South Pacific Regional Fisheries Management Organisation

9th MEETING OF THE SCIENTIFIC COMMITTEE

Held virtually, 27 September to 2 October 2021

SC9-DW10

Updated Candidate Encounter Thresholds for VME Indicator Taxa in the SPRFMO Area

New Zealand

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Updated candidate encounter thresholds for VME indicator taxa in the SPRFMO Area

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Contents

1. Purpose

The purpose of this paper is to update candidate encounter thresholds for the 13 VME indicator taxa included in Annex 5 of CMM03-2021, with the intention of developing an authoritative set of candidate encounter thresholds for all VME indicator taxa. These thresholds would be used to inform any future refinement of VME encounter thresholds to adjust the level of precaution included in CMM03 (if required).

2. Background

The Conservation and Management Measure for the Management of Bottom Fishing in the SPRFMO Convention Area (CMM03-2021) includes a bottom fishing Vulnerable Marine Ecosystem (VME) encounter protocol for trawl vessels, whereby if VME indicator taxa are encountered in any one tow at or above the threshold weight limits in Annex 6A of CMM03-2021, or three or more different VME indicator taxa at or above the weight limits in Annex 6B of CMM03-2021, bottom fishing vessels are required to cease fishing immediately within an area of one nautical mile either side of the encounter trawl track extended by one nautical mile at each end. The encounter is then required to be immediately reported to the SPRFMO Secretariat, in accordance with the Guidelines for the preparation and submission of notifications of encounters with potential VMEs, contained in Annex 7 of CMM03-2021. The encounter area then remains closed to bottom fishing until the Commission, taking into account the Scientific Committee's review of the encounter and its advice, determines management actions for the encounter area.

The encounter thresholds included in CMM03-2021 were developed and subsequently refined following the presentation of SC5-DW08 by New Zealand to the 5th SPRFMO Scientific Committee, which outlined the utility of move-on rules as part of a bottom fishing Conservation Management Measure. Following discussion of SC5-DW08, in its report the Scientific Committee:

- **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, 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

Consistent with SC5 direction that thresholds should be set high, in 2018, New Zealand presented SC6-DW09 to the 6th Scientific Committee which outlined a method for deriving thresholds for VME indicator taxa. The method was based on developing VME indicator taxon-specific cumulative distribution curves of historic bycatch weights and then calculating a range of percentiles from the ordered bycatch weights, with the percentiles serving as candidate encounter threshold values. Naturally occurring or ecologically relevant reference points were also calculated and used to identify 'high' candidate threshold weights for triggering move-on rules and 'low' candidate biodiversity weights indicating increasing numbers of taxa in a single tow. Following discussion of SC6-DW09, in its report the SC6:

- **Noted** that a data-informed approach has been used to identify a range of candidate thresholds, but the selection of a final VME [indicator] taxa threshold for bottom trawls is a somewhat arbitrary process;
- **Noted** that insufficient data on VME distribution and density and on trawl catchability exist to apply more sophisticated methods;
- **Agreed** that two VME indicator taxa thresholds for bottom trawl have been estimated (a weight threshold and a biodiversity threshold):
    - a catch of any one of the six most commonly caught VME [indicator] 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 [indicator] taxa over a taxon-specific qualifying biodiversity weight (based on the 80th percentile of the distribution of historical positive catch weights).

Subsequently, at the 7th SPRFMO Commission in 2019, thresholds based on the SC6 recommendations were incorporated into CMM03-2019.

In 2019, New Zealand presented SC7-DW13 to the 7th Scientific Committee, a review of VME indicator taxa for the SPRFMO Convention Area. In developing the paper, New Zealand recalculated the 80th, 90th, 95th, 97th, 98th, 99th and 99.5th percentiles as candidate VME indicator taxa thresholds using the most up-to-date bycatch data available, but only included the 80th and 99th percentiles upon which the thresholds in CMM03-2019 were based in SC7-DW13. The result was that SC6-DW09 presented a full range of candidate thresholds for the 10 VME indicator taxa that had been identified at the time, whereas SC7-DW13 used more recent data for all taxa, but only presented a subset of candidate thresholds (based on the 80th and 99th percentiles) for a broader range of VME indicator taxa (13 taxa) to the Scientific Committee. SC7-DW13 also used a different separation of Alcyonacea and Gorgonian Alcyonacea than that used in CMM03-2019 that better recognized differences in structure-forming characteristics within the suborders Holaxonia, Calcaxonia and Scleraxonia. In its report, SC7:

- **Recommended** that, when the Commission reviews CMM 03-2019 in 2021, the list of VME indicator taxa should be revised to include the following additional taxa, noting that specific threshold weights may need to be revised once additional work is done to establish whether current thresholds are consistent with the objectives of CMM 03-2019:
    - Gorgonian Alcyonacea
    - Zoantharia
- **Recommended** to the Commission that, when it reviews CMM 03-2019 in 2021, the list of VME indicator taxa should be revised to remove the following taxon and associated weight thresholds:
    - Alcyonacea
- **Recommended** to the Commission that, when it reviews CMM 03-2019 in 2021, the list of VME indicator taxa used for the biodiversity component of the encounter protocol should be revised to include the following additional taxa:
    - Zoantharia
    - Hydrozoa (Hydroids)
    - Bryozoa

At the 8th SPRFMO Commission meeting in 2019, the European Union introduced a proposal (COMM8-Prop07) to make CMM03-2019 more precautionary for the avoidance of Significant Adverse Impacts on VMEs. In particular, the proposal suggested lowering the weight thresholds for all taxa triggering the VME encounter protocol. Following discussion, the European Union introduced an amended proposal lowering the thresholds for stony corals from 250 kg to 80 kg based on the 98th percentile from the calculations that were done for SC7-DW13 (noting that the 98th percentile was not presented in that paper). That proposal was adopted and the thresholds lowered in CMM03-2020 (Table 1).

