	Anthozoa	Scleractinia	Caryophylliidae	*Stepanocyathus*	*platypus*	Scleractinia	**CSS**
ERO	Deepwater branching coral	Cnidaria	Anthozoa	Scleractinia	Dendrophylliidae	*Enallopsammia*	*rostrata*	Scleractinia	**CSS**
CBR	Stony branching corals	Cnidaria	Anthozoa	Scleractinia	Dendrophylliidae, Oculinidae, Caryophylliidae			Scleractinia	**CSS**
COF	Flabellum cup corals	Cnidaria	Anthozoa	Scleractinia	Flabellidae	*Flabellum*		Scleractinia	**CSS**
CUP	Stony cup corals	Cnidaria	Anthozoa	Scleractinia	Flabellidae, Fungiacyathidae, Caryophyllidae			Scleractinia	**CSS**
MOC	Madrepora coral	Cnidaria	Anthozoa	Scleractinia	Oculinidae	*Madrepora*	*oculata*	Scleractinia	**CSS**
OVI	Deepwater branching coral	Cnidaria	Anthozoa	Scleractinia	Oculinidae	*Oculina*	*virgosa*	Scleractinia	**CSS**
COU	Coral (Unidentified)	Cnidaria	Anthozoa	Scleractinia	Stylasteridae			Scleractinia	**CSS**
SIA	Stony corals	Cnidaria	Anthozoa	Scleractinia				Scleractinia	**CSS**
CRE	White hydrocoral	Cnidaria	Hydrozoa	Anthoathecata	Stylasteridae	*Calyptopora*	*reticulata*	Stylasteridae	**AXT**
ERR	Red hydrocorals	Cnidaria	Hydrozoa	Anthoathecata	Stylasteridae	*Errina*		Stylasteridae	**AXT**
LPT	Spiny white hydrocorals	Cnidaria	Hydrozoa	Anthoathecata	Stylasteridae	*Lipidotheca*		Stylasteridae	**AXT**
COR	Hydrocorals	Cnidaria	Hydrozoa	Anthoathecata	Stylasteridae			Stylasteridae	**AXT**
BRG	Armless stars	Echinodermata	Asteroidea	Brisingida	Brisingidae, Hymenodiscidae,			Brisingida	**BHZ**

NZ Code	Common Name	Phylum	Class	Order	Family	Genus	Species	VME Group	FAO Code
					Novodiniidae, Freyellidae				
CMT	Feather stars	Echinodermata	Crinoidea	Comatulida				Crinoidea	**CWD**
CRN	Sea lilies	Echinodermata	Crinoidea	Isocrinida, Millericrinida, Cyrtocrinida				Crinoidea	**CWD**
CRI	Sea lilies	Echinodermata	Crinoidea					Crinoidea	**CWD**
CLS	Calcareous sponges	Porifera	Calcerea					Porifera	**PFR**
PHW	Rubber sponge	Porifera	Demospongiae	Dictyoceratida	Irciniidae	*Psammacinia*		Porifera	**PFR**
PHB	Grey fibrous massive sponge	Porifera	Demospongiae	Poecilosclerida	Hymedesmiidae	*Phorbas*		Porifera	**PFR**
RHA	Pink ice egg sponge	Porifera	Demospongiae	Tetractinellida	Ancorinidae	*Rhabdastrella*		Porifera	**PFR**
SLT	Orange fat finger sponge	Porifera	Demospongiae	Tetractinellida	Ancorinidae	*Stelletta*		Porifera	**PFR**
CFU	Smooth white cup sponge	Porifera	Demospongiae	Tetractinellida	Corallistidae	*Corallistes*	*fulvodesmus*	Porifera	**PFR**
GVE	Ostrich egg sponge	Porifera	Demospongiae	Tetractinellida	Geodiidae	*Geodia*	*vestigifera*	Porifera	**PFR**
PAZ	Rocky dumpling sponge	Porifera	Demospongiae	Tetractinellida	Geodiidae	*Pachymatisma*		Porifera	**PFR**
APU	Pimpled ear sponge	Porifera	Demospongiae	Tetractinellida	Scleritodermidae	*Aciculites*	*pulchra*	Porifera	**PFR**
TTL	Bristle ball sponge	Porifera	Demospongiae	Tetractinellida	Tetillidae	*Tetilla*	*australe*	Porifera	**PFR**
TLD	Furry oval sponge	Porifera	Demospongiae	Tetractinellida	Tetillidae	*Tetilla*	*leptoderma*	Porifera	**PFR**
THN	Yoyo sponge	Porifera	Demospongiae	Tetractinellida	Theneidae	*Thenea*	*novaezelandiae*	Porifera	**PFR**
PLN	Fibreglass cup sponge	Porifera	Demospongiae	Tetractinellida	Vulcanellidae	*Poecillastra*	*laminaris*	Porifera	**PFR**
DSO	Demosponges	Porifera	Demospongiae					Porifera	**PFR**
ERE	Basket-weave horn sponge	Porifera	Hexactinellida	Lyssacinosida	Euplectellidae	*Euplectella*	*regalis*	Porifera	**PFR**
HYA	Floppy tubular sponge	Porifera	Hexactinellida	Lyssacinosida	Rossellidae	*Hyalascus*		Porifera	**PFR**
FAR	Lacey honeycomb sponges	Porifera	Hexactinellida	Sceptrulophora	Farreidae	*Farrea*		Porifera	**PFR**
GLS	Glass sponges	Porifera	Hexactinellida					Porifera	**PFR**
ONG	Sponges	Porifera						Porifera	**PFR**

