SPRFMO
South Pacific Regional Fisheries Management Organisation

9th MEETING OF THE SCIENTIFIC COMMITTEE

Held virtually, 27 September to 2 October 2021

SC9-DW07

Determination of Optimal Move-on Distance in SPRFMO Bottom Fisheries

New Zealand

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Determination of optimal move-on distance in SPRFMO bottom fisheries

Marco Milardi[1], Shane Geange[2], Ashley Rowden[3], Owen Anderson[3], Fabrice Stephenson[3]

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1 – Fisheries New Zealand - Tini a Tangaroa, Ministry for Primary Industries - Manatū Ahu Matua, Wellington, New Zealand

2 – Department of Conservation – Te Papa Atawhai, Wellington, New Zealand

3 – National Institute of Water & Atmospheric Research (NIWA) – Taihoro Nukurangi, Wellington, New Zealand

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1. Purpose

This paper presents the results of analyses on the theoretical protection afforded, and the impact to fisheries, of the current move-on distance and potential alternative move-on distances, based on the size and distribution of predicted Vulnerable Marine Ecosystem (VME) habitat patches. Results are for consideration of the Scientific Committee (SC) and with the purpose of developing a recommendation to the SPRFMO Commission on the appropriateness of the current move-on distance for encounters with VMEs.

2. Background

Move-on rule

Potential encounters with VMEs are detected when VME indicator taxa caught in a trawl tow exceed certain weight thresholds, or combination of weight thresholds (CMM03-2021). The recording of such an encounter triggers a "move-on" rule. This rule stipulates that a vessel must move a minimum distance from the location where taxa indicating the presence of a VME are captured by the trawl gear. Concerns about the efficacy of the move-on rule for preventing impacts to VMEs have been raised in the past, including the concern that move-on distances are not based on the distribution patterns of the VME indicator taxa (Auster et al. 2011). That is, triggering the move-on rule using an arbitrary defined distance is unlikely to always result in moving trawling away from an area containing a VME, and might cause a resumption of fishing within the area containing the same VME or within an area containing another VME (thereby 'spreading' the potential impact). The efficacy of move-on rule distances has only rarely been examined using empirical bycatch data available from fisheries. But, given sufficient data, it is possible to conduct an analysis to identify distances that can potentially reduce the bycatch (i.e., impact) while simultaneously minimizing lost opportunities for fishers (Dunn et al. 2014).

Move-on distance in SPRFMO

The Conservation and Management Measure for the Management of Bottom Fishing in the SPRFMO Convention Area (**CMM-03-2021**) requires that:

"Where VME indicator taxa are encountered in any one tow at or above the threshold limits in Annex 6A, or three or more different VME indicator taxa at or above the weight limits in Annex 6B, Members and CNCPs shall require any vessel flying their flag to:

a) cease bottom fishing immediately within an encounter area of one (1) nautical mile either side of the trawl track extended by one (1) nautical mile at each end;…"

The European Union, at the 9th meeting of the SPRFMO Commission, proposed to increase this distance from 1 to 5 nautical miles as an additional precautionary measure to prevent significant adverse impacts to VMEs (COMM9-Prop03). Following discussion, the proposal developed into a specific task of the SPRFMO SC's Multi-Annual Work Plan to "Develop advice on appropriate move-on distances for potential VME encounters, based on the size and spatial clustering of VME indicator taxa distributions" (Scientific Committee Multi Annual Plan).

Wider RFMO context

All current bottom trawling encounter protocols incorporated within conservation and management measures used by other Regional Fisheries Management Organizations, Agreements and Commissions (henceforth referred to collectively as RFMOs) require a 2 nautical miles (nm) move-on distance (Table 1), although how that distance was selected is unclear.

However, RFMOs apply the 2 nm move-on distance differently, with some applying the move-on distance relative to the endpoint of the trawl track, whereas others apply it as a buffer around the length of the trawl track (Table 1). For example, SEAFO (CM 30/15, Article 8 -1 b - (i) and (ii)) requires vessels to move away at least 2 nm from the end point of the trawl tow that triggered an encounter, in the direction least likely to result in further encounters. NEAFC (Rec 10:2021, Article 8 -1 b - (i) and (ii)) - 1) requires movement 2 nm away from a trawl track that triggers an encounter, and 2 nm from the position that the evidence suggests is closest to the exact encounter location for other bottom fishing gears. NAFO (CEM 2021, Article 22(2)-a-2-(ii)) requires moving away at least 2 nm from the endpoint of the trawl tow/ longline set that triggers an encounter, in the direction least likely to result in further encounters. The master of the vessel is allowed to use best judgment to determine such direction. As such, the area of the seafloor effectively protected by application of the 2 nm move-on rule by other RFMOs varies considerably.

Table 1: Summary of the move on distances required by encounter protocols for bottom trawl fisheries in different RFMOs, as of 2021.

RFMO	Move-on distance
NPFC	2 nm
NAFO	2 nm from endpoint of tow in direct least likely to result in further encounters
NEAFC	2 nm wide band on both sides of the bottom trawl tracks, extended by 2 nm at both ends, or 2 nm from the position that is closest to the exact encounter location for other fishing methods
SEAFO	2 nm from the end point of a trawl tow in the direction least likely to result in further encounters and define a buffer of 2 nm radius
SIOFA	2 nm either side of a trawl track extended by 2 nautical miles at each end
SPRFMO	1 nm either side of the trawl track extended by 1 nm at each end
GFCM	No encounter protocol adopted
CCAMLR	N/A - no bottom trawling allowed

In 2015, the Food and Agriculture Organization of the United Nations (FAO) held a workshop on impact assessments and encounter protocols for deep-sea fisheries in the areas beyond national jurisdiction (FAO 2016). During the workshop, participants noted that the initial encounter protocols adopted by RFMOs were based on a rapid effort to comply with UNGA Resolution 61/105, para 83, before the deadline of 31 December 2008. The workshop also noted that for many areas, data are limited, but also that as more information on VMEs and impacts from bottom fishing activities becomes available, there should be a move to modify encounter protocols and RFMOs should update conservation measures to reflect the best available scientific information.

Specific recommendations from the workshop included:

1. Design protocols that ensure that the move-on distances and directions meet conservation objectives, while not placing undue burden on the fishing operators.

2. Protocols requiring vessel movement away from the entire trawl track (rather than the endpoint of the tow, for example) should usually be the preferred option.
3. The move-on distance should ideally be based on characteristics of the regional ecosystem (e.g., VME patch sizes, distance between patches, etc.).
4. Move-on provisions should ideally be suited to specific geomorphological features, and the spatial distribution patterns of associated VMEs with different features such as seamounts, slopes, canyons, etc.
5. The selection of a move-on distance relates back to the specification of a VME.

Taking into consideration the specific recommendations from the 2015 FAO workshop, we evaluated move-on distances of 1, 2, 5 and 10 nm with respect to available information on the size and spatial clustering of VME indicator taxa distributions to determine the optimal move-on distance for meeting conservation objectives while not placing undue burden on fishing operators. Finally, we outline the assumptions and caveats associated with our analyses, and identify future research required to draw wider conclusions.

3. Materials and Methods

Spatial scale and location

Ideally, the analysis to develop advice on appropriate move-on distances for potential VME encounters would be based on information that covered the "Evaluated Area"[1] of the SPRFMO Convention Area. Therefore, we first assessed the appropriateness of using presence-only habitat suitability models for VME indicator taxa (Stephenson et al. in press), developed for the Evaluated Area, to predict the size and distribution of VME habitat patches. Unfortunately, there were little information/data that could be used to identify a habitat suitability index (HSI) threshold that would likely identify a realistic VME habitat patch using these models. That is, using the very few reported bycatch data for VME indicator taxa above the encounter weight thresholds that could be correlated to the modelled habitat suitability data, there was no evidence of a relationship between predicted HSI and bycatch data. Consequently, it was not possible to identify a reliable HSI threshold for delineating VME habitat patches that likely equated to an encounter by a trawl tow. Furthermore, the application of arbitrarily defined high HSI values (0.65. 0.74. 0.84), based on a power relationship between HSI and VME indicator taxa abundance (SC8-DW07-Rev1), identified unrealistically large habitat patches (i.e., predicted to cover large parts of seamounts where no such large habitat patches have been directly observed by camera surveys). This result is at least in part because the grid cell size (1 km) of the Stephenson et al. (in press) habitat suitability models for VME indicator taxa is too large to represent a 'typical' patch size of habitats formed by most VME indicator taxa (e.g., stony coral reefs in the South Pacific have been observed to be mostly <1 km^2, Williams et al. 2020).

