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A Review of VME Indicator Taxa for SPRFMO

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A review of VME indicator taxa for the SPRFMO Convention Area

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1 Purpose

The purpose of this paper is to review the lists of VME indicator taxa used by different RFMOs in terms of the relationship of their morphological, ecological, and life history characteristics within the SPRFMO Convention Area to the FAO criteria for VME indicator taxa, and to identify those taxa that are suitable for use by SPRFMO as VME indicator taxa. Where necessary, we also calculate single-taxon and biodiversity weight thresholds that could be included in an update to the encounter protocol included in CMM 03-2019.

2 Introduction

Based on growing concern about the risks to the marine biodiversity of vulnerable marine ecosystems related to fishing activities[1], the 2006 United Nations General Assembly (UNGA) Resolution 61/105 called upon regional fisheries management organizations (RFMOs; including general fisheries management organizations such as CCAMLR) to develop and adopt binding conservation management measures requiring their members to protect vulnerable marine ecosystems (VMEs) from significant adverse impacts of bottom fishing (UNGA 2007). To support the implementation of the resolution, the United Nations Food and Agriculture Organization (FAO) developed and published criteria for defining VMEs, which included: (i) uniqueness or rarity of species or habitats; (ii) functional significance; (iii) fragility; (iv) life-history traits that limit the probability of recovery; and (iv) structural complexity (FAO 2009). The guidelines also provided examples of taxa indicative of VMEs, including: (a) cold-water corals and hydroids (e.g., stony corals, alcyonaceans and gorgonians, black corals and hydrocorals); (b) sponge-dominated communities; (c) communities composed of emergent fauna where large sessile protozoans and invertebrates form an important structural component; and (d) seep and vent communities comprised of invertebrate and microbial species found nowhere else. Although many RFMOs have used the guidelines to develop lists of VME indicator taxa (i.e., those taxa that suggest the presence of a VME) for inclusion in bottom fishing-VME encounter protocols, there are inconsistencies between RFMOs in the number and identity of taxa identified as VME indicators (Table 1). These inconsistencies are partly because of regional differences in patterns of deep-sea biodiversity (e.g., Costello et al. 2017, Watling et al 2013) and species morphology (e.g., Wheeler et al 2007; De Clippele et al. 2018), with individual RFMOs tailoring lists of VME indicator taxa to the specific habitats, benthic assemblages and the type of fisheries they manage (e.g., bottom trawl versus bottom long-line fisheries). However, inconsistencies also arise because for some RFMOs there is a lack of available data of sufficient quality and extent to assess candidate VME indicator taxa against the FAO criteria. Consequently, as new data becomes available it is important that lists of VME taxa are reviewed to ensure they include all relevant taxa.

Parker et al. (2009) identified VME indicator taxa for the South Pacific Regional Fisheries Management Organisation (SPRFMO) Convention Area as being any taxonomic group that met the FAO's criteria for defining VMEs, while also meeting two additional criteria: (1) taxa had to have previously been

[1] Report of the UN Secretary General to the 59th session of the General Assembly, A/59/298.

encountered in deep-sea fisheries and retained as bycatch; and (2) taxa had to be readily identifiable by scientific observers on board fishing vessels without the aid of complex morphological characters (such as calculating the number of polyps cm^{-1} or ratio of mertistics). Applying these criteria, Parker et al. (2009) identified 10 taxonomic groups (designated variously at the level of phylum, class, order or family) that could be used as an indicator of a VME in the South Pacific Ocean (Table 2). The ten taxa did not include some groups explicitly mentioned by the FAO guidelines as examples of VMEs because they had not been previously encountered as bycatch in the area (e.g., xenophyophores), were poorly retained by fishing gear (e.g. bryzoans), or were deemed difficult to identify in the field by observers (e.g. hydroids).

The ten VME indicator taxa identified by Parker et al. (2009) were subsequently incorporated into a bottom fishing-VME encounter protocol (a 'move-on rule') for New Zealand vessels (SPRFMO CMM-2.03), and most recently for vessels of all member countries within the SPRFMO Convention Area (SPRFMO CMM03-2019). Under the latter protocol, a single bottom trawl catch which either: a) exceed taxon-specific weight threshold limits for a single taxon (sponges 50 kg, stony corals 250 kg, black corals 5 kg, true soft corals 60 kg, seafans 15 kg or anemones 40 kg), or (b) contain three of more VME indicator taxa each of which exceeds a lesser taxon-specific minimum weight threshold (ranging between 1-5 kg) triggers the encounter protocol. These thresholds were developed using a data-informed approach that examined taxon-specific cumulative catch rate curves that distinguished between the initial part of the curve associated with linear increase, and the final part of the curve associated with asymptotic decrease in slope (Fig.1). The transition between these parts of the curve was taken as an ecologically relevant reference point, with weight thresholds derived from the linear asymptotic part to the right, and multiple-taxon (biodiversity) thresholds from the linear part to the left (Cryer et al 2018). The thresholds selected using this approach were developed as a "backstop" to spatial management measures based on model predictions of VME taxon distributions, allowing a rapid response to benthic bycatch events (e.g., via a move-on rule) in cases where high VME indicator bycatch suggests that the predicted distributions of VME taxa used to underpin the spatial management measures were misleading (following guidance in the SC-05 report[2]). Once an encounter protocol has been triggered, flagged vessels of all SPRFMO members and cooperating non-contracting parties are required to cease bottom fishing immediately within a one nautical mile buffer around the trawl tow until the SPRFMO Scientific Committee has reviewed the encounter and the SPRFMO Commission has determined that bottom fishing in the area can resume (SPRFMO CMM03-2019). The success of the encounter protocol in determining the potential presence of a VME is thus determined by the suite of taxa identified as VME indicators and their associated threshold limits.

[2] SC-05 **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… involving weights of bycatch of benthic fauna that would indicate the models used to predict the distribution of VME taxa are misleading.

