7th MEETING OF THE SCIENTIFIC COMMITTEE

La Havana, Cuba, 7 to 12 October 2019

SC7-DW21_rev1

Progress with investigating uncertainty in the habitat suitability model predictions and VME indicator taxa thresholds underpinning CMM 03-2019

Australia

PO Box 3797, Wellington 6140, New Zealand
P: +64 4 499 9889 – F: +64 4 473 9579 – E: secretariat@sprfmo.int
www.sprfmo.int

South Pacific Regional Fisheries Management Organisation

7th Meeting of the Scientific Committee

La Havana, Cuba 7–12 October 2019

Progress with investigating uncertainty in the habitat suitability model predictions and VME indicator taxa thresholds underpinning CMM 03-2019

Roland Pitcher[1], Alan Williams[1], Lee Georgeson [2]

September 2019

1. Commonwealth Scientific and Industrial Research Organisation, St Lucia (R. Pitcher), Hobart (A. Williams), Australia.

2. Australian Bureau of Agricultural and Resource Economics and Sciences, Department of Agriculture, GPO Box 858, Canberra ACT 2601, Australia.

Purpose of this paper

This paper updates the SC regarding progress on work undertaken by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) commissioned by the Australian government. It informs a number of specific tasks outlined in paragraph 36 of CMM 03-2019 as well as broader review of whether the CMM is meeting/will meet its objective to prevent and/or manage significant adverse impacts (SAIs) on vulnerable marine ecosystems (VMEs). This work will contribute to full review of CMM 03-2019 in 2021.

Background and introduction

The Australian government has commissioned CSIRO to review the models and methods used to identify the distributions of VMEs in the SPRFMO area, and the interpretations of model outputs used to formulate fishery management approaches. The review has examined VME habitat models, identified uncertainties in the model predictions of VME habitat suitability and other outputs that underpin the spatial management approach adopted in CMM 03-2019. The review also provides advice on the appropriateness of the VME encounter thresholds and the implementation of an appropriate monitoring program that is responsive to potential errors in the modelling approach.

This work is directly relevant to the SC tasks and requirements to provide advice to the Commission outlined in paragraph 36 of CMM 03-2019, with these being:

> *36. At its annual meetings in 2019 and 2020, the Scientific Committee shall review and provide advice on the effectiveness of the applied management measures, including:*
>
> - ***VME indicator thresholds;***
> - *The number of encounters;*
> - *The number of encounters that were expected based on habitat suitability models;*
> - ***The appropriateness of the management approach (e.g. scale);***
> - *Additional relevant VME indicator species that have not been modelled, assessed or for which thresholds have not been established;*
> - ***Refinement of the encounter protocol;***
> - *Measures to prevent the catch and/or impacts on rare species; and*
> - *Anything else the SC considers relevant*
>
> *to ensure the measure is achieving its objective and the objectives of the Convention.*

This paper is directly relevant to the bolded items above: VME indicator thresholds, the appropriateness of the management approach, and refinement of the encounter protocol.

Methods and results

Progress is structured against three tasks for which results are available at this time:

Task 1: Use previous CSIRO empirical data and modelling outputs to examine relationships between predicted probability of presence and observed abundances of VME taxa—i.e., what level of predicted probability corresponds to actual VME taxa abundances on the seabed.

Task 2: Examine the potential over-prediction of the SPRFMO 1km habitat suitability probability (HSP) modelling, using CSIRO observations data from south-eastern Australia and by quantitatively comparing with previous CSIRO prediction modelling of VME indicator taxa data for the Australian south-eastern region slope.

Task 3: Analyse existing CSIRO research data (seabed observations and sampling) to estimate VME catchability, using a 'seabed-up' approach, to contribute to review of the encounter thresholds.

Task 1

Use previous CSIRO empirical data and modelling outputs to examine relationships between predicted probability of presence and observed abundances of VME taxa— i.e. what level of predicted probability corresponds to actual VME taxa abundances on the seabed.

Outputs from previous CSIRO modelling of VMEs in Australia's southeast marine region (SEMR, Pitcher et al. 2015) were investigated to examine empirical relationships between predicted probability of presence and observed VME taxa abundances. Data included cover of the reef-building stony coral *Solenosmilia variabilis* in tow-video transects (Althaus et al. 2009) and predicted probability of presence at the same sites from presence:absence modelling of all available observations (sled & video) with 33 environmental predictors. Results to date show that it is only at the very highest predicted probabilities of presence that the observed *S. variabilis* abundances were substantive and/or non-zero (Figure 1). Thus, while there is a relationship between predicted probabilities of presence and observed abundance, the relationship is non-linear. If the relationship is similar in the SPRFMO HSP predictions, then summing habitat suitability probability (HSP) will be overly-optimistic for low to medium probabilities because most such predictions will likely correspond to *S. variabilis* abundance of zero; that is, coral reef will be absent. Analysis indicates that the best-fit power that approximately linearly relates probability of presence to abundance is power=8, which makes presence predictions between 0-1 smaller. The implication of these results is that post-accounting by summing predicted presence probabilities is inappropriate because it will lead to overly-optimistic, potentially highly inflated, estimates of the percentage of *S. variabilis* and likely other VME taxa spatially protected in areas closed to fishing under CMM 03-2019.

An alternative method for post-accounting summation is to use the best-fit power estimate (HSP^8) instead of HSP, both weighted by 1/(1+CV). This substantively changes (1) the estimated amount of *S. variabilis* remaining outside the SPRFMO Bottom Trawl Management Areas (from 89.9% to 82.7%); (2) the estimated SPRFMO-wide impact given the naturalness layer (from 3.9% to 17.5%); and (3) the estimated impact within Bottom Trawl Management Areas (from 29.8% to 63.1%). Hence, it is critically important to test the generality or otherwise of this relationship across the SPRFMO model region.