As an alternative to using presence-only habitat suitability models for VME indicator taxa at the scale of the Evaluated Area, fine-scale (25 x 25 m grid cell) abundance-based models for three VME indicator taxa (*Solenosmilia variabilis*, Brisingida, Crinoidea) are available for a small sub-set of the Evaluated Area (Rowden et al. 2017). We considered these models suitable for describing the spatial distribution

[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 (as identified in Annex 1 of CMM03-2021).

of VME habitat patches (see below). These models cover six seamounts on the Louisville Seamount Chain (LSC), with three of these seamounts closed to fishing (39South, Forde, JCM), and three open to fishing (Censeam, Ghost and Valerie) under CMM03-2021 (Figure 1).

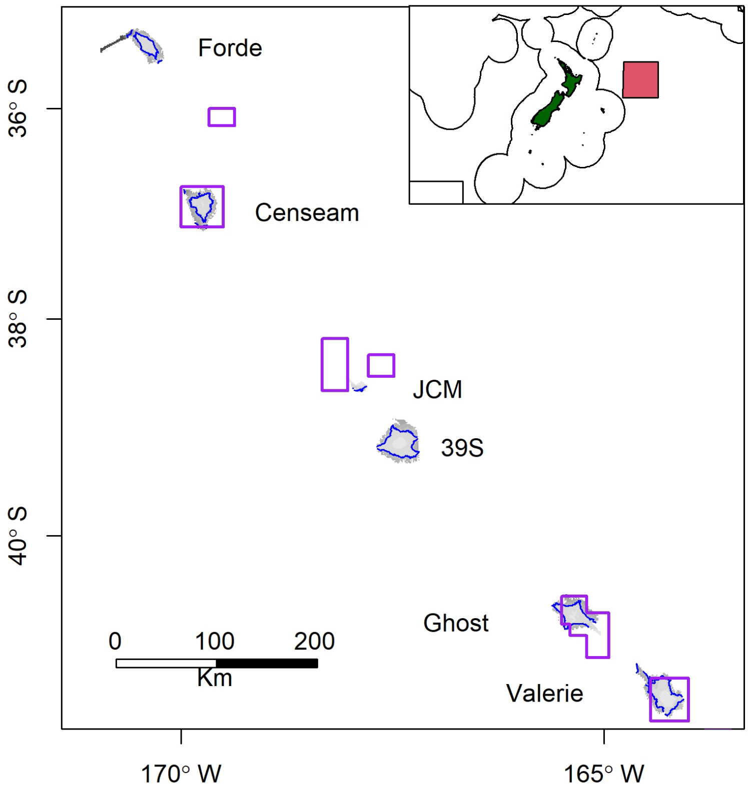


Figure 1: Seamounts of the Louisville Seamount Chain included in the move-on distance analysis. Purple boxes show SPRFMO Management Areas open to fishing, blue lines indicate the spatial extent of the distribution and abundance models for the VME indicator taxon, *Solenosmilia variabilis* (Scleractinia).

VME indicator taxon

Of the abundance-based distribution models available for the analysis (Rowden et al. 2017), we selected the model for the stony coral *Solenosmilia variabilis*. Models for Brisingida and Crinoidea were not selected because these taxa are considered as "VME habitat indicators" of the stony coral reefs formed by *Solenosmilia variabilis* (Parker et al. 2009), and therefore any analysis of data from these models would be redundant at best. *Solenosmilia variabilis* is the predominant representative of the Scleractinia (stony corals) VME indicator taxon for the SPRFMO area found on the LSC seamounts (Anderson et al. 2016). Stony corals can form reef structures, which are known or likely to satisfy all five of the criteria used to identify a VME (FAO 2009). *Solenosmilia variabilis* forms reefs that are fragile and susceptible to degradation by anthropogenic activities (criterion iii) (Koslow et al. 2001, Althaus et al. 2009, Clark & Rowden 2009,) and it has life-history traits that make recovery difficult from such disturbances (criterion iv) (e.g., long-lived, Fallon et al. 2014, Hitt et al. 2020). Furthermore, *Solenosmilia variabilis* forms reefs that are structurally complex and have a high diversity which is dependent on this structuring species (criterion v) (Rowden et al. 2020). While there is currently no published evidence that *Solenosmilia variabilis*-formed reefs provide functional significant habitat (criterion ii), studies of reefs formed by similar stony coral species elsewhere have demonstrated that these habitats are of particular significance for some fish species, including as a spawning ground (Husebø et al. 2002, Henry et al. 2013). *Solenosmilia variabilis* is globally distributed species and is thus not unique to the SPRFMO area. However, while it is predicted to occur throughout the area (Anderson et al. 2016), it is one of the VME indicator taxa that has the least amount of grid cells with a predicted HSI >0.5 (Stephenson et al. in press). Therefore, at the scale of the Evaluated Area and compared to other VME indicator taxa, it could be considered relatively rare (criterion i). Furthermore, the coral reefs that this species forms could provide important habitat for endemic, threatened or endangered species whose loss may not be compensated for by similar areas or ecosystems elsewhere (also criterion i). Studies to evaluate the importance of *Solenosmilia variabilis* reef habitat for such species have not been conducted in the SPRFMO Area nor the Australian nor New Zealand regions. However, similar coral reefs in the North Atlantic apparently provide habitat for species not recorded elsewhere (Jensen & Frederiksen 1992).

Defining and describing VME habitat patches

To define coral reefs, we applied abundance thresholds to the fine-scale abundance-based ensemble model for *Solenosmilia variabilis* on the six LSC seamounts (Rowden et al. 2017). The three available abundance thresholds relate to: (1) a subjective coral density definition of coral reef habitat in the New Zealand EEZ applied to the LSC seamounts (>2.78 coral heads per 25 m^2, Rowden et al. 2017); (2) coral reefs similarly identified on seamounts in the Tasman Sea (>5.6 coral heads per 25 m^2, Williams et al. 2020); and (3) an objectively defined abundance threshold for coral reefs on Forde Seamount that are capable of supporting a high diversity of other species (>3.5 coral heads per 25 m^2, Rowden et al. 2020). Figure 2 illustrates the variation in the size and clustering of the coral reef habitat patches when the three abundance thresholds are applied to the abundance model for *Solenosmilia variabilis* in the northwest corner of Forde seamount, at the resolution of the 25 x 25 m model grid cells.

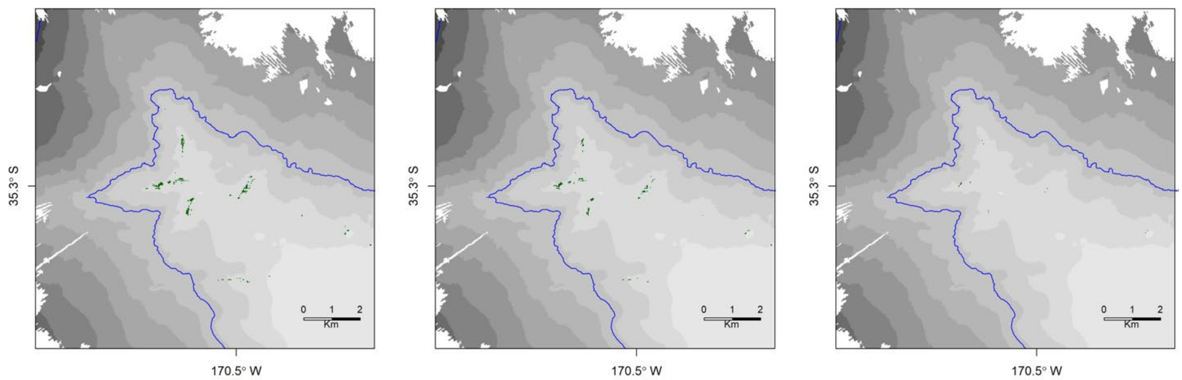


Figure 2: Digital terrain maps of the northwest corner of Forde seamount illustrating the application of the three abundance thresholds (left: >2.78; middle: >3.5; right: >5.6 coral heads per model cell) to the abundance model for *Solenosmilia variabilis* used to identify coral reef habitat patches (green) within the modelled area (blue line).