In 2020, New Zealand presented a cumulative bottom fishing impact assessment (BFIA) for Australian and New Zealand bottom fisheries in the SPRFMO Convention Area (SC8-DW07_rev1) to the 8th Scientific Committee, which included a risk assessment for benthic habitat, biodiversity and VMEs. The risk assessment included an estimation of the performance of spatial management measures included in CMM03-2020. Following discussion of the risk assessment, in its report the SC8 recommended that additional precautionary measures could be put in place to address uncertainty in the performance of spatial management measures included in CMM03-2020. Following this recommendation, members submitted several competing proposals to 9th SPRFMO Commission meeting in 2020 (COMM9-Prop02, COMM9-Prop03, COMM9-Prop04). These proposals and following negotiations mainly focussed on lowering VME encounter thresholds, with lower thresholds variously informed by the full range of thresholds explicitly presented in SC6-DW09, the full range of thresholds calculated for SC7-DW13 but not explicitly presented in that paper, and new thresholds calculated for subsets of taxa that were identified in SC8-DW07 rev1 as having less favourable levels of protection (i.e., splitting the Porifera into Demospongiae and Hexactinellidae). Although all the proposed thresholds were based on the methodology outlined in SC6-DW09 and reviewed by SC6, the application of the methodology to identify thresholds included in some of the proposals had not been reviewed by the Scientific Committee. Consequently, there was considerable debate about the transparency of using percentiles that hadn't been explicitly reviewed by the Scientific Committee to inform threshold selection. Following discussion, and negotiation between members, a consensus was reached to lower thresholds for three VME indicator taxa (Table 1) and this was incorporated into CMM03-2021.

There is a possibility that the management measures included in CMM03 may need to be continually refined to adjust the level of precaution as a better understanding is developed of their effectiveness in preventing significant adverse impacts on VMEs. An important tool in adjusting the level of precaution to date has been the refinement of VME indicator taxa encounter thresholds; however, this has been complicated due to the absence of an authoritative set of candidate thresholds that has been reviewed by the Scientific Committee.

Here, a range of candidate encounter thresholds for all 13 VME indicator taxa included in CMM03-2021 are recalculated using the most up-to-date trawl bycatch data (for the period 2008-2020) from within the "Evaluated Area" of the SPRFMO Convention Area[1]. Recognizing that New Zealand

[1] "Evaluated Area" means 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 (see Annex 1 of CMM 03-2021)

presented a proposal to COMM9 to split Porifera into Demospongiae and Hexactinellidae, thresholds for those component taxa are also calculated.

Table 1 | A history of VME indicator taxa thresholds included in Annex 6A of SPRFMO CMM03-2021. Red cells indicate thresholds lowered from previous year. - indicates indicator taxa not included within Annex 6, noting that Alcyonacea was removed in 2021 due to a reclassification of fisheries species codes contributing to Alcyonacea and Gorgonian Alcyonacea.

VME indicator taxon	CMM03-2019	CMM03-2020	CMM03-2021
Porifera	50 kg	50 kg	25 kg
Scleractinia	250 kg	80 kg	60 kg
Antipatharia	5 kg	5 kg	5 kg
Alcyonacea	60 kg	60 kg	-
Gorgonian Alcyonacea	15 kg	15 kg	15 kg
Actiniaria	40 kg	40 kg	35 kg
Zoantharia	-	-	10 kg

3. Methods

Data used in the analysis were extracted from the Fisheries New Zealand Centralized Observer Database (*cod*) (accessed 28 May 2021). Data were collected by scientific observers (the New Zealand bottom trawl fleet has 100% observer coverage in the SPRFMO Convention Area) and included 10,388 New Zealand trawl tows (including both bottom and mid-water trawls) targeting black oreo (*Allocyttus niger*), alfonsinos (*Beryx splendens* and *B. decadacylus*), cardinal fish (*Epigonus telescopus*), orange roughy (*Hoplostethus atlanticus*) and spiky oreo (*Neocyttus rhomboidalis*). All tows were conducted within the Evaluated Area within the western part of the SPRFMO Convention Area (west of 143˚E longitude; Figure 1) over the period 2008–2020[2]. These data consisted of tow-by-tow observer data with 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, information on whether the benthic material was encrusting anything or encrusted by something else, and observer comments.

[2] These data include bycatch from areas that are now closed to fishing under SPRFMO CMM03-2021.

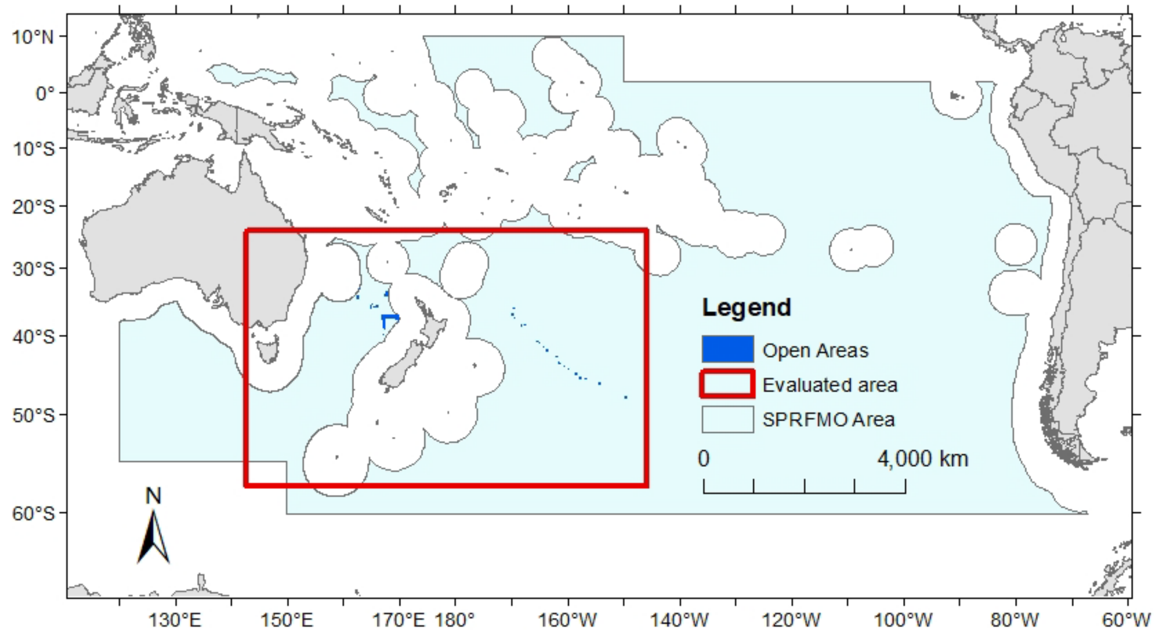

Figure 1 | The SPRFMO Convention Area with the location of the Evaluated Area from within which data collected by scientific observers from 9,771 New Zealand bottom trawl tows over the period 2008–2018 was used in this analysis. Also shown as dark blue polygons are the locations of areas open to bottom trawling under SPRFMO CMM03-2021.