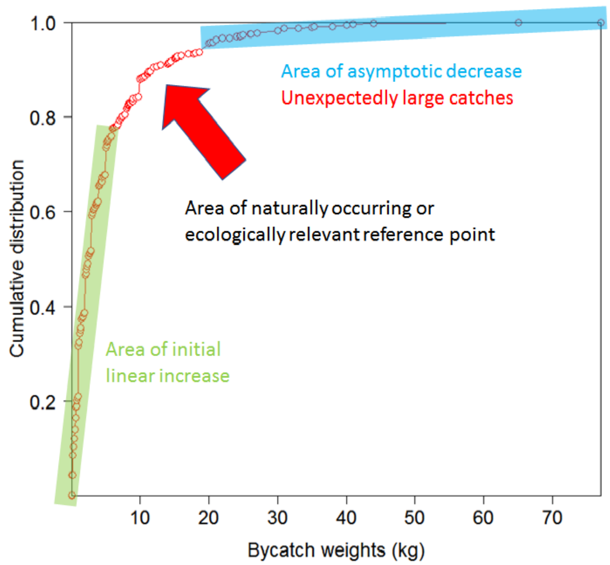


Fig.1 | Cumulative distribution curve for the weight of Actiniaria bycatch from the 2008-19 New Zealand bottom trawl fishery in the SPRFMO Convention Area, where the initial part of the curve associated with linear increase is distinguished from the final part of the curve associated with asymptotic decrease in slope. The area distinguishing between these two parts of the curve potentially indicates a naturally occurring or ecologically relevant reference point. Thresholds indicating unexpectedly large catches that indicate the models used to predict the distribution of VME indicator taxa are misleading should ideally fall to the right of such points, whereas "biodiversity weights" indicating increasing numbers of taxa in a single tow at weights below the threshold triggers indicating unexpectedly large catches should occur to the left.

In the ten years since Parker et al. (2009) identified the current suite of VME indicator taxa a larger dataset of bycatch observations has been generated, comprising data from thousands of individual bottom trawl tows and benthic bycatch records from within the western SPRFMO Convention Area. These new data represent a substantial increase in both the quantity and quality of data available, as Parker et al (2009) had access to data from only several hundreds of tows and species identification by scientific observers has improved significantly with the publication of field guides.

Using the new data now available, we compile a list of all the VME indicator taxa identified by other RFMOs at taxonomic levels that are commensurate with identification by scientific observers on bottom trawl vessels within the SPRFMO convention area. We then review these taxa in terms of their morphological, ecological, and life history characteristics in relation to the FAO criteria for VME indicator taxa. Finally, we identify a subset of VME indicator taxa suitable for use within the SPRFMO Convention Area and calculate single-taxon and biodiversity catch-weight thresholds that can be included in an updated encounter protocol.

3 Methods

We reviewed applicable Conservation Management Measures from six RFMOs: (Northwest Atlantic Fisheries Organization; North East Atlantic Fisheries Commission; South East Atlantic Fisheries Organization; North Pacific Fisheries Commission; South Pacific Regional Fisheries Management Organization; Southern Indian Ocean Fisheries Management Organization); and the Convention for the Conservation of Antarctic Marine Living Resources, to compile a comprehensive list of candidate taxa. To enable direct comparison, we aggregated individual taxa to higher-level taxonomic groups (typically Class and Order), commensurate with the taxonomic level scientific observers on bottom trawl vessels in the SPRFMO Convention Area can consistently identify benthic bycatch to (Table 1).

For each taxa identified in Table 1 (with the exception of Pectinidae, for which a single endemic species is included as an indicator in CCAMLR), we reviewed the relationship of their morphological, ecological and life history characteristics within the SPRFMO Convention Area to the FAO criteria for VMEs. The FAO guidelines list five characteristics of taxa, assemblages, habitats or ecosystems useful in determining VME status:

i. 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.

ii. 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.

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

iv. 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.

v. 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.

Table 1: VME indicator taxa adopted by Regional Fisheries Management Organizations in different oceans and implemented within their respective encounter protocols as of 2019. Taxa are aggregated into higher-order taxonomic groups (typically Class and Order) to allow direct comparisons between RFMOs. NOTE: Although taxonomists consider Alcyonacea to include gorgonians, they are separated here because of the contrast in structure-forming characteristics.

Phylum	Lower taxonomic group	NW Atlantic[1]	NE Atlantic[2]	SE Atlantic[3]	Southern Indian[4]	North Pacific[5]	South Pacific[6]	Southern Ocean[7]
Porifera		X	X	X	X		X	X
Cnidaria	Alcyonacea (Soft corals) - Order		X	X	X	X	X	X
	Gorgonian Alcyonacea -Tree-like forms, sea fans, sea whips, bottlebrush	X	X	X	X	X	X	X
	Anthoathecatae (Hydrocorals) - Order			X	X		X	
	Scleractinia (Stony corals) - Order	X	X	X	X	X	X	X
	Antipatharia (Black corals) - Order		X	X	X	X	X	X
	Actiniaria (Anemones) - Order				X		X	X
	Pennatulacea (Sea pens) - Order	X	X	X	X		X	X
	Zoantharia (Zoanthids) - Order			X	X			X
	Ceriantharia (Tube-dwelling anemones) - Subclass	X	X					
	Hydrozoa (Hydroids) - Class							X
Echinodermata	Brisingida ('Armless' stars) - Order						X	
	Euryalida (Basket and snake stars) - Order			X	X			X
	Crinoidea (Sea lillies) - Class	X	X	X	X		X	X
	Cidaroida (Pencil spine urchins) - Order				X			X
Bryozoa		X	X	X	X			X
Brachiopoda					X			X
Foraminifera			X					
Retaria	Xenophyophorea (Xenophyophores) - Class		X		X			X
Chordata	Ascidiacea (Sea squirts) - Class	X		X	X			X
Annelida	Serpulidae (Serpulid tube worms) - Family			X	X			X
Arthropoda	Bathylasmatidae (Goose and acorn barnacles) - Family				X			X
Hemichordata	Graptolithoidea (Acorn worms) - Class				X			X
Mollusca	Pectinidae - (Scallops) - Family							X

[1]NAFO CEM 2019; [2]NEAFC Rec. 19:2014 (amended 09:2015 and 10:2018); [3]SEAFO CM 30/15; [4]SIOFA SC-4 Report (2019); [5]NPFC CMM 2018-05; NPFC CMM 2017-06; [6]SPRFMO CMM 3-2019; [7]CCAMLR CM 22-07(2013)

Because the list of VME indicator taxa compiled in Table 1 is necessarily defined at higher-level taxonomic groupings such as class and order, summarizing life-history characteristics of species-level attributes is problematic, especially when the full range of species in question is not known, and the life-histories of the known species are not fully resolved. Because there are few studies of the life-history characteristics of deep-sea invertebrates in the SPRFMO Convention Area, it was necessary to extrapolate life-history characteristics derived from members of each taxon from deep-sea environments in other parts of the world, even then, essential characteristics are not known for many groups. Therefore, we used a combination of peer-reviewed literature focused on the SPRFMO Convention Area, peer-reviewed scientific literature external to the SPRFMO Convention Area, and expert opinion.