We selected the abundance threshold of >3.5 coral heads per model cell as the most 'realistic' density threshold corresponding to a coral reef patch that would be likely to trigger an encounter, should it be trawled upon. That is, this abundance threshold operationalizes the FAO criteria for identifying VMEs by identifying "significant concentrations" of a structure-forming organism that supports a "high diversity" of associated or dependent fauna (see also the text above that argues that it is likely such identified coral reef patches would also likely satisfy the other FAO criteria for identifying a VME). To illustrate the 'sensitivity' of the analysis to the abundance threshold used, results derived with the lower and higher subjectively-derived thresholds are presented in Appendix 1 and 2, respectively (NB: these do not represent lower or higher confidence bounds of the threshold chosen for our study).

To describe the size and distribution patterns of the VME habitat patches, we calculated five patch landscape metrics using the R package 'landscapemetrics' (Hesselbarth et al., 2019). These metrics were: (1) number of patches (individual patches were defined using the 4-cell rule - i.e., only cells directly adjacent to each other will be aggregated); (2) area of patches; (3) minimum distance between patches, i.e., the Euclidean Nearest Neighbour (ENN) distance; (4) contiguity index, i.e., the spatial connectedness of 25 m x 25 m cells in patches. Contiguity index values range from 0 to 1, where 0 indicates a one-cell patch and increases as patch connectedness increases; and (5) patch density, i.e., the fragmentation of a patch standardised by the total landscape area (in this case the total seamount area), increasing from 0 to 1,000,000 as the landscape becomes patchier.

Assessment framework

To realistically simulate encounters between bottom fishing trawl tows and the size and spatial clustering of stony coral 'VME habitat patches' on each seamount, we used historic New Zealand bottom trawl data (1989-2019) (very little fishing from other SPRFMO Members has occurred in the LSC area). Tow data was treated using methods previously reviewed by the SPRFMO SC to jitter rounded positions, adjust trawl data for gear offset used to determine the fisheries footprint, and set a nominal tow width of 115 m (see SC8-DW07_Rev1).

We applied 'polygons' representing the application of move-on distances of 1, 2, 5 and 10 nm to all historic tows (i.e., either side of the trawl tow track extended by the same distance at each end) that encountered one or more VME habitat patches defined by the abundance threshold (Figure 3). For each of these simulated encounters, we calculated the number of additional encounters that could occur within the move-on distance areas, based on the distribution of the trawl tows relative to the distribution of the VME habitat patches, and the proportion of tows that would be displaced by the encounter. We also calculated a standardized number of additional encounters, based on the area of the polygons, to account for the square increase of area originating from linear increases in the move-on distance.

To determine the number of additional encounters that could theoretically occur within the move-on polygons, we estimated the mean and standard deviations of additional encounters for each move-on distance (1, 2, 5 and 10 nm).

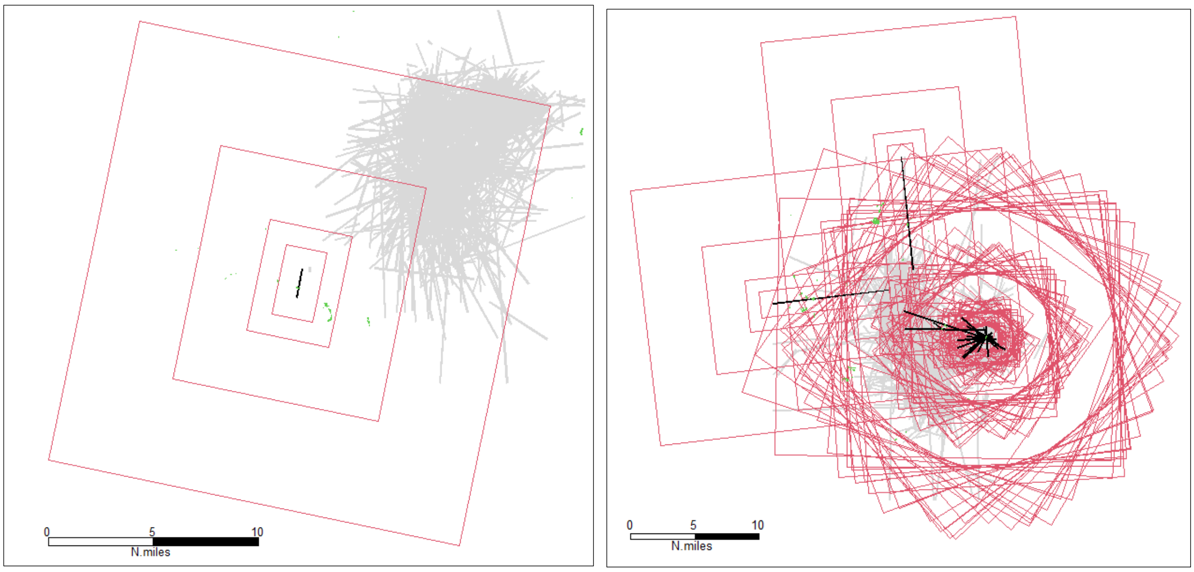


Figure 3: Spatial configuration of bottom trawl tows (grey polygons) and simulated encounters (solid black polygons) with predicted VME habitat patches (green; note these are small and hard to see). Polygons for move-on distances of 1, 2, 5 and 10 nm are shown (red rectangles) for the 1 encounter on 39South seamount (left) and the 29 encounters on Valerie seamount (right). An abundance threshold of >3.5 coral heads per model cell was used to define VME habitat patches.

To determine the potential implications for the fishery of the different move-on distances, we calculated the proportion of the currently used and accessible area that would be theoretically closed to the fishery with the application of the move-on distances. That is, the combined move-on distance polygon area for all tows that encountered VME habitat patches, for each move-on distance, as a proportion of: (1) the historical trawl footprint on a seamount; (2) the seamount feature (defined by the bathymetric extent of models for the VME habitat patches, i.e., 2000 m); and (3) the Management Area enclosing each seamount open to trawling. We clipped encounter tows that only partly occurred within a move-on distance area to exclude sections lying outside the encounter area (Figure 4). We only applied this analysis to seamounts currently open to trawling.

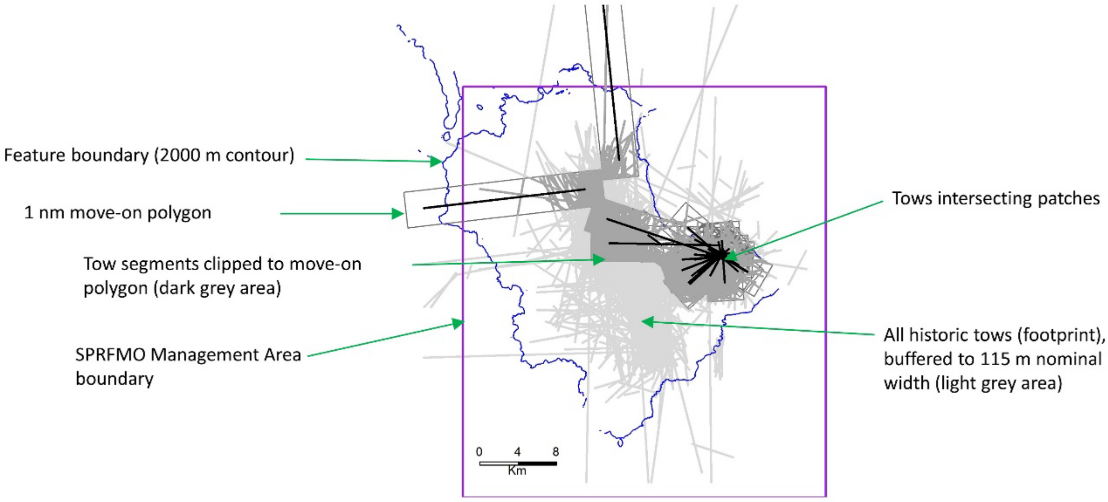


Figure 4: Illustration, on Valerie seamount, of the application of the three metrics used to determine the impact on the fishery for the different VME encounter move-on distances.