Furthermore, assessments of protection should be done at spatial scale extents relevant to VME populations (as is done for Orange Roughy stock assessments that use three stock boundaries on the Louisville Seamount Chain and four on the Lord Howe Rise). Herein, two sub-regions of the SPRFMO area (the entire Louisville Seamount Chain and Lord Howe Rise) were used separately to examine the importance of scale extents for *S. variabilis* assessment. On the Louisville Seamount Chain, summing HSP^8 instead of HSP, reduces the estimated protection of *S. variabilis* (from 64.8% to 52.7%), increases estimated regional impact due to naturalness (from 13.5% to 46.9%) and increases estimated impact within Bottom Trawl Management Areas (from 28.6% to 68.7%). On the Lord Howe Rise, the estimated protection reduces from 78.8% to 57.8%, regional naturalness estimated impact increases from 8.6% to 24.1% and estimated impact within trawl areas increases from 38.1% to 51.1%. Note that these adjustments by power=8 do not account for the effects of model over-prediction examined in the following section.

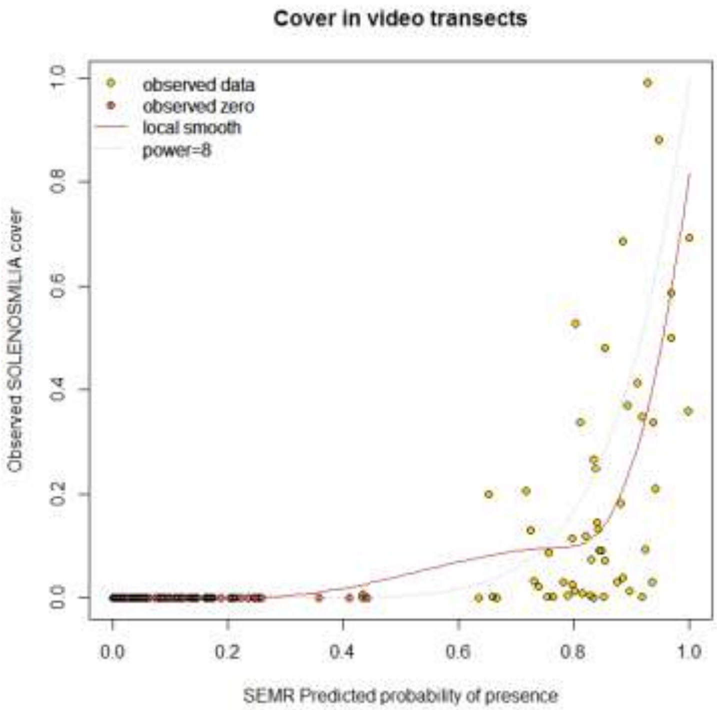

Figure 1. Relationship between predicted probabilities of presence and observed proportional cover of *Solenosmilia variabilis* in southeast Australia.

Task 2

Examine the potential over-prediction of the SPRFMO 1km habitat suitability probability (HSP) modelling, using CSIRO observations data from south-eastern Australia and by quantitatively comparing with previous CSIRO prediction modelling of VME indicator taxa data for the Australian south-eastern region slope

Outputs from the same previous CSIRO assessments of VME taxa in Australia's southeast marine region (SEMR, Pitcher et al. 2015) were used to investigate the potential over-prediction of habitat suitability for *S. variabilis* by the SPRFMO 1km habitat suitability probability (HSP) modelling. This was achieved by quantitatively comparing the SPRFMO predictions with existing observations data (some of which had been used in the SPRFMO predictions), and with previous CSIRO model predictions of VME indicator taxa data for the Australian SEMR slope.

There were 427 CSIRO tow-video segments (~1km long) that mapped onto the SPRFMO HSP 1km prediction grid. The observed *Solenosmilia variabilis* covers were substantive or non-zero only at the highest predicted habitat suitability probabilities (Figure 2), whether or not HSP was weighted by CVs. Thus, while there is a relationship between predicted habitat suitability probabilities and observed abundance, the relationship is not linear. This result independently indicates that summing predicted HSP will be overly-optimistic for low to medium probabilities, with similar implications and consequences as described by Task 1.

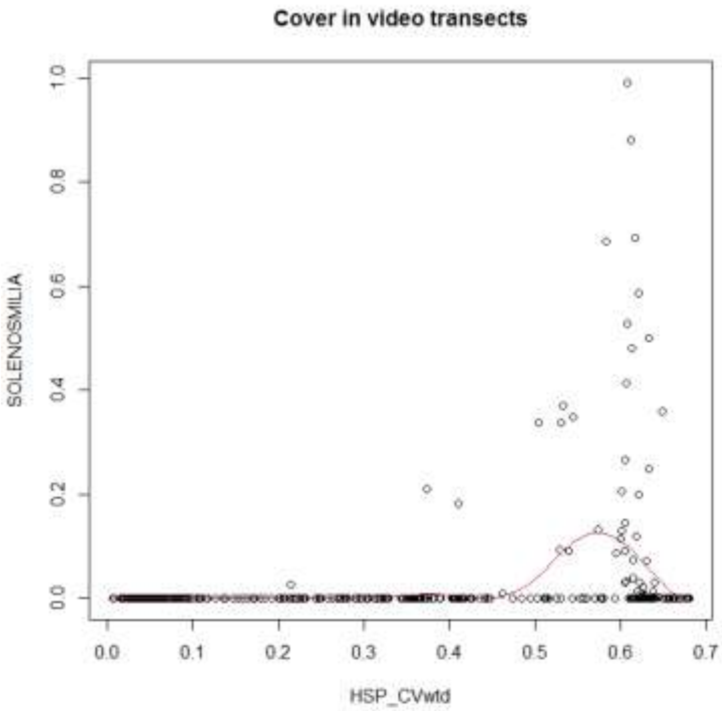

Figure 2. Relationship between SPRFMO predicted habitat suitability probabilities (HSP) and proportional cover (abundance) of *Solenosmilia variabilis* observed in tow-video transects in southeast Australia.