For each taxon, we scored the vulnerability to deepsea bottom fishing within the evaluated portion of the SPRFMO Convention Area relative to FAO VME criteria as low, medium or high using the scoring rules presented in Table 2. Although the FAO guidelines do not explicitly state whether one or all of the criteria need to be met to qualify as a VME indicator, we consider scoring highly against any of the five criteria sufficient for a taxa to be designated as a VME indicator. The following justifications were used to develop the scoring rules:

- *i.* *Rarity:* An organism is considered rare if its loss in one area could not be compensated for in other areas (Ardron et al 2014). Therefore, taxa with widespread distributions within the SPRFMO Convention Area were scored as low, those that are moderately distributed were scored as medium, and those that only occur in a few discrete areas were scored as high.
- *ii.* *Functional significance of the habitat:* An organism that contributes to the survival of other species by creating nursery habitats, filtering water or recycling nutrients are considered to be functionally significant (Morato et al. 2018). Therefore, taxa that likely make only a limited contribution to habitat provisioning or higher ecosystem functional roles scored low, those with a moderate contribution scored medium, and those that made an obvious and demonstratable contribution scored high.
- *iii.* *Fragility:* An organism's susceptibility to damage or dislodgement by the various components of bottom trawl fishing gear determines their fragility (Morato et al. 2018). Therefore, taxa that are flexible and strong were scored low, those that are somewhat flexible with tough integuments were scored medium, and those that are brittle, delicate or have 3-dimensional structures making them susceptible to entanglement in bottom trawl gear were scored high.
- *iv.* *Recovery:* Longevity is indicative of potential recovery time in the event of a disturbance, and organisms that live for less than 10 years are expected to have higher potential rates of recovery than those that live for more than 30 years (Hanson et al 2013). Taxa with the former recovery potential were scored low and those with the latter recovery potential were scored high, with taxa judged to have recovery rates in between scored medium. Although additional metrics of recovery are listed by the FAO (slow growth rates; late age of maturity; low or unpredictable recruitment), our current understanding of the life-history traits for benthic taxa within the deep sea make these criteria more difficult to evaluate across the broad range of taxa included in this review.
- *v.* *Structural complexity*: An important component of structural complexity is size, with larger individuals considered to be structure forming. Tissot et al. (2006) considered invertebrates > 50 cm in height as structure forming. Therefore, taxa that do not exceed 50 cm in height were

scored as low, and those that exceed 50 cm in height were scored as high. A medium score was given to taxa that has some individuals or species that exceed 50 cm in size. These criteria are similar to those used by Parker and Bowden 2010 to score structural complexity of VME taxa for the CCAMLR region.

Table 2: Rules used to score each of five FAO criteria for identifying VME indicator taxa against vulnerability to deepsea bottom fishing within the evaluated portion of the SPRFMO Convention Area.

FAO Criteria	**Low**	**Medium**	**High**
Rarity	Loss of the taxon in one area or ecosystem would be compensated for by its presence in many other similar areas or ecosystems	Loss of the taxon in one area or ecosystem would be compensated for by its presence in a small number of similar areas or ecosystems	Loss of the taxon in one area or ecosystem would not be compensated for in any other areas or ecosystems
Functional significance	Has limited contribution to habitat provisioning, nutrient cycling or water filtration	Has moderate contribution to habitat provisioning, nutrient cycling or water filtration	Provides habitat for other species, and/or has a role in nutrient cycling and water filtration
Fragility	Flexible, robust or strong form	Somewhat flexible or brittle form	Complex 3-d structure of brittle material
Recovery	Longevity < 10 years	Longevity 10-30 years	Longevity > 30 years
Structural complexity	No individuals exceed 50 cm in height	Few individuals may exceed 50 cm	Many individuals exceed 50 cm

Because some taxa designated as VME indicators are likely to have low retention by bottom trawl gear, or are difficult to identify by scientific observers on fishing vessels, we evaluated two additional criteria related to the suitability of VME taxa as indicators: (1) the presence of the taxa in historic bycatch records (indicator taxa need to be able to be sampled by bottom trawl gear to be effective indicators); and (2) the likelihood that taxa could be reliably identified by observers in the field. To assess these criteria, we extracted data from the New Zealand Centralized Observer Database (*cod*, accessed 14 May 2019). Data were collected by scientific observers (the New Zealand bottom trawl fleet has 100% observer coverage in the SPRFMO Convention Area) and included 9,802 New Zealand bottom trawl tows (including mid-water trawls) conducted in the Convention Area over the period 2008–2019 (although 2019 data was for a partial fishing year and only included data from 1–12 January). These data consisted of tow-by-tow observer data with one record per benthic taxon encountered on each tow, and included trip number, station number, event number, target species, benthic bycatch code, common name, bycatch weight, method of weight analysis, and observer comments. For each tow, we used taxonomic designations from the World Register of Marine Species (WoRMS, RRID:SCR_013312) to assign relevant benthic bycatch to the groupings of VME indicator taxa presented in Table 2.

We evaluated bycatch of taxa by identifying taxa suitable as indicators as those that have previously been observed as bycatch within New Zealand bottom trawls conducted within the SPRFMO Convention Area. For each VME indicator taxon, we also calculated the number of times observer codes in the *cod* database disagreed with coral codes assigned by taxonomic experts. This provides a quantitative measure of the accuracy of taxonomic identification by observers in the field. Taxa were scored low if > 5% of records within the database were misidentification at the taxonomic level at which the VME indicator was designated (e.g., at the level of order for Scleractinia), medium for 1 – 5% misclassifications, and high for < 1% misclassifications (Table 3). We considered that good indicators should score at least medium against the identification criterion.

Table 3: Rules used to score *the identification* criteria for identifying VME indicator taxa.