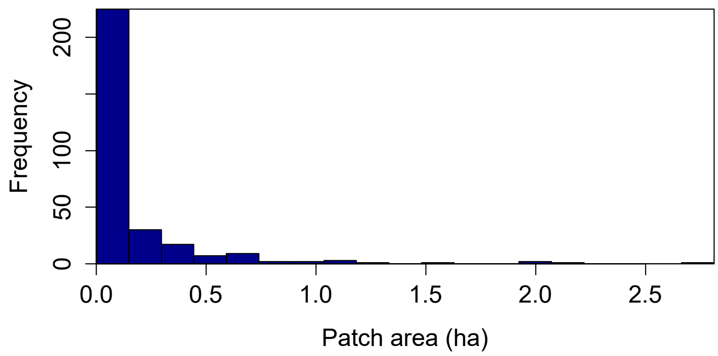
Additional analyses

We carried out additional analyses to: (1) identify the optimal move-on distance based on using empirical bycatch data; and (2) to see if we could directly support the assumption that VME habitat patches identified by thresholding abundance models were likely to result in an encounter if contacted by a trawl tow. For the first analysis, there were too few data to use the approach of Dunn et al. (2014), so we examined the pattern of additional encounters with increasing move-on distances, where the initial encounters were those tows that recorded a stony coral bycatch weight above the current encounter threshold of 60 kg (we also used lower arbitrary thresholds of 5 kg and 10 kg). There are relatively few such tows, but the results of this analysis for 60 kg were similar to those of the theoretical encounter tows described below. As such, the results of this analyses are not considered further in the main body of this report but are provided in Appendix AA. For the second analysis, bycatch records from only two of the 35 observed tows could be matched to the catch-effort tow data (by inference; there is no direct key link between the two data recording systems), and these tows caught 10 kg and 5.7 kg of stony coral. Neither of these two tows overlapped with the predicted VME habitat patches identified using any of the coral head thresholds used in the main analysis. The results of this, obviously inconclusive, second analysis are not considered any further in this report.

4. Results

VME habitat patch characteristics

Predicted VME habitat patches of stony coral reef, based on an abundance threshold of >3.5 coral heads, were overall small and highly clustered (Figure 5). The number of patches and other patch characteristics were variable across seamounts. The seamounts Valerie and Ghost, which are both open to trawling, have the most (183) and least (5) number of patches, respectively. The variation in the number of patches among the seamounts is generally reflected in the variation in patch density and contiguity (Table 2). The size and distribution characteristics of VME habitat patches identified using different patch abundance thresholds are provided in Appendix 1.1 and 2.1.



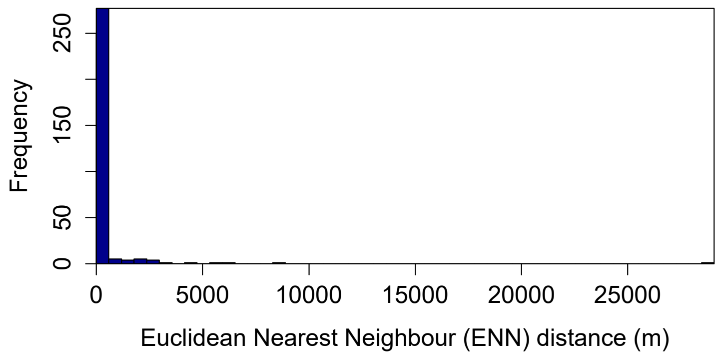


Figure 5: Frequency histograms of VME habitat patch area (top) and minimum distance between patches (bottom) on all seamounts. An abundance threshold of >3.5 coral heads per model cell was used to define VME habitat patches.

Table 2: Summary of VME habitat patch characteristics for all seamounts. An abundance threshold of >3.5 coral heads per model cell was used to identify VME habitat patches. Seamounts in italics are open to fishing. ENN = minimum Euclidean Nearest Neighbour distance. See Methods text for further details about each metric.

Seamount	**Number of patches**	**Patch area (ha)**	**Min-max patch area (ha)**	**ENN (m)**	**Min-max ENN (m)**	**Contiguity Index (0-1)**	**Patch density (0-1 million)**
Forde	43	0.27	0.06-2.19	142	35-1635	0.18	372
39South	50	0.19	0.06-2.06	485	35-5651	0.12	516
Censeam	11	0.07	0.06-0.19	401	35-1406	0.02	1354
Ghost	5	0.06	0.06-0.06	5852	50-29060	0.00	1600
JCM	9	0.07	0.06-1.13	1098	35-2929	0.02	1440
Valerie	183	0.2	0.06-2.81	193	35-8762	0.13	511

VME encounters

Theoretical encounters with VMEs occurred on only two of the six study seamounts (Table 3). There were zero theoretical encounters on seamounts with the lowest number of VME habitat patches, including two seamounts open to bottom trawling (Censeam and Ghost). There were 29 theoretical encounters on Valerie, the other open seamount, but these were a low proportion of the total number of trawl tows (< 2%). There was only one theoretical encounter on the closed seamount 39South (Table 3). The encounter summaries for the different VME habitat patch thresholds are provided in Appendix 1.2 and 2.2.

Table 3: Summary statistics for theoretical VME encounters for seamounts on the Louisville Seamount Chain. An abundance threshold of >3.5 coral heads per model cell was used to identify VME habitat patches. Seamounts in italics are open to fishing.

Seamount	**Number of tows**	**Number of VME patches on seamount**	**Max number of VME patches encountered on a single tow**	**Number of tows encountering one or more VME patches**	**Proportion of tows with encounter (%)**
Forde	371	43	0	0	0.00
39South	1142	50	3	1	0.09
Censeam	689	11	0	0	0.00
Ghost	4954	5	0	0	0.00
JCM	127	9	0	0	0.00
Valerie	2012	183	6	29	1.44
All	9295	301	6	30	0.32

For the two seamounts where theoretical initial VME encounters occurred, additional encounters from other tows only occurred in the move-on distance polygons on Valerie seamount. Most of these additional encounters occurred within 1 nm of the initial encounter tows (Table 4). Beyond 1 nm, on average, there were relatively few additional encounters, but these showed a slight increase with increasing move-on distances (Figure 6). The latter result could suggest a ‘spreading’ of encounters with increasing move-on distance, particularly between 5 nm and 10 nm. However, the average increase in additional encounters within the 10 nm move-on polygon was driven by just two tows on Valerie seamount (Table 4). The result of this analysis when accounting for spatial standardisation of the encounters is also shown in Figure 6.

Table 4: Detail of the total number of additional theoretical encounters from an initial encounter tow in each move-on distance polygon for the open seamount Valerie (the only seamount on which additional encounters occurred within the move-on areas). An abundance threshold of >3.5 coral heads per model cell was used to define VME habitat patches.

	Total number of additional encounters (in each move-on polygon area)			
Encounter tow	**1 nm**	**2 nm**	**5 nm**	**10 nm**
1	25	25	26	28
2	25	25	26	28
3	25	26	26	28
4	25	25	26	28
5	25	26	26	28
6	25	25	26	28
7	25	25	26	28
8	25	26	26	28
9	25	26	26	28
10	25	25	26	28
11	25	25	26	28
12	25	25	26	28
13	25	25	26	28
14	25	25	26	28
15	25	26	26	28
16	25	26	26	28
17	26	25	28	28
18	0	0	6	28
19	25	25	26	28
20	0	1	5	28
21	25	25	26	28
22	25	25	26	28
23	25	25	26	28
24	25	26	27	28
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26	25	25	26	28
27	25	25	26	28
28	25	25	28	28
29	2	8	28	28

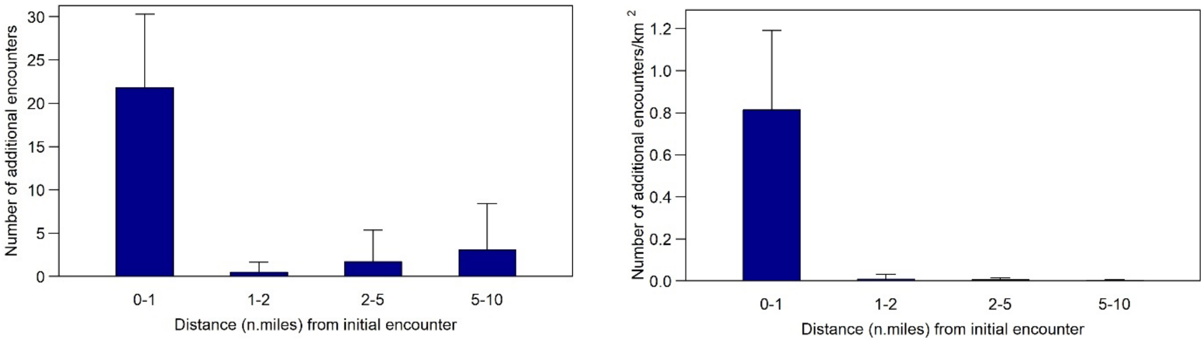

Figure 6: Mean number (+SD) of additional theoretical VME encounters with move-on distance from initial encounter. Data are for the seamounts 39South and Valerie (the only seamounts on which initial encounters occurred) and are shown unstandardised (left) and standardised (right) for the increasing area encompassed by the increasing move-on distance. An abundance threshold of >3.5 coral heads per model cell was used to define VME habitat patches.