Furthermore, the SPRFMO HSP 1km predictions are frequently high in cells where no *S. variabilis* was observed in CSIRO video tows (Figure 3). Table 1 shows that 20% of all CV-weighted HSP predictions (and 64% of high HSP predictions) were for high HSP in grid cells where no *S. variabilis* were observed. In addition, 28% of all HSP predictions (and 97% of medium HSP predictions) were for medium HSP in grid cells where no *S. variabilis* corals were observed.

These results indicate substantive over-prediction of the SPRFMO HSP 1km predictions in south-eastern Australia, and are likely indicative of over-prediction elsewhere in the modelled SPRFMO region. This also suggests high likelihood of overly-optimistic estimates of the percentage of VME taxa spatially protected in areas outside of Bottom Trawl Management Areas, and high uncertainty that the expected level of protection has been achieved. Addressing this kind of over-prediction requires revisiting the modelling and the data and the predictors used. It is possible that the use of 'pseudo'-absences in the modelling, rather than observed absences, may have contributed to this over-prediction.

Table 1. Percentage frequencies of SPRFMO predicted habitat suitability probabilities (HSP) in categories of low, medium and high predictions against categories of observed cover abundance of *Solenosmilia variabilis* (zero, low, medium and high) in tow-video transects in southeast Australia.

Observed cover category		SPRFMO Predicted HSP category		
		Low	Medium	High
		[0.00683,0.2)	[0.2,0.5)	[0.5,0.68]
Zero	[0,0.000)	**39.58**	**28.1**	**20.14**
Low	[0.000115,0.0309)	**0**	**0.47**	**3.51**
Medium	[0.0309,0.206)	**0**	**0.23**	**3.75**
High	[0.206,0.992]	**0**	**0.23**	**3.98**

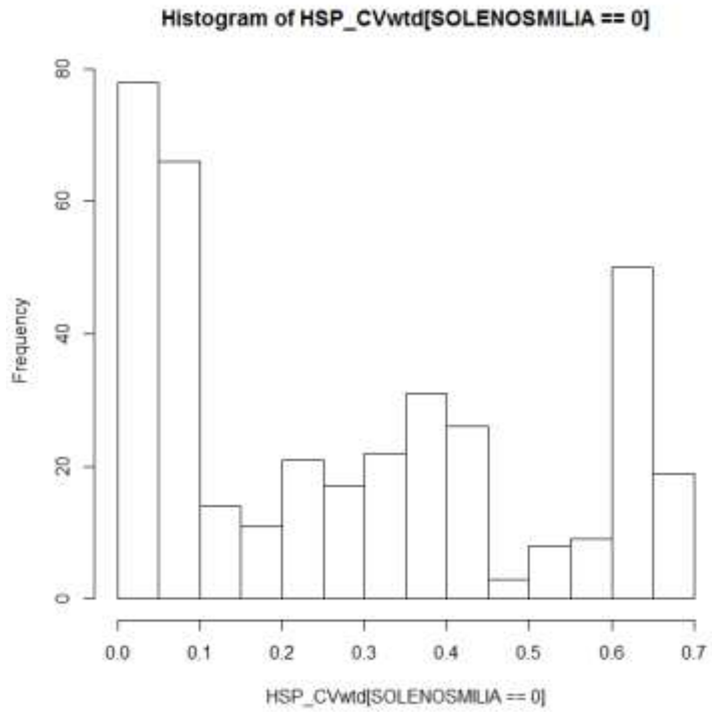

Figure 3. Histogram of SPRFMO predicted habitat suitability probabilities (HSP) for cells where observed cover (abundance) of *Solenosmilia variabilis* = zero in tow-video transects in southeast Australia.

Similar results were found when comparing weights of *S. variabilis* sampled in 142 CSIRO sled tows with the SPRFMO HSP 1km predictions that overlapped. Sampled *S. variabilis* was substantive only where the predicted habitat suitability probabilities were highest (Figure 4).

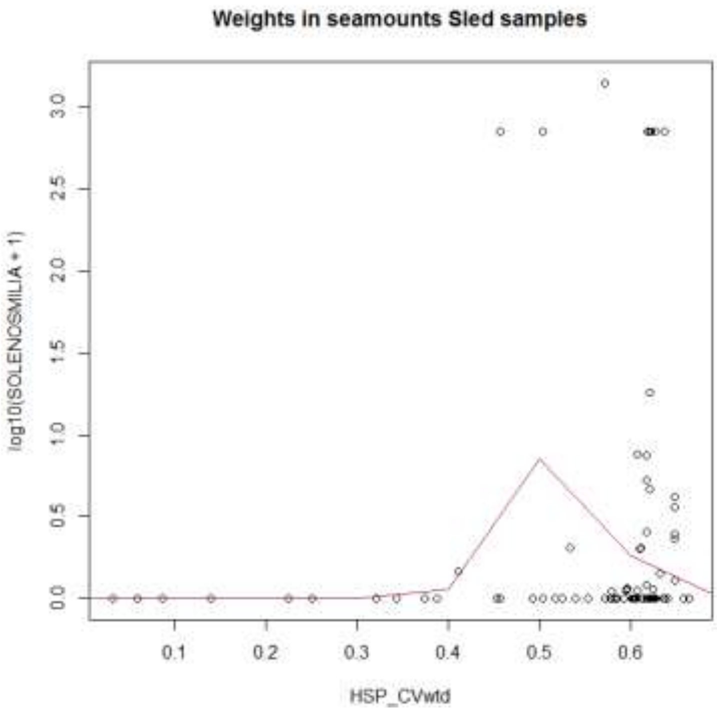

Figure 4. Relationship between SPRFMO predicted habitat suitability probabilities (HSP) and sampled abundance of *Solenosmilia variabilis* ($log_{10}(g+1)$) in epibenthic sled tows in southeast Australia.