Additional Criteria	**Low**	**Medium**	**High**
Identification	> 5% misidentifications in *cod* database	1-5% misidentifications in *cod* database	<1% misidentifications in *cod* database

For each taxon identified as a VME indicator we constructed indicator-specific cumulative distribution curves for catch weights from all bottom trawl tows for which the indicator was reported as bycatch, and then calculated weight and biodiversity thresholds as the 99th and 80th percentiles, respectively. These percentiles were chosen for consistency with the approach used to select the encounter thresholds currently included in SPRFMO CMM03-2019, as outlined in SC6-DW09[3] (a review of the percentiles used to select thresholds was beyond the scope of this study).

Acknowledging that extensive lists of VME indicator taxa can be burdensome for observers to utilise as part of an encounter protocol in the field, we evaluated the optimal number of indicators to include in a streamlined encounter protocol without compromising the ability to detect the presence of potential VMEs. We applied a revised encounter protocol incorporating the VME indicator taxa and corresponding weight and biodiversity thresholds identified in this study (see Table 6) to each of the 9,802 New Zealand bottom trawl tows conducted in the SPRFMO Convention Area over the period 2008–2019. As per the CMM 03-2019, the encounter protocol was deemed to have been triggered if bycatch in a single bottom trawl either exceeded a taxon-specific weight threshold or contained three or more VME indicator taxa each of which exceeded a lesser taxon-specific biodiversity threshold (although see Appendix 4 for a review of the sensitivity of the biodiversity rule to the number of taxa required to exceed their biodiversity thresholds). For each of the historic bottom trawl tows that would have triggered the revised encounter protocol we identified which VME indicator taxa made meaningful contributions to the encounter protocol by triggering weight or biodiversity thresholds.

[3] Recognizing that during the development of CMM03-2019 Gorgonacea within the sub-orders Halaxonia, Calaxonia and Scleraxonia that weren't explicitly tagged with the New Zealand Fisheries Code GOC (Gorgonacea) were assigned to Alcyonacea, weight and biodiversity thresholds for Gorgonacea were also recalculated.

4 Results

Where peer-reviewed literature was available, it predominantly comprised studies from elsewhere in the world; consequently, scoring the suitability of taxa as VME indicators against FAO criteria relied heavily on expert opinion. Of the 22 taxa evaluated, 15 scored high against at least one of the FAO criteria for identifying VME indicator taxa (Table 4). With the exception of Hydroids which scored highly against a single criterion, all 15 taxa scored highly against two or more criteria, with Gorgonian Alcyonacea, Scleractinia and Antipatharia scoring high against all five criteria. The criteria most frequently met was structural complexity (Table 4). These scores may, however, change if new data were to become available and if finer resolution taxonomic groupings were to be used.

Of the 15 candidate taxa that meet FAO VME criteria, Xenophyophorea and Serpulidae did not satisfy the additional criteria related to suitability as indicators. Of the 13 taxa that did meet the additional criteria, Zoantharia, Hydrozoa and Bryozoa are not currently identified as a VME indicator taxa within SPRFMO CMM03-2019. All ten taxa currently included as indicators in SPRFMO CMM03-2019 scored highly against at least 1 of the FAO criteria and satisfied the additional criteria related to suitability as indicators.

Weight and/or biodiversity thresholds calculated for Porifera, Stylasteridae, Scleractinia, Antipatharia, Actinaria, Pennatulacea, Brisingida and Crinoidea in this study were all the same as or similar to those calculated in SC6 DW-09 and specified in current encounter protocol (SPRFMO CMM03-2019), while the weight threshold for Gorgonian Alcyonacea was approximately double (Table 6 and Figure 2). The weight and biodiversity thresholds for the three new indicator taxa (Zoantharia, Hydrozoa and Bryozoa) are reported in Table 5.

Table 4: Matrix scoring candidate VME indicator taxa against FAO criteria for identifying vulnerable marine ecosystems (blue cells) and indicator taxa (green cells). Blue cell shading indicates the scoring against FAO criteria, with taxa scored low, medium or high by comparing the likely maximum for known species within each taxonomic group against rules described in Table 3. Green shaded indicates the scoring against rules for selecting indicator taxa. * indicates taxa currently included in SPRFMO CMM 03-2019. The evidence used to score against FAO criteria is presented in Appendix 1, and evidence used to score against indicator criteria is presented in Appendix 2.

		Uniqueness or rarity	Functional significance	Fragility	Recovery	Structural complexity	Meets FAO VME criteria	Bycatch	Identification	Meets Indicator criteria
Porifera*		M	H	M	H	H	Y	Y	H	Y
Cnidaria	Gorgonian Alcyonacea (Tree-like forms, sea fans, sea whips, bottlebrush) *	H	H	H	H	H	Y	Y	M	Y
	Alcyonacea (Soft corals) *	M	M	H	M	H	Y	Y	H	Y
	Stylasteridae (Hydrocorals) *	H	H	H	M	H	Y	Y	M	Y
	Scleractinia (Stony corals) *	H	H	H	H	H	Y	Y	H	Y
	Antipatharia (Black corals) *	H	H	H	H	H	Y	Y	H	Y
	Actiniaria (Anemones) *	H	L	L	M	L	Y	Y	H	Y
	Pennatulacea (Sea pens) *	H	H	M	H	H	Y	Y	H	Y
	Zoantharia (Hexacorals)	H	L	M	H	M	Y	Y	H	Y
	Ceriantharia (Tube-dwelling anemones)	M	L	M	M	L	N			
	Hydrozoa (Hydroids)	M	M	H	M	M	Y	Y	M	Y
Echinodermata	Brisingida ('Armless' stars) *	H	L	H		L	Y	Y	H	Y
	Euryalida (Basket and snake stars)	M	L	M		L	N			
	Crinoidea (Sea lillies) *	H	L	M	H	H	Y	Y	H	Y
	Cidaroida (Pencil spine urchins)	L	L	L	L	L	N			
Bryozoa		L	H	H	H	H	Y	Y	H	Y
Brachiopoda		L	M	M	M	M	N			
Retaria	Xenophyophorea (Xenophyophores)	L	H	L	H	H	Y	N		
Chordata	Ascidiacea (Sea squirts)	L	M	L		M	N			
Annelida	Serpulidae (Serpulid tube worms)	M	H	H		H	Y	N		
Anthropoda	Bathylasmatidae (Goose and acorn barnacles)		M	L	L	L	N			
Hemichordata	Graptolithoidea (Acorn worms)		L	M		L	N			