For Valerie seamount, the only seamount open to fishing where theoretical VME encounters occurred, 37, 16 and 7% of the historical footprint, the feature, and the area open to fishing would be closed within a move-on distance of 1 nm of the initial theoretical VME encounters, respectively. These metrics increase predictably with increasing move-on distances, with all closed area values for 2 and 5 nm being approximately 40% and 60% greater than for a move-on distance of 1 nm, respectively (Table 5, Figure 7). Impact to the fishery results based on identification of VME habitat patches using other abundance thresholds are illustrated in Appendix 1.3 and 2.3.

Table 5: Percentage area of the historical trawl footprint, seamount feature (to 2000 m), and management area closed to fishery as a consequence of different move-on distances due to theoretical VME encounters on Valerie seamount. An abundance threshold of >3.5 coral heads model cell was used to define VME habitat patches.

Valerie	**Footprint**				**Feature**				**Management Area**			
Distance (nm)	**1**	**2**	**5**	**10**	**1**	**2**	**5**	**10**	**1**	**2**	**5**	**10**
% area lost	37	59	90	96	16	26	39	42	7	11	16	17

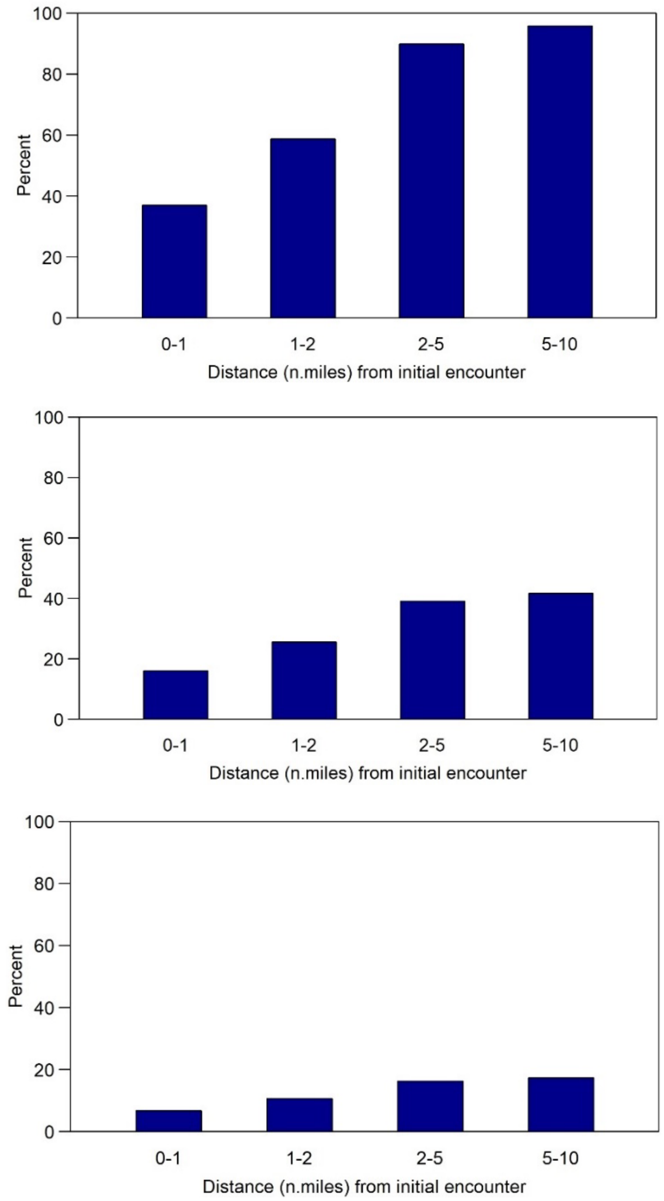

Figure 7: Percent area of the historical bottom trawling footprint (top), the seamount feature (to 2000 m) (middle), and the open Management Area (bottom) closed to the fishery with increasing move-on distance from initial theoretical encounter with VMEs on Valerie seamount. An abundance threshold of >3.5 coral heads per model cell was used to define VME habitat patches.

5. Conclusions

Predicted VME habitat patches of coral reefs on the study seamounts, identified using an abundance threshold of >3.5 coral heads per model cell, are typically small and highly clustered. These patches were either not encountered or encountered only rarely by the simulated trawl tows on the six seamounts. When theoretical encounters did occur, on average the current move-on distance of 1 nm avoids of 73% of additional encounters with stony coral reefs. Use of the 2 nm move-on distance, commonly used by other RFMOs, would avoid 74% of additional encounters. Use of 5 nm, as proposed by the EU, would avoid 80% of potential additional encounters. That is, increasing the move-on distance from 1 nm to 5 nm, as proposed, would potentially achieve an *additional* 7% gain in the avoidance of encounters with VMEs.

The impact analysis on the fishery of changing the move-on encounter distances showed that the current move-on distance of 1 nm could have theoretically closed up to 37% of the historical footprint, 16% of the feature (to 2000 m), and 7% of the Management Area for the open seamount Valerie (the only open seamount where theoretical VME encounters occurred). Use of a move-on distance of 2 nm would close 59% of the footprint, 26% of the feature and 11% of the Management Area. Use of 5 nm would close 90% of the footprint, 39% of the feature and 16% of the Management Area. That is, increasing the move-on distance from 1 nm to 5 nm, as proposed, would potentially result in up to an *additional* 53%, 23%, and 9% reduction in the footprint, feature, and Management Area used and accessible to the fishery on Valerie.

In summary, increasing the move-on distance from 1 nm to 5 nm would offer a relatively small additional gain in VME encounter avoidance but would potentially more than double the impact on the fishery. Thus, our analyses indicate that the current move-on distance of 1 nm effectively avoids most of the potential additional interactions with VMEs while not placing undue burden on fishing operators.

6. Assumptions and caveats

It is important to make clear that the above analyses are based on a number of assumptions, which impose some caveats on the conclusions, and together these suggest that additional research is required to better resolve the question of what the optimal move-on distance for meeting conservation objectives is, while not placing undue burden on fishing operators.

To avoid the use of unrealistic simulation of trawling patterns for the analysis, we used historical tow data to generate ‘realistic’ tow lengths and distribution patterns. The tow data were not intended to be used as highly accurate representations of individual trawl positions on the bottom.

We used abundance models and published abundance thresholds to identify VME habitat patches of stony coral reef that are presumed to equate to areas where VME indicator taxa would be caught in bottom trawls at weights that meet the VME encounter threshold. We have no direct information on the relationship between stony coral bycatch catch weights and coral head densities. This component of the analysis was not intended to define a VME per se, but rather to evaluate the effect of different move-on distances on the likelihood of additional encounters with VME indicator taxa, also under the assumption that overlap with one patch will likely yield enough bycatch to exceed the VME encounter threshold.

All VME habitat patch predictions were based on observed records for the stony coral *Solenosmilia variabilis* that were obtained in 2014, after up to 20 years of bottom trawling (trawling on the LSC began in 1994). Some VME habitat patches may have been removed by this fishing, and therefore could not be included as records in the abundance model used to make the habitat patch predictions. Therefore, the VME habitat patch predictions are unlikely to represent a pristine baseline situation.