Overall, 59% of CV-weighted HSP predictions (and 70% of high HSP predictions) were for high HSP in grid cells where no *S. variabilis* was sampled—and 8.5% of all HSP predictions (and 67% of medium HSP predictions) were for medium HSP in grid cells where no *S. variabilis* was sampled (Table 2 and Figure 5).

Table 2. Percentage frequencies of SPRFMO predicted habitat suitability probabilities (HSP) in categories of low, medium and high predictions against categories of observed cover abundance of *Solenosmilia variabilis* (zero, low, medium and high) in tow-video transects in southeast Australia.

Observed sled weight category		SPRFMO Predicted HSP category		
		Low	Medium	High
		[0.0314,0.2)	[0.2,0.5)	[0.5,0.664]
Zero	[0,0.000)	**2.82**	**8.45**	**59.15**
Low	[0.000767,0.103)	**0**	**1.41**	**8.45**
Medium	[0.103,0.876)	**0**	**0.7**	**9.15**
High	[0.876,3.15]	**0**	**2.11**	**7.75**

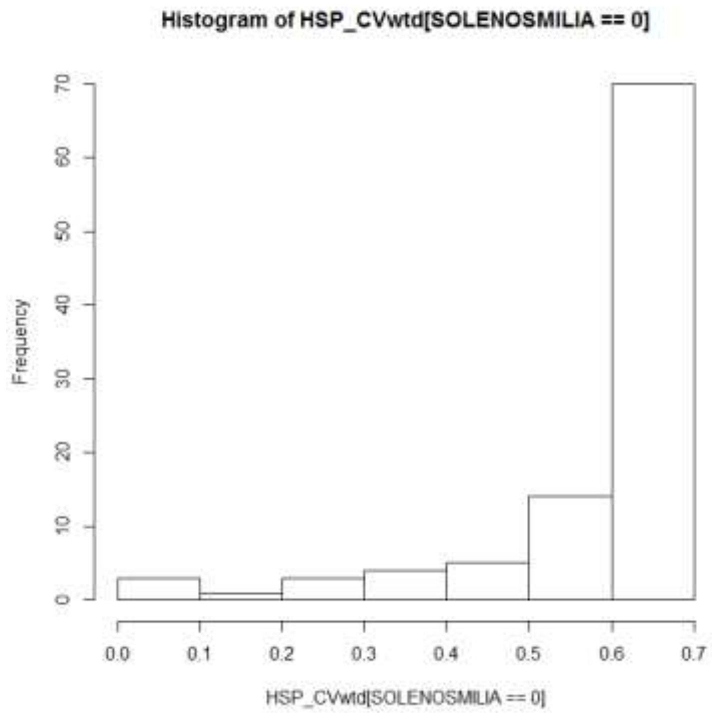

Figure 5. Histogram of SPRFMO predicted habitat suitability probabilities (HSP) for cells where sampled biomass of *Solenosmilia variabilis* = zero in epibenthic sled tows in southeast Australia.

In addition, the SPRFMO HSP 1km predictions tended to be more optimistic than the SEMR predictions as quantified in 38,408 grid cells that were common to both model prediction domains. In particular, the SPRFMO modelling frequently predicted medium and high HSP where the SEMR modelling predicted zero *S. variabilis* abundance (Figure 6).

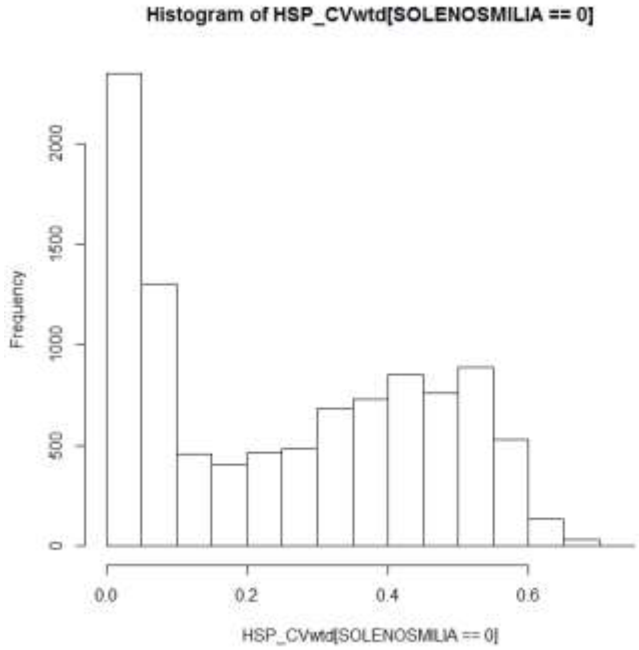

Figure 6. Histogram of SPRFMO predicted habitat suitability probabilities (HSP) for cells where SEMR modelling predicted abundance of *Solenosmilia variabilis* = zero in southeast Australia.

Task 3

Analyse existing CSIRO research data (seabed observations and sampling) to estimate VME catchability, using a 'seabed-up' approach, to contribute to review of the encounter thresholds

Several existing CSIRO research survey datasets, where two or more sampling devices were deployed at stations, were used to quantify relative catchability of benthic fauna.

The first was the northern Great Barrier Reef Effects of Trawling ('GBR_EoT') dataset (ca. 1992-1995) (Poiner et al. 1998), where most stations were sampled by epi-benthos dredge, prawn trawl and fish trawl—and many of those were also observed by towed-video cameras.

A total of 266 stations were sampled by all three gear types. These were matched and catches of demersal and benthic biota were compared. Catches were standardised by the swept area of each gear as grams/hectare (g/Ha). The ratios of these catches provide indicators of the relative catchability of benthic fauna (

Table *3* below). First, the low ratios of catch in the trawls relative to dredge (except for fishes, cephalopods and to some extent crustaceans) indicate that trawl catches greatly undersample benthos biomass and that therefore their impacts may be greatly underestimated by landed bycatch. Second, this underestimate is magnified by the much higher observed cover of sessile epi-benthos in video tows than is sampled by dredge. These results are consistent with Wassenberg et al. (2002) for sponges and gorgonians on the northwest shelf of Australia.