Appendix B: Sensitivity analysis of management implications

Analyses were conducted to explore the sensitivity of management implications to threshold and biodiversity weights using the ranges in retained VME indicator taxa weights and the number of retained VME indicator taxa per bottom trawl tow in the western SPRFMO Convention Area since 2008. Applying the threshold weights presented in Table B1 and the biodiversity weights presented in Table B2 to the 8,850 bottom trawl tows, Table B3 reports the number of times the move-on rule would have been triggered for each pairwise combination of the threshold and biodiversity weights.

Table B1: Taxon-specific threshold weights based on the 0.95, 0.97, 0.98 and 0.99 percentiles of historical catch weight distributions.

		Threshold weight (kg)			
FAO Code	Taxon	0.95	0.97	0.98	0.99
PFR	Porifera (Phylum) *Sponges*	15	20	25	50
GGW	Gorgonacea (Order) *Sea fans*	2	5	5	15
CSS	Scleractinia (Order) *Stony corals*	20	40	60	250
AQZ	Antipatharia (Order) *Black corals*	5	5	5	5
ATX	Actiniaria (Order) *Anemones*	20	25	30	30
AJZ	Alcyonacea (Order) *Soft corals*	15	25	30	30

Table B2: Taxon-specific biodiversity weights based on the 0.8, 0.9 percentiles of historical catch weight distributions.

		Biodiversity weight (kg)	
FAO Code	Taxon	0.8	0.9
PFR	Porifera (Phylum) *Sponges*	5	10
GGW	Gorgonacea (Order) *Sea fans*	1	1
AXT	Stylasteridae (Subclass) *Hydrocorals*	1	2
CSS	Scleractinia (Order) *Stony corals*	5	10
AQZ	Antipatharia (Order) *Black corals*	1	2
ATX	Actiniaria (Order) *Anemones*	5	10
AJZ	Alcyonacea (Order) *Soft corals*	1	2
NTW	Pennatulacea (Order) *Sea pens*	1	1
CWD	Crinoidea (Class) *Sea lillies*	1	1
BHZ	Brisingida (Order) *'Armless' stars*	1	2

Table B3: The number of times (and percent of total tows) the move-on rule would have been triggered for each pairwise combination of the threshold and biodiversity weights presented in Tables B1 and B2 when applied to VME bycatch data from the 8,850 historic trawls.

	Threshold weight (kg)			
Biodiversity percentile	**0.95**	**0.97**	**0.98**	**0.99**
0.8	189 (2.14%)	114 (1.29%)	86 (0.97%)	**56 (0.63%)**
0.9	189 (2.14%)	113 (1.28%)	85 (0.96%)	55 (0.62%)

Table B4: The number of times the move-on rule would have been triggered by either the biodiversity weight or the threshold weight when applied to VME bycatch data from the 8,850 historic trawls for each pairwise combination of the threshold and biodiversity weights presented in Tables B1 and B2. Cell values indicate: number of times triggered by biodiversity weight / number of times triggered by threshold weight (number of times triggered by both biodiversity and threshold weights).

	Threshold weight (kg)			
Biodiversity percentile	**0.95**	**0.97**	**0.98**	**0.99**
0.8	5/189 (5)	5/113 (4)	5/85 (4)	5/55 (4)
0.9	2/189 (2)	2/113 (2)	2/85 (2)	2/55 (2)

Table B5: The number of times each of the VME indicator taxa triggered the Threshold Weight or were one of three taxa triggering the Biodiversity component of the proposed move-on rule (as presented in Figure 5) when applied to VME bycatch data from the 8,850 historic trawls. Of the 55 move-on events triggered by VME taxa exceeding the Threshold weight, four would have been triggered by more than one VME indicator taxa exceeding the Threshold weight.

FAO Code	Taxon	Number of times Threshold weight triggered	Number of times contributing to Biodiversity trigger
PFR	Porifera (Phylum) *Sponges*	9	4
GGW	Gorgonacea (Order) *Sea fans*	3	0
AXT	Stylasteridae (Subclass) *Hydrocorals*	0	1
CSS	Scleractinia (Order) *Stony corals*	13	4
AQZ	Antipatharia (Order) *Black corals*	12	5
ATX	Actiniaria (Order) *Anemones*	18	0
AJZ	Alcyonacea (Order) *Soft corals*	4	5
NTW	Pennatulacea (Order) *Sea pens*	0	0
CWD	Crinoidea (Class) *Sea lillies*	0	0
BHZ	Brisingida (Order) *'Armless' stars*	0	1