VME indicator taxa were defined as in Annex 5 of SPRFMO CMM03-2021 (Table 2). Only those tows that included VME indicator taxa as bycatch (33.9% of bottom trawl tows retained VME indicator taxa as bycatch) were selected. For tows containing VME indicator taxa as bycatch, individual VME indicator species were aggregated into higher-order VME indicator taxa using taxonomic designations from the World Register of Marine Species (Horton et al. 2019) (RRID:SCR_013312), resulting in a final dataset consisting of 3,362 bottom trawl tows and 5,385 aggregated VME indicator taxa records (Figure 2, see Appendix 1 for the allocation of New Zealand fisheries codes to VME indicator taxa).

Table 2 | Designation of VME indicator taxa included in Annex 5 of SPRFMO CMM03-2021.

VME indicator taxon	Common Name	Qualifying Taxa
Porifera	Sponges	All taxa of the classes Demospongiae and Hexactinellidae
Scleractinia	Stony corals	
Antipatharia	Black corals	All taxa
Alcyonacea	True soft corals	All taxa excluding Gorgonian Alcyonacea
Gorgonian Alcyonacea	Sea fans octocorals	All taxa within the following suborders: Holaxonia; Calaxonia; Scleraxonia
Pennatulacea	Sea pens	All taxa
Actiniaria	Anemones	All taxa
Zoantharia	Hexacorals	All taxa
Hydrozoa	Hydrozoans	All taxa within the orders Anthoathecata and Leptothecata, excluding Stylasteridae
Stylasteridae	Hydrocorals	All taxa

Bryozoa	Bryozoans	All taxa within the orders Cheilostomatida and Ctenostomatida
Brisingida	Armless stars	All taxa
Crinoidea	Sea lillies	All taxa

Prior to analysis, data were checked for spurious bycatch weights. Of the 5,385 VME indicator taxa records, 42 had no or zero specified weight due to either small samples (< 0.1 kg) not being accurately weighed at sea, rounding error, or presence only being recorded. Because zero weights are indicative of the presence of VME indicator taxa, all zero weights were retained in the analysis, but were assigned a taxon-specific minimum weight corresponding to the minimum non-zero weight that had been recorded for that taxon (see Appendix 2).

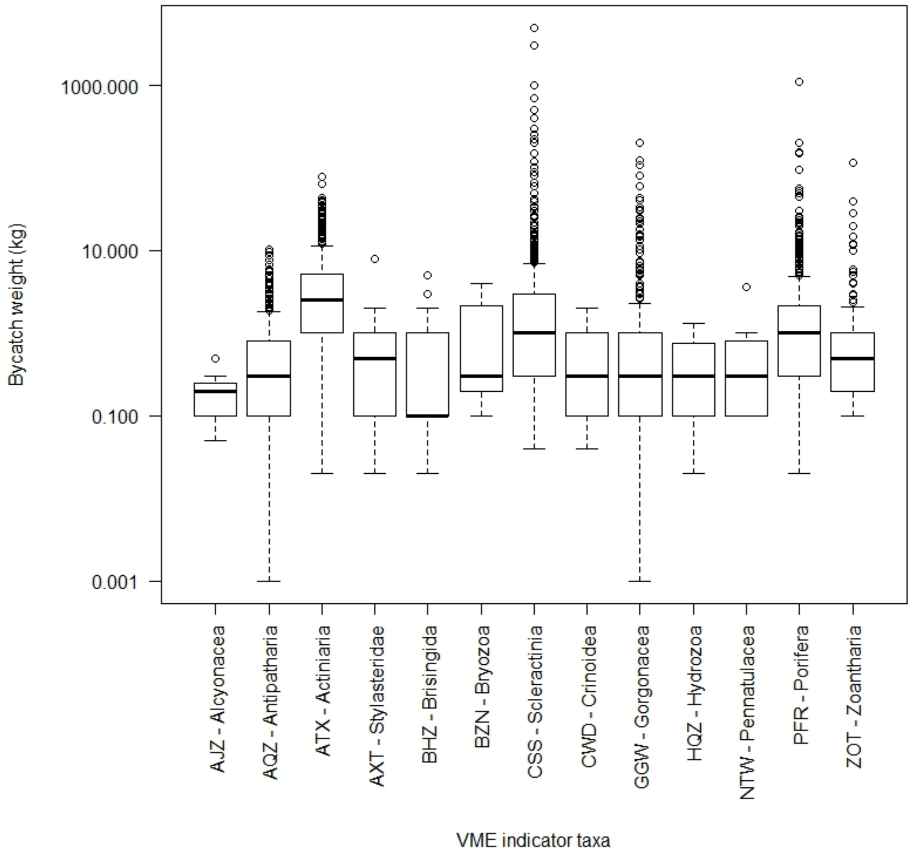

Figure 2 | Bycatch weight (kg) of VME indicator taxa in New Zealand bottom trawls within the SPRFMO Convention Area as reported by observers for the 2008-2020 period. Within each boxplot the line indicates the 50th percentile (median), the box encompasses 50% of the data, from the 25th to the 75th percentile and the dashed vertical lines extend to 1.5 times the interquartile range, with circles indicating "outliers". Note that the y-axis is plotted on a log-scale.

For each VME indicator taxon a range of percentiles (70th, 80th, 85th, 90th, 95th, 96th, 97th, 98th, 99th) were calculated using type 7 linear interpolation included in quantile function as part of the statistical software *R* (R Core Team 2019), with the percentiles serving as candidate encounter threshold values. This approach differs from that previously presented in SPRFMO SC6-DW09, which calculated candidate thresholds from ordered values without interpolation. The use of interpolation overcomes issues related to the lower limit of the sample size required for the estimation of the 100α and 100(1-α) percentile from ordered values, which is equal to 1/α (e.g., the estimation of the 99^{th} percentile requires 1/0.01 = 100 values). In SPRFMO SC6-DW09 the use of ordered values resulted in some taxa having insufficient bycatch samples to calculate the full range of percentiles (a comparison of percentiles calculated within and without linear interpolation is presented in Appendix 3).