Table 3. Average catch rates (g/Ha) of demersal and benthic biota sampled by epi-benthos dredge, prawn trawl ('bycatch') and fish trawl in the northern Great Barrier Reef Effects of Trawling dataset, with ratios of the catch rates of the two trawls over dredge indicating relative catchabilities of the trawls. These catchability estimates for benthos are a maximum because the dredge also does not have 100% efficiency for sampling benthos.

PHYLUM	CLASS	DREDGE	BYCATCH	PT/DR	TRAWL	FT/DR
Algae	Chlorophyceae	9406.4	14.9	0.0016	4.9	0.0005
Algae	Phaeophyceae	619.1	10.3	0.0167	0.9	0.0014
Algae	Rhodophyta	605.6	2.0	0.0032	0.9	0.0014
Bryozoa	**Bryozoa**	**2525.8**	**10.7**	**0.0042**	**0.4**	**0.0002**
Cnidarian	**Octocorallia**	**4209.4**	**350.3**	**0.0832**	**933.0**	**0.2216**
Cnidarian	Hydrozoa	1246.2	3.9	0.0032	1.3	0.0010
Cnidarian	**Hexacorallia**	**11370.0**	**207.2**	**0.0182**	**658.4**	**0.0579**
Crustacea	Decapoda	1621.4	574.7	0.3545	60.8	0.0375
Echinodermata	Crinoidea	6960.1	61.4	0.0088	15.2	0.0022
Echinodermata	Echinoidea	4619.8	13.0	0.0028	0.4	0.0001
Echinodermata	Holothuroidea	4183.1	133.0	0.0318	100.8	0.0241
Echinodermata	Asteroidea	6171.0	81.2	0.0132	21.3	0.0035
Echinodermata	Ophiuroidea	766.8	57.3	0.0747	0.4	0.0005
Marine plants	Seagrasses	144.6	4.6	0.0315	0.0	0.0000
Mollusca	Bivalve	64184.4	369.2	0.0058	22.8	0.0004
Mollusca	Cephalopoda	177.3	85.7	0.4832	206.2	1.1629
Mollusca	Opisthobranchia	753.9	31.8	0.0421	1.9	0.0026
Porifera	**Sponges**	**17948.1**	**655.9**	**0.0365**	**864.4**	**0.0482**
Tunicata	Ascidia	6167.7	26.5	0.0043	12.6	0.0020
Vertebrata	Pices: Fishes	219.0	1603.2	7.3216	10109.0	46.1669

Pairing the towed-video transects with each of the gear-sampled stations (separately) provided a total of 365 stations for empirically comparing sampled biomasses of VME indicator taxa against quantified cover of benthic fauna. Plotting of the sampled biomasses ($\log_{10}$(g/Ha+1)) against benthic faunal cover estimates (

Table *3*Figure 7 below), shows that even when faunal cover is substantive the catches by any gear type is small—even the dredge, which typically catches ~10× – 20× more than the trawls for most sessile benthos. Cover of habitat-forming benthos is relatively rare both in the GBR_EoT study region, as well as more broadly throughout the Great Barrier Reef (Pitcher et al. 2007 'GBR_SBD'). Thus, benthic covers of a few percent or more are indicative of significant biogenic habitat, particularly for hard corals, on open seabed in the region. Typically (fitted linear regression lines, Table *3*Figure 7), fish trawls may catch only ~100 g/Ha of coral when benthic cover with corals is about 4%, only ~100 g/Ha of sponges when benthic cover with sponges is about 9%, and only ~100 g/Ha of gorgonians when benthic cover with gorgonians is about 16%. Catches of bryozoans by fish trawls were negligible even when they were present as sampled by the dredge (note that bryozoans were not coded directly from the GBR EoT video but catch of bryozoans appears to show a reasonable relationship with cover of other habitat-forming epibenthos).