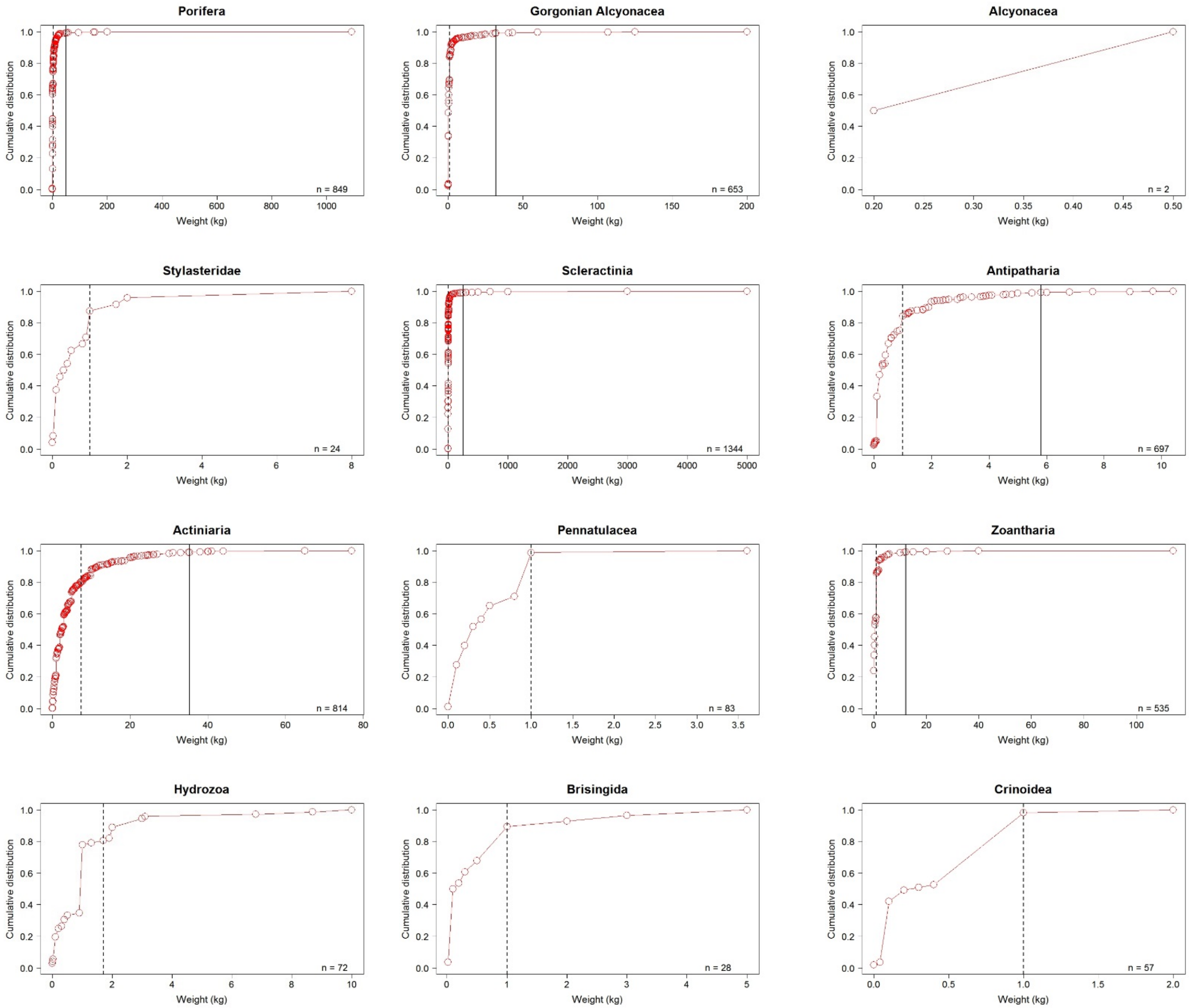
Contribution to FAO criteria for identifying VME taxa	
H	High
M	Medium
L	Low
	Could not be assessed

Contribution to indicator taxa criteria			
Y	Yes	H	High
N	No	M	Medium
		L	Low
			Not assessed

Table 5: Percentiles in bycatch weight (kg) per VME indicator taxon as calculated in SC DW-09, and this study, and encounter thresholds as specified in CMM 03-2019. ** Indicates sample sizes were too small to calculate the 80th percentile from ordered values; therefore, a nominal threshold of 1 kg was selected.*

Taxon	Percentiles calculated in SC6 DW-09		Percentiles calculated in this study		Thresholds specified in CMM 03-2019	
	0.8	0.99	0.8	0.99	Biodiversity	Weight
Porifera (Sponges)	3.0	50.0	3.1	50.0	5	50
Gorgonian Alcyonacea (Tree-like forms, sea fans, sea whips, bottlebrush)	0.6	15.0	1.0	32.0	1	15
Alcyonacea (Soft corals)	1.0	60.0	1.0*	NA	1	60
Stylasteridae (Hydrocorals)	1.0	NA	1.0	NA	1	NA
Scleractinia (Stony corals)	5.0	250.0	5.0	250.0	5	250
Antipatharia (Black corals)	1.0	5.5	1.0	5.8	1	5
Actiniaria (Anemones)	7.3	38.0	7.4	35.3	5	40
Pennatulacea (Sea pens)	1.0	NA	1.0	NA	1	NA
Zoantharia (Hexacorals)	NA	NA	1.0	12.2	NA	NA
Hydrozoa (Hydroids)	NA	NA	1.7	NA	NA	NA
Brisingida ('Armless' stars)	1.0	NA	1.0	NA	1	NA
Crinoidea (Sea lillies)	0.2	NA	1.0	NA	1	NA
Bryozoa	NA	NA	1.0*	NA	NA	NA

Applying a revised encounter protocol comprising the 13 VME indicator taxa identified in this study and associated weight and biodiversity thresholds directly to the 9,802 bottom trawl tows conducted by New Zealand flagged vessels between 2009 and 2018, suggests that had the protocol been in place at the time, the move-on rule would have been triggered 69 times as a result of individual taxa exceeding their threshold weight (Table 6). The taxa most frequently exceeding their threshold weights were Scleractinia and Antipatharia; however, all six indicator taxa with weight thresholds triggered unique move-on events (i.e., move-on events triggered with only one indicator taxa exceeding their threshold weight). The biodiversity component of a revised protocol would have triggered the move-on rule 50 times; however, in nine of these cases one or more indicator taxa also exceeded their weight thresholds. Of the 13 taxa identified as indicators, only Alcyonacea and Bryozoa would not have triggered their biodiversity thresholds. Compared to the existing encounter protocol described in (SPRFMO CMM03-2019), the revised encounter protocol would have triggered 60 of the 74 move on events that would have been triggered if the current encounter protocol was applied to the same data due to changes in the weight thresholds for Gorgonian Alcyonacea and Alcyonacea. Relative to the existing encounter protocol, the revised encounter protocol would have triggered an additional 46 move-on events, primarily due to the inclusion of a weight threshold for Zoantharia and a broader suite of indicator taxa assigned biodiversity thresholds.