A proposal was tabled at SPRFMO COMM-9 to split Porifera into its component Demospongiae and Hexactinellidae taxa and adjust the thresholds for Demospongiae in Fishery Management Areas (FMAs) where this type of sponge was at higher risk from bottom trawl fisheries. Recognizing this, candidate encounter thresholds were calculated for Demospongiae and Hexactinellidae separately and in addition to calculating an overall threshold for Porifera.

To help inform the systematic selection of weight and biodiversity thresholds for individual taxa from the candidate values, taxon-specific cumulative catch curves were examined to distinguish between the initial part of the curve associated with linear increase, and the final part of the curve associated with asymptotic decrease in slope. Assuming a strong relationship between the weight of VME indicator taxa landed on deck as bycatch and the functional role of VMEs, the transition between these two parts of the curve, especially if sharp, could potentially indicate a naturally occurring or ecologically relevant reference point (Figure 3, left-hand panel); e.g., the biomass of the indicator taxon has reached a point where it is sufficient to constitute a distinct VME, such as coral reef or sponge garden where densities of the indicator taxa would be expected to be high. Weight thresholds indicating unexpectedly large catches should ideally fall to the right of such points, whereas biodiversity thresholds indicating increasing numbers of taxa in a single tow at weights below the threshold trigger should occur to the left.

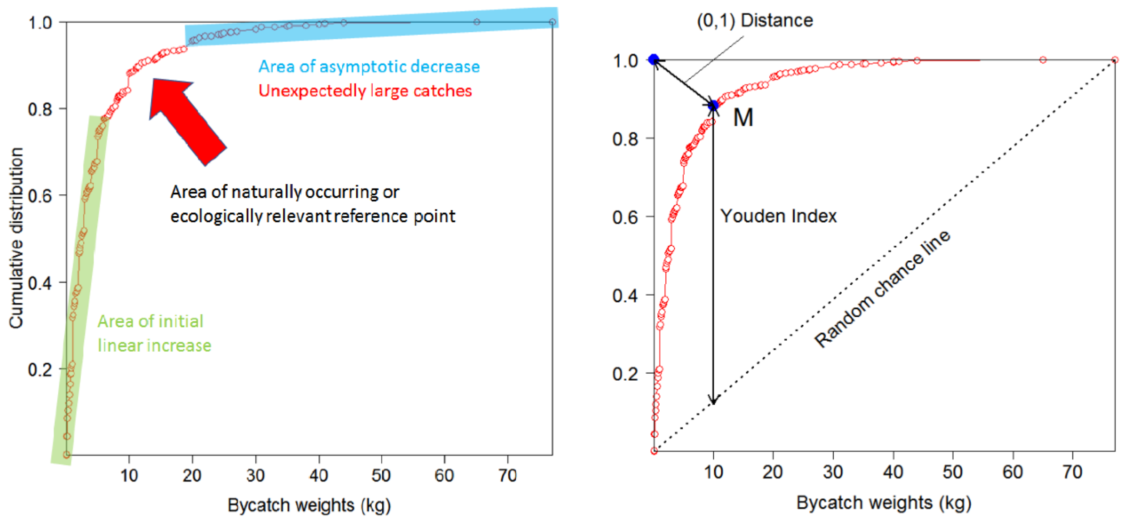

Figure 3 | Cumulative distribution curve for the weight of Actiniaria bycatch from the 2008-20 New Zealand bottom trawl fishery in the SPRFMO Convention Area. Left-hand panel distinguishes between the initial part of the curve associated with linear increase is and the final part of the curve associated with asymptotic decrease. The area distinguishing between these two parts of the curve potentially indicates a naturally occurring or ecologically relevant reference point. Right-hand panel show two approaches used to distinguish between the two parts of the curve: (1) the point on the curve that is closest to the top-left corner ((0,1) Distance); and (2) the point on the curve that maximizes the distance between the curve and a random chance line drawn between the extreme points on the curve (Youden Index).

Two different methods were used to calculate ecologically relevant reference points for taxa (Figure 3 right-hand panel): (1) the point on the cumulative distribution curve that is closest to the top-left corner (0,1), calculated as $q_1 = \min\{\sqrt{(1-y)^2 + (1-x)^2}\}$ for each point belonging to the cumulative distribution M(1-y,x) (Tilbury et al. 2000); and (2) the point on the cumulative distribution curve that maximizes the distance between the curve and a line drawn between the extreme points on the curve (Youden Index), calculated as $q_2 = \max\{y + x - 1\}$ for each point belonging to the cumulative distribution M(1-y,x) (Ruopp et al. 2008). Points on a curve closest to (0,1) or which maximize the Youden Index are commonly used in medical research to identify thresholds and facilitate treatment decisions (e.g., Tilbury et al. 2000, Youden 1950) and can provide identical estimates for smooth curves without large steps.

Recognizing that there may be regional differences in the structure of VMEs and the associated density or biomass of VME indicator taxa or that bottom fishing practices may differ regionally, the validity (from the perspective of our current understanding of VMEs) and feasibility (from the perspective of data availability) of calculating area-specific thresholds was explored. While there is good evidence that stony corals on seamounts can differ in form among regions (compare Rowden et al. 2017 with Williams et al. 2020) there is no direct evidence that these regional differences would be reflected in differences in the weight of the corals caught by a tow that has encountered a stony coral VME, and that thresholds should therefore vary regionally. For other VME indicator taxa there is little to no evidence that regional variation occurs in the VMEs that they form. An assessment of the feasibility of calculating area-specific thresholds at the scale of individual FMAs identified there were insufficient bycatch records to calculate FMA-specific thresholds (of the 177

FMA x VME combinations 80 had less than 20 bycatch records per VME indicator taxon and 36 had no bycatch records). At the regional scale (Tasman Sea vs. Louisville Seamount Chain), only 5 of the 13 VME indicator taxa had more than 30 bycatch records within each region, and there was a disproportionately greater number of bycatch records from the Tasman Sea than the Louisville Seamount Chain, which introduces a risk that the difference in the amount of data available between the regions could have a greater influence on thresholds than regional differences in the density or biomass of the VME indicator taxa. Therefore, overall it was considered not defensible at this time to calculate area-specific encounter thresholds, and instead taxon-specific candidate thresholds for the entire Evaluated Area combined were calculated.