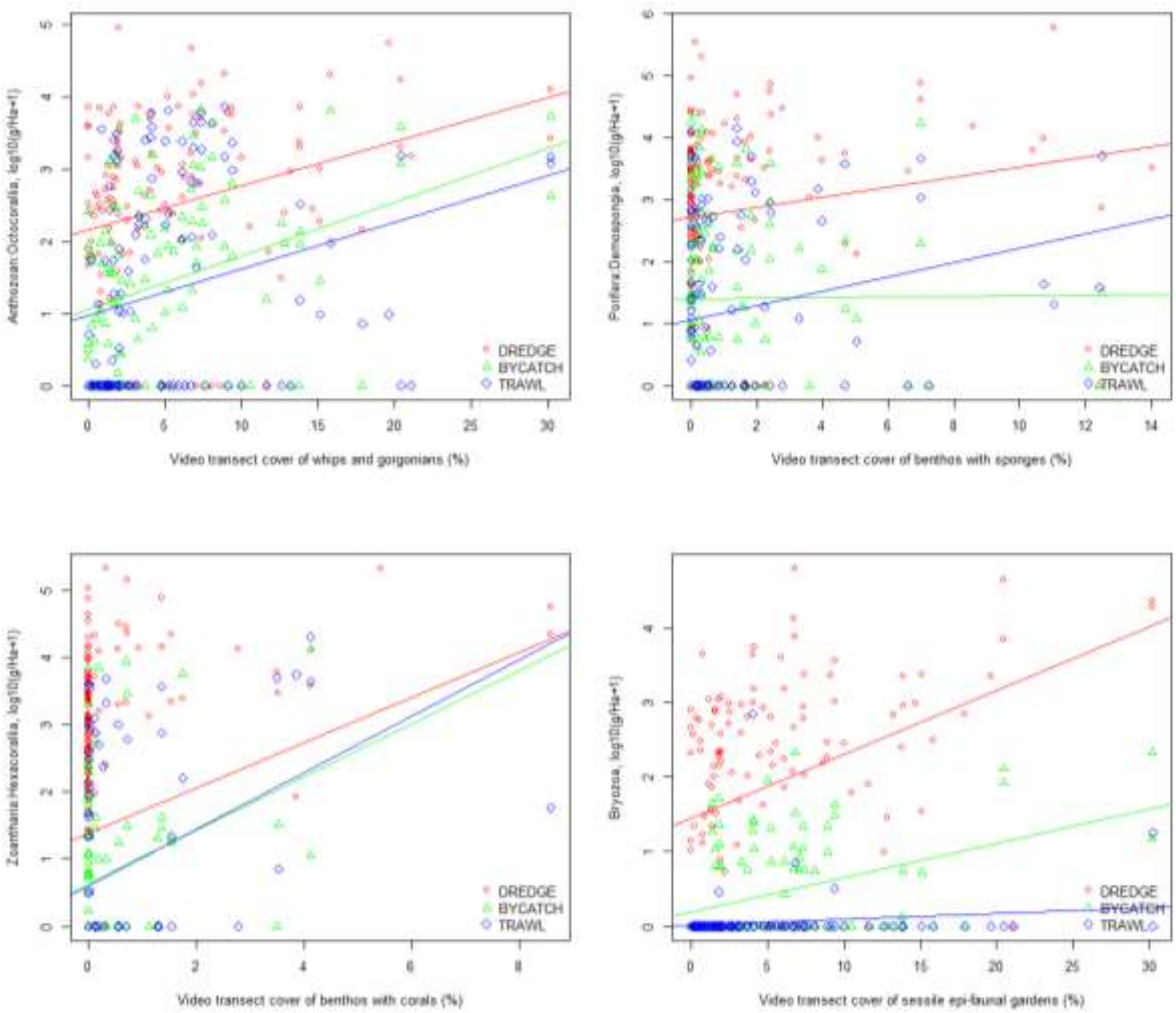

Figure 7. Relationships between biomasses ($\log_{10}$(g/Ha+1)) of VME indicator taxa sampled by epi-benthos dredge, prawn trawl ('bycatch') and fish trawl against benthic faunal %cover observed in paired video transects at the same stations in the northern Great Barrier Reef Effects of Trawling dataset.

Transferring these estimates to a typical SPRFMO fish trawl tow[1] with ground gear spread-width of ~20 m and towed for a mean distance of 9.5 km (Mormede et al. 2017), giving a mean net catch-area for benthos of ~18.81 Ha, would scale 100g/Ha (indicative of substantive biogenic habitat of VME taxa) up to a total of 1.881 kg per taxa of benthos catch by the trawl for the tow. Adding bridles and sweeps widens the contact width to ~150 m (Mormede et al. 2017) and the total tow contact area to ~142.5 Ha (see Appendix 1). Thus, considering the maximum catchability (relative to dredge) of 2–6% for coral, 4–5% for sponges and 8–22% for alcyonarians (

[1] 84.1% of trawls are on 'flat' seabed and are long tows, accounting for 97.1% of total footprint, whereas 18.2% of trawls are on topographic features and are short tows with shorter sweeps (2.9% of footprint) (Mormede et al. 2017). See Appendix 1 for details of tow types and comparison of estimated VME contact.

Table *3*), then the *minimum* estimated contact biomasses would be ~245–780 kg for coral, ~295–390 kg for sponges and ~65–170 kg for alcyonarians—with a corresponding contact on bryozoans of ~40-940 kg. However, all could be considerably larger given the dredge also greatly under-samples these fauna.

These estimates indicate that rather small catches of sessile benthos in fish trawls scale to large contacts on the seabed, particularly for fragile corals and bryozoans. Based on the assumptions in Appendix 1, a trawl catch of 250 kg of corals could scale to a seabed contact of more than 33–104 t of corals on the seabed. Given the estimated impact proportion of 0.82 (Mormede et al. 2017), this contact range may translate to seabed impacts of more than 27–85 t.

In previous CSIRO surveys on seamounts in southeast Australia (Williams et a., 2015), some video-tow transects were also sampled by co-located heavy epi-benthos sled. There were 48 paired video observations and sled catches, which were matched and the sled catches (g/Ha) of *Solenosmilia* were empirically compared against the video cover observations. Plotting the sled sampled biomasses ($\log_{10}$(g/Ha+1)) against quantified cover of coral (Figure 8), shows that even when cover of *Solenosmilia* is very substantive (consistent with 'VME habitat' as defined by FAO 2009) the catches by the sled are small (only ~1–3 kg/Ha at 40–50% cover, black fitted line and CIs) — even though sleds typically catch ~17–55× more coral than trawls (

Table *3*). With maximum catchability of ~2–6% for coral (relative to sled, blue dashed lines Figure 8), fish trawls may catch only ~100 g/Ha of coral when cover of *Solenosmilia* is 45-55% — and, using the assumptions in Appendix 1, the corresponding *minimum* estimated contacted biomass on the seabed would be ~245–780 kg.

A trigger-level catch of 250 kg of corals (Figure 8, dark red dotted line) by a typical SPRFMO trawl, would correspond to *Solenosmilia* cover on the seabed of ~80–95%, which would be defined as VME habitat based on the definition of VMEs given in the FAO Deep-sea Fisheries Guidelines (FAO 2009) and by others (e.g. >15% cover with other criteria, Rowden et al. 2017), and would correspond to very large biomass contacts and impacts on the seabed (as estimated above). However, *Solenosmilia* cover of 15% corresponds to an estimated trawl catch of <1 g/Ha (Figure 8, orange dotted line), scaling up to <20 g total in a typical SPRFMO trawl. Thus, almost any bycatch of coral could be indicative of presence of VME habitat. Even using the upper CI sled catch of 100 g/Ha at 20% cover would scale up to only <2 kg of coral bycatch for a typical trawl tow. The previous (prior to CMM-03-2019) trigger-threshold catch of 30 kg of corals in place for New Zealand vessels would correspond to *Solenosmilia* cover on the seabed of ~65–80% (Figure 8, light red dotted line), and could scale to seabed contact of more than 3.9–12.5 t of corals and to seabed impacts of more than 3.2–10.2 t (see Appendix 1.