Our theoretical analysis assumes that the historic trawl footprint will remain stable when encounter events are triggered. However, if encounters result in the redistribution of fishing effort within an open area to locations that contain VME habitats but haven't historically been fished, then the analysis may misrepresent the number of additional encounters that could occur within move-on areas.

The impact to fishery analysis determined the maximum theoretical reduction in the areas currently used and accessible to the fishery. The relative impact on the fishery resulting from different move-on distances could have, alternatively, been assessed on an individual tow encounter basis. Such an assessment would be more akin to determining a minimum likely impact, i.e., assuming no more VME encounters over time beyond a single encounter.

The most obvious caveat to be attached to this research is that the results of this analysis are certain or likely to be VME habitat-, fishery- and region-specific. For example, VME patches formed by other VME indicator taxa (e.g., other coral groups, sponges) will have different size and distribution patterns to those formed by the stony coral VME indicator taxon examined here, which will influence encounter patterns. The patch characteristics of even the species of stony coral VME indicator taxon examined here may vary by region within the SPRFMO area. Reefs formed by *Solenomsmilia variabilis* on the LSC are apparently different in size from those formed on seamounts outside of the SPRMO area (e.g., Williams et al. 2020). Trawling practices differ by broad scale habitat, e.g., on seamount features of the LSC compared to the 'slope' habitat of the Northwest Challenger Plateau. These differences in how the fishery operates will also likely influence VME encounter patterns. Such differences in encounter patterns could suggest a different optimal move-on distance compared to that indicated by the analysis reported here.

7. Future research

Ideally, future analyses to examine the question of optimal move-on distances would be able to better resolve or remove some of the assumptions that underpin the analysis reported here, and be able to account for some of the described variability that is likely to occur in encounter patterns. In doing so, such analyses would reduce the number of caveats that have been applied to this research and the caution that has to be extended to any inference of generality from the results.

Future research effort would usefully be directed first to developing new abundance models for different areas and VME indicator taxa, so that similar methods used here can be applied to other VMEs and areas that receive different trawling practices. In particular, building abundance-based models for VME indicator taxa on 'slope' environments within the Evaluated Area, such as the Northwest Challenger Plateau. While the development of such models does not necessarily require the undertaking of new surveys of VME abundance in the SPRFMO area, these would be useful for more than future move-on analyses (e.g., ground truthing existing habitat suitability models that underpin the design of the current spatial management measures). Further consideration could be given also to exploring the approach of Dunn et al. (2014) for determining optimal move-on distances, taking into account bycatch data for all VME indicator taxa across the Evaluated Area. In addition, there is a range of other research that would benefit both future move-on encounter analysis and other areas of SPRFMO research interest. Foremost among such research is to build upon previous work to determine the trawl catchability of VME indicator taxa. This research would provide a better understanding of the relationship between VME encounter thresholds and VME indicator taxa density on the seafloor for the move-on analysis, as well as inform the setting of encounter thresholds (SC9-DW10, Updated candidate encounter thresholds for VME indicator taxa in the SPRFMO Area) and allow the inclusion of a robust measure of trawl catchability as a factor in any future VME habitat suitability models.

8. Recommendations

It is recommended that the Scientific Committee:

- **Notes** that an analysis has been provided detailing the effectiveness and impact of the current move-on distance in SPRFMO, and its comparison with other potential move-on distances to avoid additional encounters with VMEs;
- **Notes** that the analysis was focused on stony coral reef habitat on the Louisville Seamount Chain, as it was the only available information suitable for this task at this time. Also **notes** that other taxa and areas could only be addressed in the future, when abundance models are available to perform such analyses (in particular, such models for 'slope' environments). Finally **notes** that abundance models are already included in the SC multi annual work plan for 2022
- **Agrees** to recommend to the Commission that, utilising the best available scientific information, the current move-on distance seems to provide a suitable level of avoidance of additional interactions with the stony coral *Solenosmilia variabilis* on the Louisville Seamount Chain, while not placing undue burden on fishing operators.

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Appendices

Appendix AA

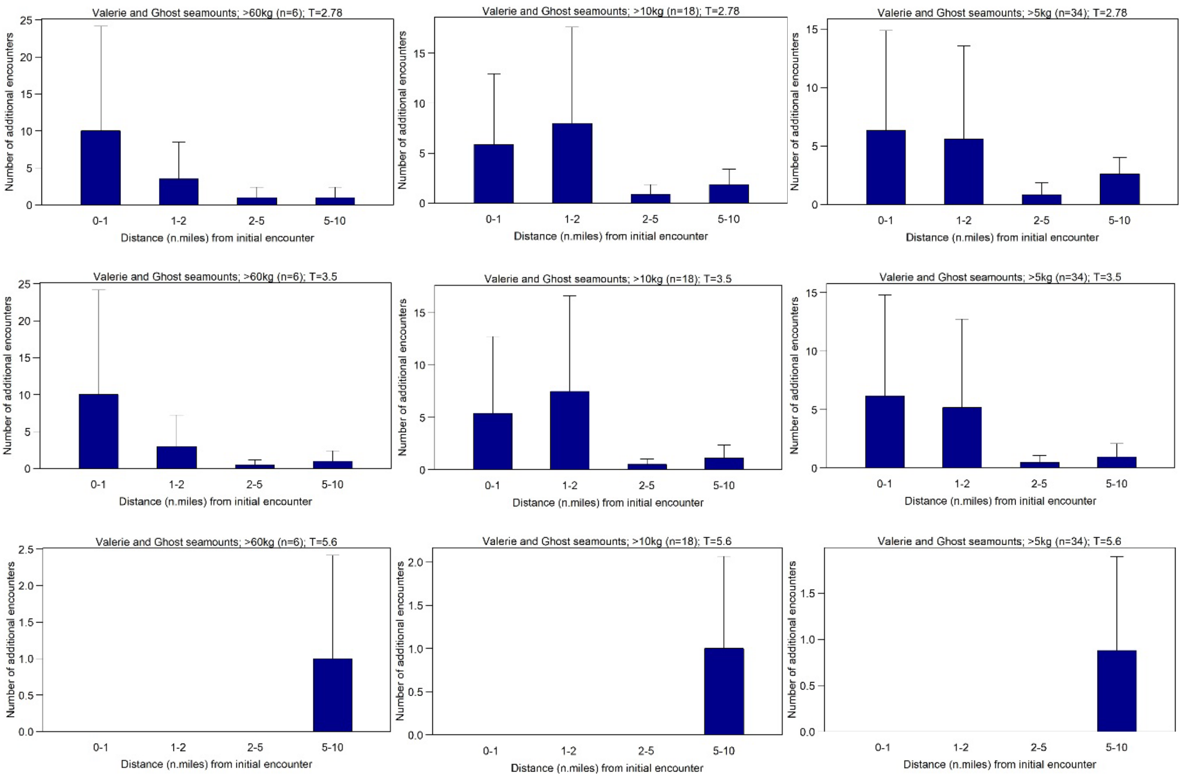


Figure AA1: Results of analyses to identify the optimal move-on distance based on empirical bycatch data for Scleractinia from Valerie and Ghost seamounts using tows that exceeded a 'theoretical encounter threshold' of 60 kg (left), 10 kg (centre) and 5 kg (right), and using three abundance thresholds to identify VME patches (>2.78 (top), >3.5 (middle), >5.6 (bottom) coral heads per model cell).