An alternative approach to calculating candidate encounter thresholds for VME indicator taxa that is more commensurate with encounter protocols being the primary means for preventing significant adverse impacts on VMEs, rather than acting as a “backstop” to spatial management measures was also explored. For this approach, taxon-specific inverse cumulative catch curves were plotted and candidate encounter thresholds required to avoid catching 70%, 80%, 90% and 95% of historic bycatch were calculated, which prioritizes the avoidance of the largest bycatch events. Results from this alternative approach are presented separately in Appendix 4.

4. Results

Proposed candidate encounter thresholds for VME indicator taxa and reference points are presented in Table 3. For some taxa (Alcyonacea, Hydrozoa and Bryozoa), reference points could not be accurately determined due to a lack of data. Both reference points and candidate encounter thresholds varied by taxa. For example, based on the 95th percentile, thresholds ranged between 5 kg for Antipatharia and 250 kg for Scleractinia (Table 4).

Table 3 | Percentiles calculated from interpolation. The number of bottom trawl tows recorded as bycatch (n), range in bycatch weight (kg), reference points ((0,1) distance and Youden distance) and percentiles in bycatch weight per VME indicator taxon recorded in all New Zealand bottom trawls within the Evaluated Area of the SPRFMO Convention Area between 2008 and 2020. Cell shading indicates percentiles above (blue) and below (green) both reference points. Grey cells indicate reference points could not be calculated due to insufficient sample sizes. *Note, candidate encounter thresholds are presented for Porifera as a Phylum, and also disaggregated into the Classes Demospongiae and Hexactinellidae.*

			Reference Points		Percentiles (candidate encounter thresholds in kg)								
VME indicator taxon	**n**	**range (kg)**	**(0,1)**	**Youden**	**0.7**	**0.8**	**0.85**	**0.9**	**0.95**	**0.96**	**0.97**	**0.98**	**0.99**
Porifera	907	0.02 - 1091.2	26.00	26.00	2.00	3.00	5.00	7.04	12.58	15.00	20.00	22.99	49.70
Demospongiae	164	0.10 - 155	13.90	13.90	2.20	5.00	6.00	10.00	11.99	13.34	13.72	18.41	48.38
Hexactinellidae	430	0.02 - 200	10.00	10.00	1.10	2.00	3.00	4.20	7.15	10.00	14.13	20.00	41.38
Scleractinia	1395	0.04 - 5000	60.00	60.00	2.38	5.00	5.20	10.00	20.00	30.00	40.00	67.94	221.99
Antipatharia	739	0.001 - 10.4	1.10	1.10	0.60	1.00	1.00	1.82	2.63	3.00	3.89	4.65	5.50
Alcyonacea	7	0.05 - 0.5	-	-	0.22	0.28	0.32	0.38	0.44	0.45	0.46	0.48	0.49
Gorgonacea	681	0.01 - 200	5.70	5.70	1.00	1.00	1.30	2.00	5.20	7.44	15.07	24.10	34.50
Pennatulacea	99	0.1 - 3.6	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.05
Actiniaria	977	0.02 - 77	10.00	10.00	5.00	7.00	9.52	11.20	20.00	20.19	23.72	30.00	35.07
Zoantharia	544	0.1 - 114	5.00	5.00	1.00	1.00	1.00	2.00	3.00	4.42	5.00	6.56	11.99
Hydrozoa	12	0.02 - 1.3	-	-	0.47	0.90	1.00	1.00	1.14	1.17	1.20	1.23	1.27
Stylasteridae	33	0.02 - 8	1.00	1.00	0.84	1.00	1.00	1.00	1.82	1.92	2.24	4.16	6.08
Bryozoa	3	0.1 - 4	-	-	1.78	2.52	2.89	3.26	3.63	3.70	3.78	3.85	3.93
Brisingida	29	0.02 - 5	1.00	1.00	0.80	1.00	1.00	1.20	2.60	2.88	3.32	3.88	4.44
Crinoidea	59	0.04 - 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.42

5. Discussion

Analysis of data for benthic invertebrate bycatch in deep-sea trawl fisheries suffers from poorly known catchability in bottom trawls, limited historical identification of bycatch taxa, and limited spatial extent of samples. With these constraints in mind, candidate encounter threshold weights were developed for the Evaluated Area of the SPRFMO Convention Area based on taxon-specific cumulative distributions of bycatch weights. These distributions show that most historic bycatch encounter events were of small amounts, with fewer large catches. The candidate encounter thresholds for VME indicator taxa calculated in this paper are the same as or similar to those calculated in SC6-DW09 and SC7-DW13, indicating that recent bycatch events have not changed the shape of the cumulative distribution curves.

It is difficult to fully assess the ecological relevance of candidate encounter thresholds determined here without incorporating estimates of the trawl catchability of the VME indicator taxa to understand how catches relate to the presence of habitats that constitute VMEs. Although studies linking the density or biomass of VME indicator taxa on the seafloor to bycatch (i.e., catchability) are limited, those that have been attempted indicate that bycatch of individual trawl events may be a poor indicator of the density of VME indicator taxa on the seabed. For example, studies in shelf waters elsewhere (Freese et al. 1999, Wassenberg et al. 2002) and those from deeper waters in the SW Pacific presented at SC7 and in the BFIA 2020 (SC7-DW14, SC7-DW21_rev1, SC8-DW07_rev1), that opportunistically used data from seabed imagery and trawl bycatch estimated catchability of VME indicator taxa to often be less than 1%, but could be up to 15%. Consequently, encounter weight thresholds likely correspond to high densities and high biomasses of VME indicator taxa on the seabed, and the potential for substantial amounts of VME indicator taxa, and possible VMEs, to be contacted and impacted by trawl gear. Although the recent catchability analyses represent the best available estimates of catchability for VME indicator taxa within the SPRFMO Convention Area, the estimates should be interpreted with caution for a number of reasons, including differences between the types of fishing gear incorporated in these analyses and bottom trawling gear used within the SPRFMO Commission Area, spatial mismatches between data from benthic surveys and bycatch from benthic trawls, and high uncertainty in the estimates of seafloor biomass. Consequently, inferences from those analyses are limited as gear-specific, taxon-specific and ideally location-specific estimates of catchability are required if catchability is to be incorporated into the development of encounter thresholds.