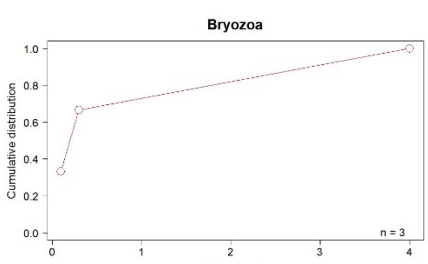


Figure 2 |Cumulative distribution of bottom trawl catch weights (kg) indicating the position of the 80th (dashed line) and 98th percentiles (sold line) used to calculate biodiversity and weight thresholds for Porifera, Gorgonacea, Stylasteridae, Scleractinia, Antipatharia, Actinaria, Pennatulacea, Zoantharia, Crinoidea and Brisingida. Note that the x-axis scale differs between panels.

Table 6: The per taxa number of move-on events triggered by the weight or biodiversity threshold being exceeded. Unique events are the number of times a move-on event was triggered by only one indicator exceeding its threshold weight, or the biodiversity weights of three of more taxa being exceeding without a weight threshold also being exceeded.

	Number events		Number unique events	
VME Indictor taxa	**Weight threshold**	**Biodiversity threshold**	**Weight threshold**	**Biodiversity threshold**
Porifera (Sponges)	10	17	7	1
Gorgonian Alcyonacea (Tree-like forms, sea fans, sea whips, bottlebrush)	10	34	7	0
Alcyonacea (Soft corals)	NA	0	NA	0
Stylasteridae (Hydrocorals)	NA	3	NA	1
Scleractinia (Stony corals)	14	9	14	5
Antipatharia (Black corals)	14	16	11	9
Actiniaria (Anemones)	10	11	10	6
Pennatulacea (Sea pens)	NA	4	NA	4
Zoantharia (Hexacorals)	11	12	11	10
Hydrozoa (Hydroids)	NA	25	NA	24
Brisingida (‘Armless’ stars)	NA	3	NA	2
Crinoidea (Sea lillies)	NA	21	NA	21
Bryozoa	NA	0	NA	0

5 Discussion

The analysis presented here identified 15 broad taxonomic groups within the SPRFMO Convention Area that meet FAO criteria for identifying VME taxa, and of these, 13 groups met two additional criteria related to suitability as VME indicators. All 15 taxa scored highly against at least one of the FAO criteria, with those not selected as indicators failing to qualify due to not having previously been caught as bycatch. Further, applying of the list of 13 VME indicator taxa and thresholds identified here and those listed in SPRFMO CMM 03-2019 to the historic bycatch dataset suggest an encounter protocol incorporating the VME indicator taxa and thresholds identified in this study would result in approximately 40% more move-on events as the current encounter protocol.

An important difference exists in how Gorgonian Alcyonacea were differentiated from other Alcyonacea in the analysis presented here and the earlier analysis used to inform the thresholds incorporated within SPRFMO CMM 03-2019. Although taxonomists consider Alcyonacea to include gorgonians, we have separated the suborders Holaxonia, Calcaxonia and Scleraxonia because of their contrast in structure-forming characteristics to other Alcyonacea. This separation differs from that used to inform the encounter thresholds included in SPRFMO CMM 03-2019, which distinguished VME indicator taxa explicitly coded as Gorgonacea from all other Alcyonacea, but which didn’t consistently separate out the Holaxonia, Calcaxonia and Scleraxonia suborders. This difference in taxonomic groupings also explains differences in the thresholds for Gorgonain Alcyonacea between those included in CMM 03-2019 and those calculated in this study.

Of the ten VME indicator taxa identified in this study, Zoantharia, Hydrozoa and Bryozoa are not currently included in CMM 03-2019. Zoanthids are anemone-like hexacorals that generally have a colonial lifestyle (although solitary species also exist). Deep-sea zoanthids associate with cold seeps (Reimer et al., 2007) and seamounts (Reimer et al., 2008, Carreiro-Silva et al. 2011, Sinniger et al. 2013) at depths of up to 5000 m (reviewed by Ryland *et al*. 2000). They have a broad range of morphologies, with individuals of the genus *Gerardia* reaching up to 3 m in height (Parker and Bowden 2010). Several species are extremely long-lived, with estimated growth rates of 14-45 um yr^{-1} and trunk radiocarbon ages of 450 to more than 2000 years (Roark et al. 2006). Zoanthids often associate with several species of sponges, hydroids, octocorals and antipatharians, and appear to form monophyletic groups correlated to the organisms they colonize (Carreiro-Silva et al. 2017). Some species appear to be parasitic, where the zoantharian progressively kills gorgonian tissue and uses the gorgonian axis for structure and support, and coral sclerites for protection (Carreiro-Silva et al. 2017). Given their longevity, functional significance and prevalence in the bycatch data, Zoantharia appear to be a justifiable addition to the list of VME indicator taxa for the SPRFMO Convention area.

Hydrozoa are highly varied, and can be solitary or colonial, with polyp and medusa phases, or either phase may be lacking. Little information on the growth rate or longevity of Hydrozoa is available, although some estimates of colony ages in New Zealand fjords approach 30 years (Miller et al., 2004). Hydrozoa can be large, up to 1 m high in Alaska (Stone 2006), and their coarse texture and brittle skeleton makes them susceptible to fishing impacts. The class Hydrozoa includes the family Stylasteridae, which was also identified as a separate VME indicator taxa within this study.