Appendix 1

Appendix 1.1

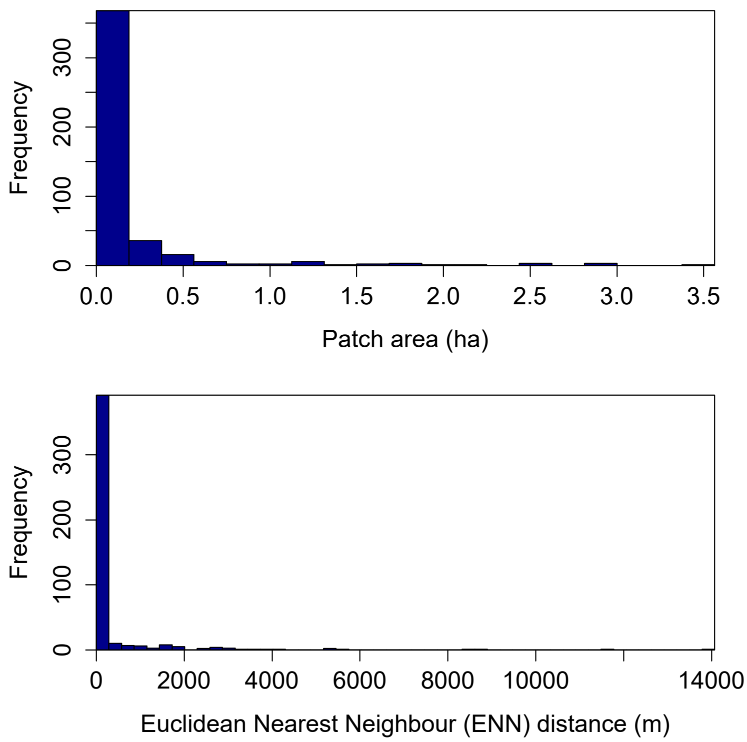


Figure A1.1.1: Frequency histograms of VME habitat patch area (top) and minimum distance between patches (bottom) in all seamounts. An abundance threshold of >2.78 coral heads per model cell was used to define VME habitat patches.

Table A1.1.1: Summary of VME habitat patch characteristics for all seamounts. An abundance threshold of >2.78 coral heads per model cell was used to identify VME habitat patches. Seamounts in italics are open to fishing. ENN = minimum Euclidean Nearest Neighbour distance.

Seamount	Number of patches	Patch area (ha)	Min-max patch area (ha)	ENN (m)	Min-max ENN (m)	Contiguity Index (0-1)	Patch density (0-1 million)
Forde	74	0.27	0.06 - 3	21	35 - 3055	0.17	367
39South	94	0.19	0.06 - 2.63	546	35 - 14069	0.12	533
Censeam	33	0.1	0.06 - 0.31	787	35 - 5716	0.07	1035
Ghost	12	0.06	0.06 - 0.06	1612	35- 11685	0.00	1600
JCM	17	0.08	0.06 - 0.19	272	35 - 2420	0.03	1295
Valerie	221	0.26	0.06 - 3.56	22	35 - 8735	0.15	382

Appendix 1.2

Table A1.2.1: Summary statistics for theoretical VME encounters for seamounts on the Louisville Seamount Chain. An abundance threshold of >2.78 coral heads per model cell was used to identify VME habitat patches. Seamounts in italics are open to fishing.

Seamount	Number of tows	Number of VME patches on seamount	Max number of VME patches encountered on a single tow	Number of tows encountering one or more VME patches	Proportion of tows with encounter (%)
Forde	371	74	0	0	0.00
39South	1142	94	3	2	0.18
Censeam	689	33	0	0	0.00
Ghost	4954	12	1	4	0.08
JCM	127	17	0	0	0.00
Valerie	2012	221	8	31	1.54
All	9295	451	8	37	0.40

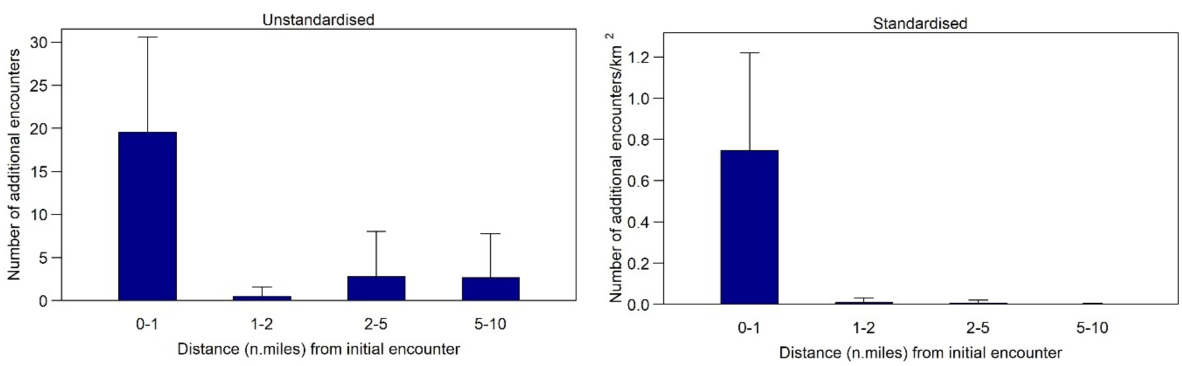


Figure A1.2.1: Mean number (+SD) of additional theoretical VME encounters with move-on distance from initial encounter. Data are for the seamounts 39South, Ghost and Valerie (the only seamounts on which initial encounters occurred) and are shown unstandardised (left) and standardised (right) for the increasing area encompassed by the increasing move-on distance. An abundance threshold of >2.78 coral heads per model cell was used to define VME habitat patches.

Appendix 1.3

Table A1.3.1: Percentage area of the historical trawl footprint, seamount feature (to 2000 m), and management area closed to fishery as a consequence of different move-on distances due to theoretical VME encounters on Valerie seamount. An abundance threshold of >2.78 coral heads per model cell was used to define VME habitat patches.

Valerie	**Footprint**				**Feature**				**Management Area**			
Distance (nm)	**1**	**2**	**5**	**10**	**1**	**2**	**5**	**10**	**1**	**2**	**5**	**10**
% area lost	41	62	90	95	18	27	39	41	7	11	16	17

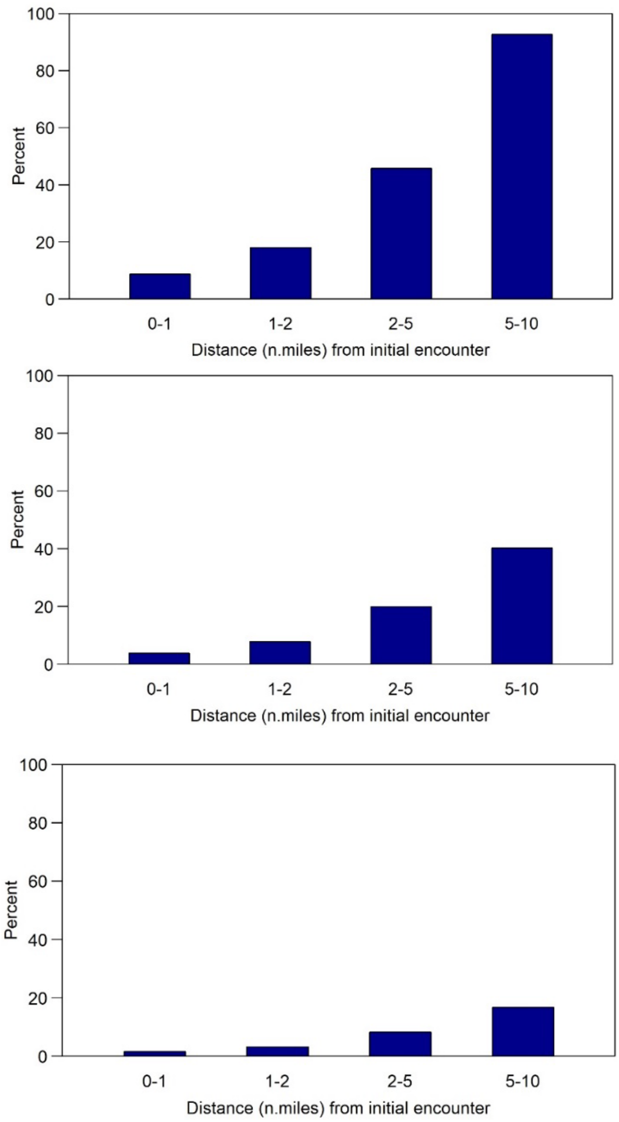


Figure A1.3.1: Percent area of the historical bottom trawling footprint (top), the seamount feature (to 2000 m) (middle), and the open Management Area (bottom) closed to the fishery with increasing move-on distance from initial theoretical encounter with VMEs (for all seamounts in total). An abundance threshold of >2.78 coral heads per model cell was used to define VME habitat patches.