In its report SC7 "*noted that estimates of catchability may, in the future, be useful in converting reported bycatch of VME indicator taxa into estimates of the extent of the impact of individual events on VME indicator taxa on the seafloor which could help inform the review of VME indicator thresholds in SPRFMO CMM 03-2019*". However, as already noted, to implement this approach we require more robust area- and taxon-specific estimates of catchability. To achieve estimates of catchability with less uncertainty we need to compare VME indicator taxa bycatch weights from bottom trawls to those determined from seafloor imagery from exactly the same area swept by the trawls, and at the same time. To achieve this goal several key pieces of work should be undertaken:

- Deploying headline and net cameras on commercial trawls to estimate taxon-specific abundance of VME indicator taxa on the seafloor;

- Developing metrics to convert taxon-specific estimates of abundance into biomass estimates;
- Determining catchability estimates directly by comparing tow-specific biomass of VME indicator taxa landed on deck with tow-specific estimates of seabed biomass from headline and net cameras.

6. Recommendations

It is recommended that the Scientific Committee:

- **Notes** that the candidate encounter thresholds for VME indicator taxa have been updated using the most up-to-date New Zealand bycatch data.
- **Recommends** to the Commission that the updated candidate encounter thresholds for VME indicator taxa are used to inform any future refinement of the VME indicator taxa thresholds included in Annex 6A and 6B of SPRFMO CMM03-2021.
- **Recommends** to the Commission that it adds to the VME Encounters and Benthic Bycatch task in the Scientific Committee Multi-Annual Work Plan a 2023+ subtask to implement a data collection programme within the SPRFMO Convention Area to allow the determination of taxon-specific estimates of catchability for VME indicator taxa.
- **Recommends** that in the interim, the best available catchability estimates are used to improve the Commissions understanding of the implications of the current encounter thresholds with regard to preventing significant adverse impacts on VMEs.

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Appendix 1 - Assignment of benthic taxonomic codes used by New Zealand scientific observers to VME indicator taxa

Table A1.1 | Assignment of benthic bycatch taxa to higher order VME indicator taxa groups, where NZ Code is the benthic taxonomic code used by scientific observers to report benthic bycatch in the SPRFMO Convention Area.

VME indicator taxon	NZ Code	Taxa	Common Name
Porifera	ONG	Porifera	Sponges
Porifera (Demospongiae)	ANZ	Ecionemia novaezelandiae	Knobbly sandpaper sponge
Porifera (Demospongiae)	APU	Aciculites pulchra	Maroon pimpled ear sponge
Porifera (Demospongiae)	CFU	Corallistes fulvodesmus	Smooth white cup sponge
Porifera (Demospongiae)	CRM	Callyspongia sp.	Airy finger sponge
Porifera (Demospongiae)	DSO	Demospongiae	Demosponges
Porifera (Demospongiae)	GRE	Geodia regina	Curling stone sponge
Porifera (Demospongiae)	GVE	Geodia vestigifera	Ostrich egg sponge
Porifera (Demospongiae)	LBI	Lissodendoryx bifacialis	-
Porifera (Demospongiae)	PAZ	Pachymatisma sp.	Rocky dumpling sponge
Porifera (Demospongiae)	PHB	Phorbas sp.	Grey fibrous massive sponge
Porifera (Demospongiae)	PHW	Psammocinia cf hawere	-
Porifera (Demospongiae)	PLN	Poecillastra laminaris	Chipped fibreglass matt sponge
Porifera (Demospongiae)	RHA	Rhabdastrella sp.	Pink ice egg sponge
Porifera (Demospongiae)	SLT	Stelletta sp.	Orange fat finger sponge
Porifera (Demospongiae)	THN	Thenea novaezelandiae	Yoyo sponge
Porifera (Demospongiae)	TLD	Tetilla leptoderma	Furry oval sponge
Porifera (Demospongiae)	TTL	Tetilla australe	Bristle ball sponge
Porifera (Hexactinellida)	ERE	Euplectella regalis	Basket-weave horn sponge
Porifera (Hexactinellida)	FAR	Farrea sp.	Lacey honeycomb sponge
Porifera (Hexactinellida)	GLS	Hexactinellida	Glass sponges
Porifera (Hexactinellida)	HYA	Hyalascus sp.	Floppy tubular sponge
Scleractinia	CBR	Dendrophylliidae, Oculinidae, Caryophylliidae	Stony branching corals
Scleractinia	CUP	Flabellidae, Fungiacyathidae, Caryophyllidae	Stony cup corals
Scleractinia	DDI	Desmophyllum dianthus	-
Scleractinia	ERO	Enallopsammia rostrata	Deepwater branching coral
Scleractinia	GDU	Goniocorella dumosa	Bushy hard coral
Scleractinia	MOC	Madrepora oculata	
Scleractinia	OVI	Oculina virgosa	-
Scleractinia	SIA	Scleractinia	Stony corals
Scleractinia	SVA	Solenosmilia variabilis	-
Antipatharia	ATP	Antipathes spp.	-
Antipatharia	BTP	Bathypathes spp.	-
Antipatharia	COB	Antipatharia	Black coral
Antipatharia	DDP	Dendropathes spp.	-
Antipatharia	DEN	Dendrobathypathes spp.	-
Antipatharia	LEI	Leiopathes spp.	-
Antipatharia	LIL	Lillipathes spp.	-
Antipatharia	LSE	Leiopathes secunda	-
Antipatharia	PTP	Parantipathes spp.	-
Antipatharia	SLP	Stylopathes spp.	-
Antipatharia	STI	Stichopathes spp.	-
Antipatharia	TDP	Triadopathes spp.	-
Antipatharia	TPT	Trissopathes spp.	-