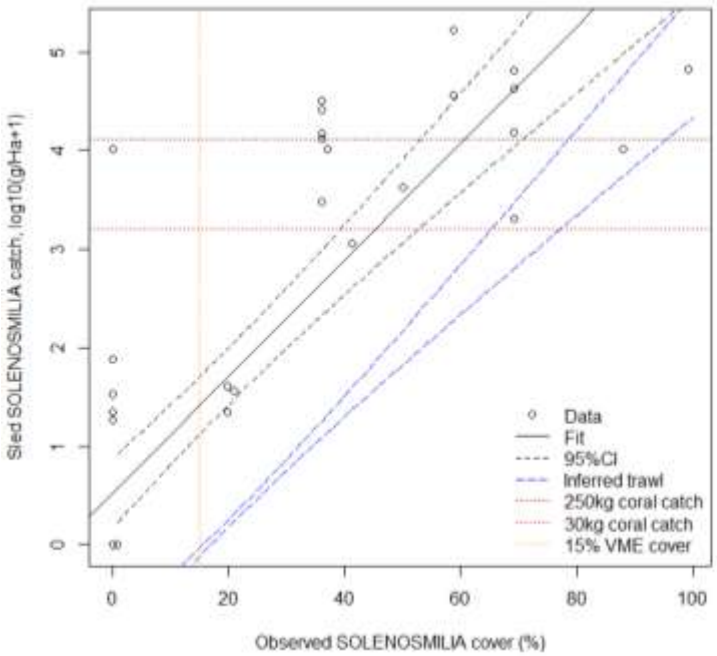

Figure 8. Relationship between biomass ($\log_{10}$(g/Ha+1)) of *Solenosmilia variabilis* sampled by heavy epi-benthos sled against %cover of *S. variabilis* observed in co-located video transects at the same stations in the southeast Australian seamounts surveys. Catch range for fish trawls is inferred from maximum estimated catchabilities of trawls relative to dredges/sleds.

Note that the trawl vs. sled relative catchability for hard corals of 2–6% as used above (from GBR EoT, Table *3*) is also consistent with estimates for Scleractinia from the GBR SBD dataset (mean=4.4%, Pitcher et al. 2007; Pitcher 2014 Table C-1). Collectively, the results show that because sleds obviously also under-sample these corals, the actual seabed biomasses contacted and impacted will be larger than any estimates provided above.

Conclusions

The results of this work provide strong objective evidence that there are considerable and demonstrable uncertainties as to whether CMM 03-2019 is meeting (or will meet) the objective to manage and prevent SAIs on VMEs at local/site scales, population scales, and regional scales. Given SPRFMO's mandate to apply a precautionary approach in the face of uncertainty around risks and impacts from fishing, we suggest that the results presented herein (as well as concurrent analyses being undertaken by New Zealand) indicate that additional work is urgently required to further explore the uncertainties and assumptions in the analyses and outputs that underpinned CMM 03-2019 to ensure that it meets its objectives and relevant Members' international obligations. In the interim, it may be prudent to adopt a more precautionary approach to managing potential impacts on VMEs—including at local scales (i.e. within Bottom Trawl Management Areas)—which may include, *inter alia*, lowering the thresholds for some or all VME indicator taxa outlined in CMM 03-2019, and developing a more explicit mechanism within CMM 03-2019 to identify and designate VME habitats at fine scales using all existing and future data. In the future, effectively preventing SAIs on VME could be achieved by requiring fishing vessels to implement cameras on nets/headlines to collect relevant data and prospectively avoid VME habitats in real time. A combination of these approaches (and potentially others) would be more consistent with a precautionary approach and could be used to inform full review of CMM 03-2019 in 2021.

If more precautionary thresholds are implemented before full review of CMM 03-2019, they could be based on the more conservative thresholds in place within SPRFMO prior to implementation of CMM 03-2019.

Recommendations

It is recommended that the SC:

- **Notes** that considerable progress has been made on the work programme mandated by CMM 03-2019 on bottom fisheries but that there is much work in progress leading up to full review of CMM 03-2019 in 2021, including a cumulative Australian and New Zealand bottom fishery impact assessment in 2020;
- **Agrees** that the work done to date and underway by Australia demonstrates that there is considerable uncertainty in CMM 03-2019 with regard to the proportion of stony coral reef, and therefore potentially other VME taxa, protected across the modelled region, and moreover, evidence suggests a very high likelihood that CMM 03-2019 provides less protection than previously thought in subregions of SFPRMO such as the Louisville Seamount Chain and the Lord Howe Rise.
- **Agrees** that the work done to date and underway by Australia and New Zealand demonstrates that the VME indicator taxa thresholds outlined in CMM 03-2019 are very likely to correspond to very high covers and biomasses of VME taxa on the seabed, and that it is important to evaluate whether bycatches of VME indicator taxa that correspond to these thresholds would result in significant adverse impacts.

- **Agrees** that the current Bottom Trawl Management Areas include substantive distributions of VME indicator taxa within their boundaries and CMM 03-2019 lacks an explicit mechanism for designating these as VME habitats using existing data.
- **Agrees** that there is very high uncertainty with regard to whether CMM 03-2019 will achieve the objective of preventing SAIs on VMEs at local/site, population and regional scales, and in the face of this uncertainty **agrees** that until full review of the measure is undertaken in 2021, more precautionary VME bycatch trigger levels would help to mitigate and minimise risks of SAIs on VMEs until key uncertainties can be resolved.

References

Althaus, F., Williams, A., Schlacher, T.A., Kloser, R.J., Green, M.A., Barker, B.A., Bax, N.J., Brodie, P. and Hoenlinger-Schlacher M.A. (2009). Impacts of bottom trawling on deep-coral ecosystems of seamounts are long-lasting. Marine Ecology Progress Series, 397: 279-294.