Erect bryozoans form ramified structures in a variety of marine environments that can be ecologically important in providing substrata for epizoans and hiding places for motile organisms, including ophiuroids and small fish (Smith et al. 2001). The surfaces of bryozoans provide can be large (Stebbing, 1971a; Wood, 2005) and alter the balance of biotic interactions, such as predation and competition (Russ, 1980). Therefore, the presence of habitat-forming bryozoans can allow more, or different species to persist (Wood et al. 2012). Colony size can vary enormously depending on environmental conditions and species characteristics (Barnes and De Grave, 2002; Winston and Migotto, 2004; Wood et al. 2012). Some species attain sizes of 50–500 mm in three dimensions, and in exceptional circumstances can grow to 700–1000 mm across (Cocito et al., 1998, 2004; Barnes and De Grave, 2002; Batson and Probert, 2000; Lombardi et al., 2008). The conditions which enable large bryozoans to flourish often support other structure-forming suspension-feeding invertebrates (Gutt and Starmans, 1998; Cryer et al., 2000; Cranfield et al., 2004; Lombardi et al., 2008). Although most bryozoans are short-lived, some colonies can reach twenty years old (Smith et al. 2001). The fragility of bryozoans and their erect nature predispose them to damage by bottom trawling. Saxton (1980) and Bradstock and Gordon (1983) recorded the effects of the systematic destruction by trawlers of the bryozoan beds in Tasman Bay, New Zealand, which had failed to recover 10 years later, with the loss believed to be permanent (Jones 1992).

Although SPRFMO CMM 03-2019 defines a list of VME indicator taxa to be used in encounter protocols, there currently isn't a broader list of recognized VME taxa from the SPRFMO Convention Area, as developed by other RFMOs (e.g., NAFO, NEAFC, NPFC). A defined list of VME habitats or elements for the SPRFMO Convention Area would help inform further management measures to prevent significant adverse impacts on VMEs, and targeted research efforts, including mapping the spatial extent of VMEs, evaluation of the relationship between the density/biomass of a VME indicator taxa and the diversity of associated species and the ongoing reviews of fishing events that have triggered the encounter protocol. As a starting point for developing a broader list of VME taxa, we suggest the historic bycatch record and other relevant data from within the SPRFMO Convention Area (e.g., records in the Ocean Biogeographic information System - OBIS) are reviewed to identify taxa that belong to each of the 15 VME groups identified in this study, and that if required, they are then individually assessed against the FAO criteria.

To help transition from the identification of VME indicator taxa and associated thresholds based on historic bycatch and cumulative catch distributions to approaches better supported by ecological data, a long-term research plan for the collection and analysis of data should be developed. Components should include: (1) ongoing empirical checks of the accuracy of observer identifications; (2) research on life history characteristics of VME indicator taxa in the SPRFMO area, and on-the-ground observations (potentially via headline and net cameras deployed on commercial trawls complemented by fishery-independent surveys) to locate, classify and map potential VME habitats; (3) the determination of the particular seafloor density/biomass of VME indicator taxa that represents a VME (e.g., by examining the relationship between the density/biomass of a VME indicator taxa and the diversity of associated species); (4) the determination of taxa-specific catchability estimates (e.g., by comparing VME indicator taxa bycatch weights from trawls to those determined from seafloor imagery from the same area swept by the trawls); and (5) determination the magnitude of the impact that bottom fishing has on VME indicator taxa. Ideally, a research plan should be region-specific to reflect both potential regional differences in the morphology and life-history characteristics of VME indicator taxa and differences in the way bottom trawls are conducted (for example short feature-based tows versus long tows on the slope). In the interim, the choice of encounter thresholds should be re-evaluated as more experience with their application is gathered.

6 Recommendations

We recommend that the Scientific Committee:

- **Notes** that a pragmatic, data-informed approach has been used to review the list of VME indicator taxa included in CMM03-2019 and develop weight and biodiversity thresholds for proposed new VME indicator taxa;
- **Agrees** that the approach to review the list of VME indicator taxa is appropriate;
- **Recommends** to the Commission that, when it decides to update CMM03-2019, the list of VME indicator taxa should be revised to include the following taxa and weight thresholds (changes are indicated in bold):
    - Porifera (retain current threshold of 50 kg)
    - Gorgonian Alcyonacea **(increase threshold to 30 kg)**
    - Scleractinia (retain current threshold of 250 kg)
    - Antipatharia (retain current threshold of 5 kg)
    - Actiniaria (retain current threshold of 35 kg)
    - Zoantharia **(new indicator with a threshold of 10 kg)**

- **Recommends** to the Commission that, when it decides to update CMM03-2019, the list of VME indicator taxa should be revised to remove the following taxa and associated weight thresholds:
    - Alcyonacea (60 kg)
- **Recommends** to the Commission that, when it decides to update CMM03-2019, the list of VME indicator taxa used for the biodiversity component of the encounter protocol should be revised to include the following taxa and biodiversity thresholds (changes are indicated in bold):
    - Porifera (retain current threshold of 5 kg)
    - Gorgonian Alcyonacea (retain current threshold of 1 kg)
    - Alcyonacea (retain current threshold of 1 kg)
    - Scleractinia (retain current threshold of 5 kg)
    - Antipatharia (retain current threshold of 1 kg)
    - Actiniaria (retain current threshold of 5 kg)
    - Zoantharia (retain current threshold of 1 kg)
    - Hydrozoa (Hydroids) **(new indicator with a threshold of 1 kg)**
    - Stylasteridae (retain current threshold of 1 kg)
    - Pennatulacea (retain current threshold of 1 kg)
    - Brisingida (retain current threshold of 1 kg)
    - Crinoids (retain current threshold of 1 kg)
    - Bryozoa **(new indicator with a threshold of 1 kg)**
- **Agrees** that a list of VME taxa for the SPRFMO Convention area should be developed, and that the starting point for the development of such a list is a review of benthic taxa from within the SPRFMO Convention Area belonging to the VME indicator taxa listed above, plus the following VME groups:
    - Xenophyophorea (Xenophyophores)
    - Serpulidae (Serpulid tube worms)

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Appendix 1: The matrix scoring candidate VME indicator taxa against FAO criteria for identifying vulnerable marine ecosystems including reference material. Cell shading indicates the scoring against FAO criteria, with taxa scored low, medium or high by comparing the likely maximum for known species within each taxonomic group against rules described in Table 3. The numbers within cells refer to the combination of papers, reports and online material corresponding used to score the matrix as reported below. 'E' refers to expert opinion. Cells with diagonal lines indicate that they could not be assessed due to a lack of available literature and expert knowledge.