Alcyonacea	ARO	Anthomastus (Bathyalcyon) robustus	-
Alcyonacea	SOC	Alcyonacea	Soft coral
Gorgonacea	ACN	Acanella sp.	Bushy bamboo coral
Gorgonacea	BOO	Keratoisis sp.	Bamboo coral
Gorgonacea	CHR	Chrysogorgia sp.	Golden coral
Gorgonacea	CLG	Callogorgia spp.	-
Gorgonacea	CLL	Corallium sp.	Precious coral
Gorgonacea	CTP	Calyptrophora spp.	-
Gorgonacea	GOC	Gongonacea	Gorgonian coral
Gorgonacea	IRI	Iridogorgia sp.	Iridescent coral
Gorgonacea	ISI	Isididae	Bamboo corals
Gorgonacea	LLE	Lepidsis sp.	Bamboo coral
Gorgonacea	MTL	Metallogorgia sp.	Metallic coral
Gorgonacea	NAR	Narella sp.	Rasta coral
Gorgonacea	PAB	Paragorgia arborea	Bubblegum coral
Gorgonacea	PLE	Plexauridae	Sea fans
Gorgonacea	PMN	Primnoa spp.	-
Gorgonacea	PPI	Primnoidae	-
Gorgonacea	PRI	Primnoidae	-
Gorgonacea	THO	Thouarella sp.	Bottlebrush coral
Pennatulacea	AGF	Anthoptilum grandiflorum	Flower sea pen
Pennatulacea	ALF	Acanthoptilum longifolium	Long-leaf sea pen
Pennatulacea	DGR	Distichoptilum gracile	Two-lined sea pen
Pennatulacea	FQU	Funiculina quadrangularis	Rope-like sea pen
Pennatulacea	GYS	Gyrophyllum sibogae	Siboga sea pen
Pennatulacea	PNN	Pennatula sp.	Feathery sea pens
Pennatulacea	PTU	Pennatulacea	Sea pens
Pennatulacea	SPN	Pennatulacea	Sea pen
Actiniaria	ACS	Actinostolidae	Smooth deepsea anemones
Actiniaria	ATR	Actiniaria	Sea anemones
Actiniaria	BOC	Bolocera sp.	Deepsea anemone
Actiniaria	HMT	Hormathiidae	Deepsea anemone
Actiniaria	LIP	Liponema sp.	Deepsea anemone
Zoantharia	EPZ	Epizoanthus spp.	-
Zoantharia	ZAH	Zoantharia	Zoanthids
Hydrozoa	HDF	Leptomeduseae, Anthoathecatae (excluding family Stylasteridae)	Feathery hydroids
Stylasteridae	COR	Stylasteridae	Hydrocorals
Stylasteridae	CRE	Calyptopora reticulata	White hydrocoral
Stylasteridae	CRY	Cryptelia spp.	-
Stylasteridae	ERR	Errina sp.	Red coral
Stylasteridae	LPT	Lipidotheca sp.	Spiny lace coral
Bryozoa	COZ	Bryozoa	Bryozoan
Brisingida	BRG	Brisingida	-
Crinoidea	CMT	Comatulida	Feather star
Crinoidea	CRI	Crinoidea	Sea lilies
Crinoidea	CRN	Isocrinida, Millericrinida, Cyrtocrinida	Sea lily, stalked crinoid
Crinoidea	GIN	Glyptometra inaequalis	-

Appendix 2 - Zero Weight Adjustments

Table A2.1 | Number of trawl events, bycatch range (kg), trawl events with zero weights recorded and the zero weight adjustment used in the analysis.

VME indicator taxon	No. trawl events	Bycatch range (kg)	N (%) trawl events with zero weight records	Adjusted weight (kg)
PFR - Porifera	907	0 - 1091.2	2 (0.22%)	0.02
CSS - Scleractinia	1395	0 - 5000	3 (0.21%)	0.04
AQZ - Antipatharia	739	0 - 10.4	17 (2.3%)	0.001
AJZ - Alcyonacea	7	0.05 - 0.5	0 (-)	-
GGW - Gorgonacea	681	0 - 200	16 (2.3%)	0.001
NTW - Pentulacea	99	0 - 3.6	1 (1.01%)	0.1
ATX - Actiniaria	877	0.02 - 77	0 (-)	-
ZOT - Zoantharia	544	0.1 - 114	0 (-)	-
HQZ - Hydrozoa	12	0 - 1.3	1 (8.33%)	0.02
AXT - Stylasteridae	33	0 - 8	1 (3.03%)	0.02
BZN - Bryozoa	3	0.1 - 4	0 (-)	-
BHZ - Brisingida	29	0.02 - 5	0 (-)	-
CWD - Crinoidea	59	0 - 2	1 (1.69%)	0.04

Appendix 3 - Comparisons of thresholds calculated with and without interpolation

Table A3.1 | Percentiles calculated from ordered values. The number of bottom trawl tows recorded as bycatch (n), range in bycatch weight (kg), reference points ((0,1) distance and Youden distance) and percentiles in bycatch weight per VME indicator taxon recorded in all New Zealand bottom trawls within the Evaluated Area of the SPRFMO Convention Area between 2008 and 2020. Cell shading indicates percentiles above (blue) and below (green) both reference points. Grey cells indicate reference points could not be calculated due to insufficient sample sizes. Note, candidate encounter thresholds are presented for Porifera as a Phylum, and also disaggregated into the Classes Demospongiae and Hexactinellidae.

			Reference Points		Percentiles (candidate encounter thresholds in kg)								
VME indicator taxon	**n**	**range (kg)**	**(0,1)**	**Youden**	**0.7**	**0.8**	**0.85**	**0.9**	**0.95**	**0.96**	**0.97**	**0.98**	**0.99**
Porifera	907	0.02 - 1091.2	26.00	26.00	2.00	3.00	5.00	7.10	12.70	15.00	20.00	23.10	50.00
Demospongiae	164	0.10 - 155	13.90	13.90	2.20	5.00	6.00	10.00	12.00	13.50	13.90	20.00	95.00
Hexactinellidae	430	0.02 - 200	10.00	10.00	1.10	2.00	3.00	4.20	7.28	10.00	15.00	20.00	45.00
Scleractinia	1395	0.04 - 5000	60.00	60.00	2.40	5.00	5.20	10.00	20.00	30.00	40.00	80.00	250.00
Antipatharia	739	0.001 - 10.4	1.10	1.10	0.60	1.00	1.00	1.90	2.90	3.00	3.90	4.80	5.50
Alcyonacea	7	0.05 - 0.5	-	-	0.20	0.30	0.30	0.50	0.50	0.50	0.50	0.50	0.50
Gorgonacea	681	0.01 - 200	5.70	5.70	1.00	1.00	1.30	2.00	5.20	7.50	15.11	24.10	40.50
Pennatulacea	99	0.1 - 3.6	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	3.60
Actiniaria	977	0.02 - 77	10.00	10.00	5.00	7.00	9.60	11.20	20.00	20.20	24.00	30.00	35.30
Zoantharia	544	0.1 - 114	5.00	5.00	1.00	1.00	1.00	2.00	3.00	5.00	5.00	10.00	12.20
Hydrozoa	12	0.02 - 1.3	-	-	0.50	1.00	1.00	1.00	1.30	1.30	1.30	1.30	1.30
Stylasteridae	33	0.02 - 8	1.00	1.00	0.90	1.00	1.00	1.00	2.00	2.00	8.00	8.00	8.00
Bryozoa	3	0.1 - 4	-	-	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Brisingida	29	0.02 - 5	1.00	1.00	1.00	1.00	1.00	2.00	3.00	3.00	5.00	5.00	5.00
Crinoidea	59	0.04 - 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00