Appendix 2

Appendix 2.1

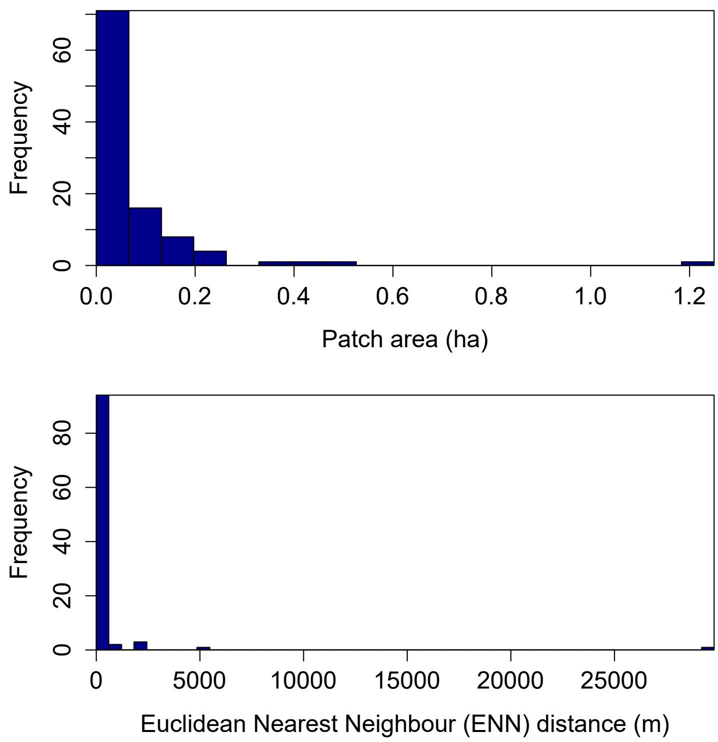


Figure A2.1.1: Frequency histograms of VME habitat patch area (top) and minimum distance between patches (bottom) in all seamounts. An abundance threshold of >5.6 coral heads per model cell was used to define VME habitat patches.

Table A2.1.1: Summary of VME habitat patch characteristics for all seamounts. An abundance threshold of >5.6 coral heads per model cell was used to identify VME habitat patches. Seamounts in italics are open to fishing. ENN = minimum Euclidean Nearest Neighbour distance.

Seamount	**Number of patches**	**Patch area (ha)**	**Min-max patch area (ha)**	**ENN (m)**	**Min-max ENN (m)**	**Contiguity Index (0-1)**	**Patch density (0-1 million)**
Forde	12	0.1	0.06 - 0.38	2598	56 - 29811	0.06	1011
39South	14	0.21	0.06 - 1.25	210	50 - 1826	0.15	467
Censeam	1	0.06	0.06 - 0.06	NA	NA	0	1600
Ghost	1	NA	NA	NA	NA	NA	NA
JCM	1	0.06	0.06 - 0.06	NA	NA	0	1600
Valerie	75	0.10	0.06 - 0.5	223	35 - 5247	0.07	1043

Appendix 2.2

Table A2.2.1: Summary statistics for theoretical VME encounters for seamounts on the Louisville Seamount Chain. An abundance threshold of >5.6 coral heads per model cell was used to identify VME habitat patches. Seamounts in italics are open to fishing.

Seamount	**Number of tows**	**Number of VME patches on seamount**	**Max number of VME patches encountered on a single tow**	**Number of tows encountering one or more VME patches**	**Proportion of tows with encounter (%)**
Forde	371	12	0	0	0.00
39South	1142	14	0	2	0.00
Censeam	689	1	0	0	0.00
Ghost	4954	0	0	0	0.00
JCM	127	1	0	0	0.00
Valerie	2012	75	2	2	0.10
All	9295	103	8	2	0.02

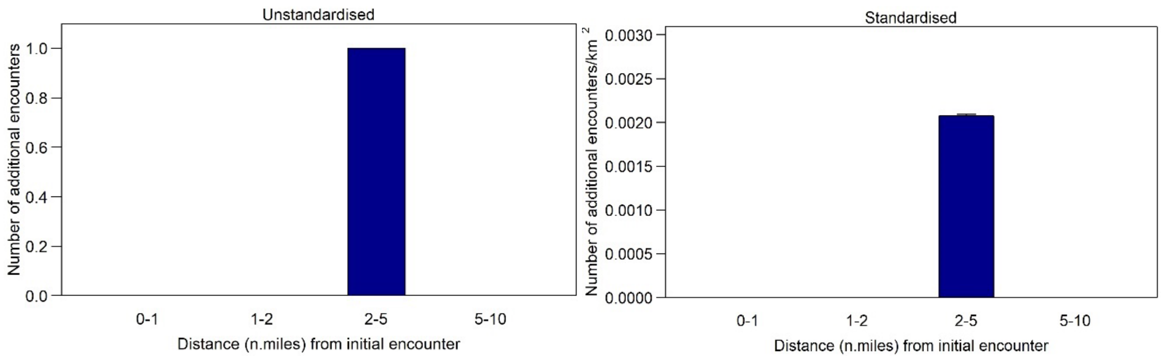
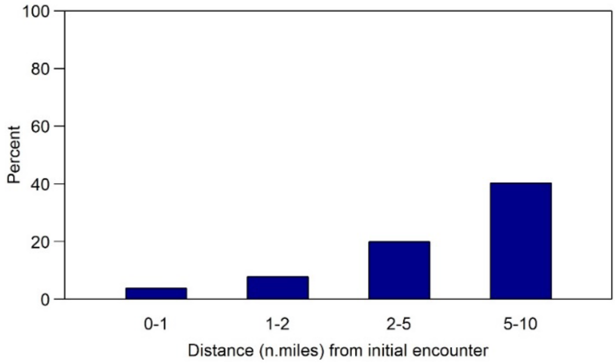


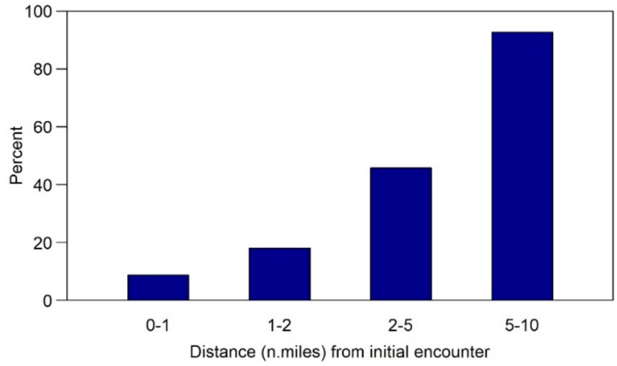
Figure A2.2.1: Mean number (+SD) of additional theoretical VME encounters with move-on distance from initial encounter. Data are for the seamount Valerie (the only seamount on which initial encounters occurred) and are shown unstandardised (left) and standardised (right) for the increasing area encompassed by the increasing move-on distance. An abundance threshold of >5.6 coral heads per model cell was used to define VME habitat patches.

Appendix 2.3

Table A2.3.1: Percentage area of the historical trawl footprint, seamount feature (to 2000 m), and management area closed to fishery as a consequence of different move-on distances due to theoretical VME encounters on Valerie seamount. An abundance threshold of >5.6 coral heads per model cell was used to define VME habitat patches.

Valerie	**Footprint**				**Feature**				**Management Area**			
Distance (nm)	**1**	**2**	**5**	**10**	**1**	**2**	**5**	**10**	**1**	**2**	**5**	**10**
% area lost	9	18	46	93	4	8	20	40	2	3	8	17





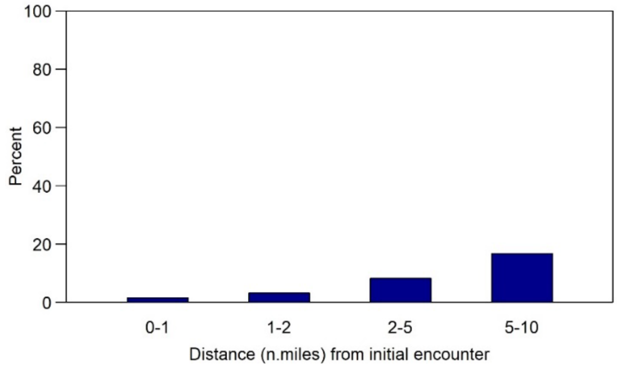


Figure A2.3.1: Percent area of the historical bottom trawling footprint (top), the seamount feature (to 2000 m) (middle), and the open Management Area (bottom) closed to the fishery with increasing move-on distance from initial theoretical encounter with VMEs (for all seamounts in total). An abundance threshold of >5.6 coral heads per model cell was used to define VME habitat patches.