Phylum	Lower taxonomic group	Uniqueness or rarity	Functional significance	Fragility	Recovery	Structural complexity
Porifera		E	1	2	3	4
Cnidaria	Gorgonian Alcyonacea (Tree-like forms, sea fans, sea whips, bottlebrush)	E	5	6	7	8
	Alcyonacea (Soft corals)	E	9	10	11	12
	Stylasteridae (Hydrocorals)	E	13	14	E	15
	Scleractinia (Stony corals)	16	17	18	19	20
	Antipatharia (Black corals)	E	21	22	23	24
	Actiniaria (Anemones)	E	E	E	E	E
	Pennatulacea (Sea pens)	25	26	27	28	29
	Zoantharia (Hexacorals)	E	E	E	30	31
	Ceriantharia (Tube-dwelling anemones)	E	E	E	E	E
	Hydrozoa (Hydroids)	E	E	E	E	E
Echinodermata	Brisingida ('Armless' stars)	32	E	33		E
	Euryalida (Basket and snake stars)	34	E	35		E
	Crinoidea (Sea lillies)	E	E	36	E	37
	Cidaroida (Pencil spine urchins)	E	E	E	E	E
Bryozoa		E	38	39	E	40
Brachiopoda		41	E	E	E	42
Retaria	Xenophyophorea (Xenophyophores)	43	44	E	E	45
Chordata	Ascidiacea (Sea squirts)	E	E	45		E
Annelida	Serpulidae (Serpulid tube worms)	E	E	E		E
Anthropoda	Bathylasmatidae (Goose and acorn barnacles)		E	E	E	E
Hemichordata	Graptolithoidea (Acorn worms)		E	E		E

Contribution to FAO criteria for identifying VME taxa	
	High
	Medium
	Low
	Could not be assessed

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Appendix 2: Bycatch information for current and candidate VME Indicator taxa, compiled from 9,802 New Zealand bottom trawls within the SPRFMO Convention Area between 2008 and 2019 (of which 3,386 recorded benthic bycatch).

Phylum	**Lower taxonomic group**	**Number trawls**	**Percent trawls**	**Range bycatch weight (kg)**
Porifera (*Sponges)*		852	25.16	0 – 1,091.2
Cnidaria	Gorgonacea (*Sea fans*)	648	19.14	0 – 200
	Stylasteridae (*Hydrocorals*)	23	0.68	0 – 8.0
	Scleractinia (*Stony corals*)	1,339	39.55	0 – 5,000.0
	Antipatharia (*Black corals*)	702	20.73	0 – 10.4
	Actiniaria (*Anemones*)	814	24.04	0.02 – 77.0
	Alcyonacea (*Soft corals*)	2	0.06	0.2 - 0.5
	Pennatulacea (*Sea pens*)	84	2.48	0 – 3.6
	Zoantharia (*Hexacorals*)	535	15.80	0.1 – 114.0
	Ceriantharia (Tube-dwelling anemones)	0	0.00	NA
	Hydrozoa (*Hydroids*)	71	2.10	0 – 10.0
Echinodermata	Brisingida (‘Armless’ stars)	28	0.83	0.02 – 5.0
	Ophiuroidea (*Basket stars*)	47	1.39	0 – 20.0
	Euryalida (Basket and snake stars)	63	1.86	0 – 30.0
	Crinoidea (*Sea lillies*)	57	1.68	0 -2.0
	Cidaroida (Pencil spine urchins)	8	0.24	0 – 1.4
Bryozoa (Lace corals)		3	0.09	0.1 – 4.0
Brachiopoda (*Lamp shells*)		1	0.03	1.0
Retaria	Xenophyophorea	0	0.00	NA
Chordata	Ascidiacea (*Sea squirts*)	6	0.18	0.1 – 10.0
Annelida	Serpulidae (Serpulid tube worms)	0	0.00	NA
Anthropoda	Bathylasmatidae (Goose and acorn	0	0.00	NA
Hemichordata	Graptolithoidea (*Acorn worms*)	0	0.00	NA
Mollusca	Pectinidae (*Scallops*)	1	0.03	0

Appendix 3: Accuracy of species identification by observers on bottom trawl and long-line vessels, with accuracy reported at the finest level of taxonomic identification, and at the taxonomic level at which VME indicator taxa are defined.

Phylum	Lower taxonomic group	Total observations	% recorded false at finest taxonomic level of identification	% recorded false at taxonomic level of VME designation
Porifera		1050	1.05%	0.00%
Cnidaria	Gorgonacea (*Sea fans*)	853	3.52%	2.34%
	Stylasteridae	27	3.70%	3.70%
	Scleractinia (*Stony*	1822	0.71%	0.05%
	Antipatharia (*Black*	805	2.48%	0.37%
	Actiniaria (*Anemones*)	1110	0.27%	0.00%
	Alcyonacea (*Soft corals*)	2	0.00%	0.00%
	Pennatulacea (*Sea pens*)	84	0.00%	0.00%
	Zoantharia (*Hexacorals*)	564	0.00%	0.00%
	Ceriantharia (Tube-	0	NA	NA
	Hydrozoa (*Hydroids*)	85	3.53%	3.53%
Echinodermata	Brisingida ('Armless'	28	0.00%	0.00%
	Ophiuroidea (*Basket*	48	0.00%	0.00%
	Euryalida (Basket and	70	5.71%	2.86%
	Crinoidea (*Sea lillies*)	61	1.64%	0.00%
	Cidaroida (Pencil spine	10	10.00%	10.00%
Bryozoa (Lace corals)		5	0.00%	NA
Brachiopoda (*Lamp shells*)		1	0.00%	0.00%
Retaria	Xenophyophorea	0	NA	NA
Chordata	Ascidiacea (*Sea squirts*)	7	0.00%	0.00%
Annelida	Serpulidae (Serpulid	0	NA	NA
Anthropoda	Bathylasmatidae (Goose	0	NA	NA
Hemichordata	Graptolithoidea (*Acorn*	0	NA	NA

Appendix 4: Number and percent of all fishing events with 0 to >4 VME indicator taxon groups exceeding taxon-specific biodiversity thresholds.

	Number of VME Indicator taxa exceeding biodiversity thresholds per fishing event					
Metric	**0**	**1**	**2**	**3**	**4**	**>4**
Number of fishing events	8703	868	181	45	5	0
Percent of fishing events	88.7%	8.9%	1.8%	0.5%	0.05%	0