Table A3.2 | Proportional differences in percentiles calculated from ordered values (presented in Table A3.1) and using linear interpolation (presented in Table 3), expressed as 1-interpolated/ordered. Cell shading indicates proportional differences < 0.01 (green), 0.01-0.05 (light green), 0.05-0.10 (yellow), 0.10-0.20 (orange and > 0.20 (red).

	Percentiles								
VME indicator taxon	**0.7**	**0.8**	**0.85**	**0.9**	**0.95**	**0.96**	**0.97**	**0.98**	**0.99**
Porifera	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01
Demospongiae	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.08	0.49
Hexactinellidae	0.00	0.00	0.00	0.00	0.02	0.00	0.06	0.00	0.08
Scleractinia	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.11
Antipatharia	0.00	0.00	0.00	0.04	0.09	0.00	0.00	0.03	0.00
Alcyonacea	-0.10	0.07	-0.07	0.24	0.12	0.10	0.08	0.04	0.02
Gorgonacea	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.15
Pennatulacea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71
Actiniaria	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01
Zoantharia	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.34	0.02
Hydrozoa	0.06	0.10	0.00	0.00	0.12	0.10	0.08	0.05	0.02
Stylasteridae	0.07	0.00	0.00	0.00	0.09	0.04	0.72	0.48	0.24
Bryozoa	0.56	0.37	0.28	0.19	0.09	0.08	0.06	0.04	0.02
Brisingida	0.20	0.00	0.00	0.40	0.13	0.04	0.34	0.22	0.11
Crinoidea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29

Appendix 4 Encounter thresholds calculated using inverse cumulative distribution curves

An alternative approach to calculating candidate encounter thresholds for VME indicator taxa was based on plotted taxon-specific inverse cumulative catch curves (Figure A4.1) and calculating candidate thresholds required to avoid 70%, 80%, 90% and 95% of historic bycatch, where the use of inverse cumulative distribution curves prioritizes the avoidance of the largest bycatch events first. However, large bycatch weights are often visually estimated, often to the nearest tonne (see first 6 points in Figure A4.1).

As a consequence of inverse cumulative distribution curves prioritizing the avoidance of the largest bycatch events first, the cumulative percent bycatch (y-axis) is sensitive to errors in the estimation of the weight of large bycatch events, which can be less precise than the estimation of weights in small bycatch events.

The use of inverse cumulative distribution curves is more commensurate with encounter protocols being the primary means for preventing significant adverse impacts on VMEs, rather than acting as a "backstop" to spatial management measures.

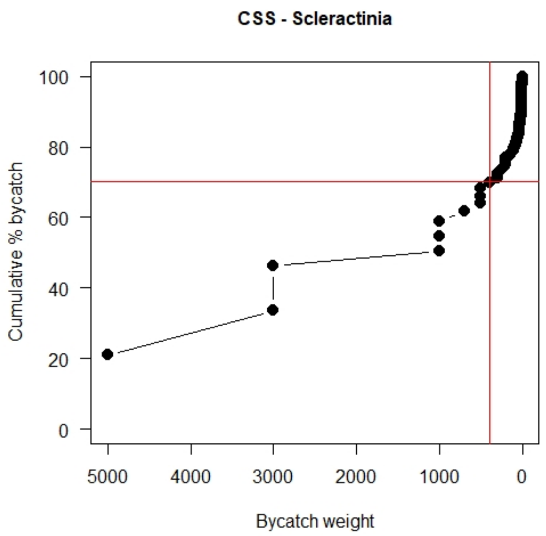

Figure 4.1 | Inverse cumulative distribution curve for the weight of Scleractinia bycatch from the 2008-20 New Zealand bottom trawl fishery in the SPRFMO Convention Area. The intersection of the horizontal red line with the inverse cumulative distribution curve represents the encounter threshold required to avoid 70% of historic bycatch of Scleractinia, which corresponds to 400 kg.

Table 4.1 | Candidate encounter thresholds for VME indicator taxa calculated from inverse cumulative distribution curves. The number of bottom trawl tows recorded as bycatch (n), range in bycatch weight (kg), and weight thresholds required to avoid 70, 80, 90 and 95% percent of historical bottom trawl bycatch. Note, encounter thresholds are presented for Porifera as a Phylum, and also disaggregated into the Classes Demospongiae and Hexactinellidae.

			Weight (kg)			
VME indicator taxon	**n**	**range (kg)**	**70%**	**80%**	**90%**	**95%**
Porifera	907	0.02 - 1091.2	10.00	5.00	2.00	1.00
Demospongiae	164	0.10 - 155	7.30	5.00	2.00	1.00
Hexactinellidae	430	0.02 - 200	4.70	2.83	1.00	1.00
Scleractinia	1395	0.04 - 5000	400.00	90.00	11.50	5.00
Antipatharia	739	0.001 - 10.4	1.00	0.60	0.30	0.20
Alcyonacea	7	0.05 - 0.5	0.20	0.20	0.10	0.10
Gorgonacea	681	0.01 - 200	11.40	2.30	1.00	0.50
Pennatulacea	99	0.1 - 3.6	0.50	0.30	0.20	0.10
Actiniaria	977	0.02 - 77	5.30	4.00	2.40	1.50
Zoantharia	544	0.1 - 114	1.00	1.00	0.60	0.40
Hydrozoa	12	0.02 - 1.3	0.50	0.40	0.20	0.20
Stylasteridae	33	0.02 - 8	1.00	0.80	0.50	0.30
Bryozoa	3	0.1 - 4	4.00	4.00	4.00	0.30
Brisingida	29	0.02 - 5	1.00	1.00	0.30	0.10
Crinoidea	59	0.04 - 2	1.00	1.00	0.30	0.10