FAO (2009). International Guidelines for the Management of Deep-Sea Fisheries in the High Seas. Food and Agricultural Organisation of the United Nations, Rome, Italy, 73pp. Available from: http://www.fao.org/docrep/011/i0816t/i0816t00.htm

Mormede, S., Sharp, B, Roux, MJ., Parker, S. (2017) Methods development for spatially-explicit bottom fishing impact evaluation within SPRFMO: 1. Fishery footprint estimation. SPRFMO SC5-DW06.

Pitcher, C.R. (2014) Quantitative Indicators of Environmental Sustainability Risk for a Tropical Shelf Trawl Fishery. Fish. Res. 151:136–174 http://dx.doi.org/10.1016/j.fishres.2013.10.024

Pitcher, C.R., Doherty, P., Arnold, P., Hooper, J., Gribble, N., and 55 others (2007). Seabed Biodiversity on the Continental Shelf of the Great Barrier Reef World Heritage Area. AIMS/CSIRO/QM/QDPI Final Report to CRC Reef Research. 320 pp. ISBN 978-1-921232-87-9 http://www.frdc.com.au/Archived-Reports/FRDC%20Projects/2003-021-DLD.pdf

Pitcher, C.R., Ellis, N., Althaus, F., Williams, A., McLeod, I. (2015) Predicting benthic impacts & recovery to support biodiversity management in the South-east Marine Region. Pages 24–25 in Bax, N.J. & Hedge, P. [Eds.]. 2015. Marine Biodiversity Hub, National Environmental Research Program, Final report 2011–2015. Report to Department of the Environment. Canberra, Australia. http://nerpmarinebiodiversity2015.report/predicting-benthic-impacts-and-recovery-to-support-biodiversity-management-in-the-south-east-marine-region/

Poiner, I.R., Glaister, J., Pitcher C.R., Burridge, C., Wassenberg, T., Gribble N., Hill B., Blaber, S.J.M., Milton, D.A., Brewer D., Ellis, N., (1998) The environmental effects of prawn trawling in the far northern section of the Great Barrier Reef Marine Park: 1991–1996. Final Report to GBRMPA and FRDC. CSIRO Division of Marine Research, Cleveland. 554 pp. ISBN 0643061762

Rowden, A,A,, Anderson, O.F., Georgian, S.E., Bowden, D.A., Clark, M.R., Pallentin, A., Miller, A. (2017) High-Resolution Habitat Suitability Models for the Conservation and Management of Vulnerable Marine Ecosystems on the Louisville Seamount Chain, South Pacific Ocean. Front. Mar. Sci. 4:335. doi: 10.3389/fmars.2017.00335

Wassenberg, T.J., Dews, G., Cook, S.D. (2002) The impact of fish trawls on megabenthos (sponges) on the north-west shelf of Australia. Fish. Res. 58,141-151.

Williams, A., Althaus, F., and T. A. Schlacher (2015). Towed camera imagery and benthic sled catches provide different views of seamount benthic diversity. Limnology and Oceanography: Methods, 13: 62-73.

Appendix 1

Trawl gear details and estimates swept areas, catches, and impacts of two types of SPRFMO trawl tows (source data from Mormede et al. 2017)

	Average "slope" trawl	Average "UTF" trawl
Door width m	2 – 4	2 – 4
Sweep/bridle	103 – 124	73 – 104
Ground gear	15 – 22	15 – 22
Door width m	3	3
Sweep/bridle	113.5	88.5
Ground gear	19.4	19.4
Swept width m	150	111
Mean tow len km	9.7	1.8
Net swept area Ha	18.81	3.49
Door-to-door swept area Ha	142.5	20.0
% of all tows	81.4	18.2
Total tow len km	268,126	10,928
Total swept area km²	40,219	1,212
% of total footprint	97.1	2.9
Impact index	0.82	0.24
Seabed biomass contacts (kg) corresponding to catch rate of 100 g/Ha		
Total catch in trawl net (kg)	1.881	0.349
corals catchability 2%	783	110
corals catchability 6%	246	34
sponges catchability 4%	390	55
sponges catchability 5%	296	41
alcyonarians catchability 8%	171	24
alcyonarians catchability 22%	64	9
Seabed %cover of *Solenosmilia* corresponding to trawl catch rate of 100 g/Ha		
corals catchability 2-6%	47-54%	47-54%
Seabed biomass contacts (t) corresponding to a trawl catch of 250 kg of corals		
corals catchability 2%	104	79
corals catchability 6%	33	25
Seabed biomass impacts (t) corresponding to a trawl catch of 250 kg of corals		
corals catchability 2%	85	19
corals catchability 6%	27	6
Catch & density per Ha of *Solenosmilia* corresponding to a trawl catch of 250 kg		
Inferred coral catch kg/Ha	13	72
Inferred seabed density kg/Ha		
corals catchability 2%	730	3,936

corals catchability 6%	230	1,237
Seabed %cover of *Solenosmilia* corresponding to a trawl catch of 250 kg		
corals catchability 2-6%	79–96%	90-110%
Seabed biomass contacts (t) corresponding to a trawl catch of 30 kg of corals		
corals catchability 2%	12.5	9.4
corals catchability 6%	3.9	3.0
Seabed biomass impacts (t) corresponding to a trawl catch of 30 kg of corals		
corals catchability 2%	10.2	2.3
corals catchability 6%	3.2	0.7
Catch & density per Ha of *Solenosmilia* corresponding to a trawl catch of 30 kg		
Inferred coral catch kg/Ha	1.6	8.6
Inferred seabed density kg/Ha		
corals catchability 2%	88	472
corals catchability 6%	28	148
Seabed %cover of *Solenosmilia* corresponding to a trawl catch of 30 kg of corals		
corals catchability 2-6%	65–78%	76-92%