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Cumulative Bottom Fishery Impact Assessment for Australian and New Zealand bottom fisheries in the SPRFMO Convention Area, 2020

Australia – New Zealand

CUMULATIVE BOTTOM FISHERY IMPACT ASSESSMENT FOR AUSTRALIAN AND NEW ZEALAND BOTTOM FISHERIES IN THE SPRFMO CONVENTION AREA, 2020

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1 EXECUTIVE SUMMARY

1.1 OBJECTIVE AND RESULT OF THIS ASSESSMENT

Through the adoption of United Nations General Assembly (UNGA) resolutions 61/105 in 2006, 64/72 in 2009, 66/68 in 2011 and 71/123 in 2016 on deep-sea fisheries, the management of bottom fisheries and protection of deep-sea ecosystems on the high seas has been a priority for the international community. UNGA Resolutions on Sustainable Fisheries (specifically, paragraph 83 of resolution 61/105, and paragraph 119(a) of resolution 64/72), States and regional fisheries management organisations were called on to assess, based on the best available scientific information, whether bottom fishing activities would have significant adverse impacts (SAIs) on vulnerable marine ecosystems (VMEs)[1] and the long-term sustainability of fish stocks, and to ensure that these activities are managed to prevent such impacts or are not authorised to proceed. This was initially reflected in the South Pacific Regional Fisheries Management Organisation (SPRFMO) interim bottom fishing measures (SPRFMO 2007) adopted prior to the entry into force of the SPRFMO Convention and carried through to the first binding measure in 2013. The SPRFMO Commission has considered the bottom fishing measures annually since 2013, adopting the most recent changes in 2020. The UNGA Resolutions also influenced the development and adoption by the SPRFMO of a standard for impact assessment of bottom fisheries (SPRFMO 2012), compatible with the Food and Agricultural Organisation's (FAO) International Guidelines for the Management of Deep-sea Fisheries in the High Seas ('the FAO Deep-sea Guidelines') (FAO 2009). The SPRFMO bottom fishery impact assessment standard was updated in 2019 (SPRFMO 2019). The updated standard requires that impacts on marine mammals, seabirds, reptiles, and other species of concern be addressed as well as impacts on fish stocks and VMEs to deliver on the action called for in the UNGA Resolutions. This cumulative bottom fishery impact assessment has been prepared jointly by Australia and New Zealand in accordance with the relevant obligations prescribed in SPRFMO Conservation and Management Measures (CMMs) and the SPRFMO Bottom Fishing Impact Assessment Standard (BFIAS) (SPRFMO 2019).

The assessment concludes that:

- Risk assessments using Productivity-Susceptibility Analysis (PSA) and Sustainability Assessment for Fishing Effects (SAFE) have been used to categorise teleost fishes into a three-tiered stock assessment framework. The first and second tiers require formal stock assessment modelling or the application of data-limited methods for orange roughy (*Hoplostethus atlanticus*) and alfonsino (*Beryx* spp., predominantly *B. splendens*) (predominantly trawl fisheries), and bluenose / blue-eye trevalla (*Hyperoglyphe antarctica*), wreckfish (*Polyprion* spp.), yellowtail kingfish (*Seriola lalandi*) and tarakihi / jackass morwong (*Nemadactylus* spp., predominantly *N. macropterus*) (predominantly line fisheries).
- The only tier 1 species for which stock assessment modelling has been concluded is orange roughy. Models suggest that there is a low risk that any of the stocks are below

[1] 'Vulnerable marine ecosystem' (VME) means a marine ecosystem that has the characteristics referred to in paragraph 42 of, and elaborated in the Annex to, the FAO (2009) Deep-sea Fisheries Guidelines.

20% of their unfished biomass. Precautionary catch limits are in place. However, there is considerable uncertainty in these stock assessments and work is underway to reduce uncertainty.

- There are no formal stock assessment models for other tier 1 or tier 2 species targeted by bottom trawl, midwater (benthopelagic) trawl, or bottom line fisheries. SAFE analyses suggest the risk posed to these species by bottom and midwater trawl fishing is low. However, risk posed by bottom line fisheries is ranked as high or extreme for tarakihi / jackass morwong, bluenose / blue-eye trevalla, and one species of wreckfish (hapuku, *Polyprion oxygeneios*). Outputs from the PSA and SAFE analyses should be considered as relative rankings rather than absolute estimates of risk. Catch limits aggregated across species are in place and priority species for additional work have been identified.
- Most species of teleost and chondrichthyan fishes are caught only as bycatch, or are only rarely targeted, and have been categorised or are proposed for categorisation into tier 3. In this tier, no assessment is required because the catches and risk are considered low. Catch limits aggregated across species are in place and catches and risk will be monitored.
- Captures of marine mammals, seabirds, reptiles and other species of concern are rare in SPRFMO bottom fisheries and the risk to affected populations appears to be low. Work to assess these impacts cumulatively with other fisheries in the Southern Hemisphere is underway but will take time to complete.
- Impact and risk to benthic habitats and VMEs is a key focus of this assessment and analyses have been conducted at a range of scales:
    - New habitat suitability models have been made for ten VME indicator taxa and, using these, estimates of the proportion of the estimated distribution of suitable habitat and abundance for each taxon outside the Bottom Trawl Management Areas (BTMAs) have been calculated. These calculations have been done at a range of spatial scales and using a variety of model structures and assumptions to assess sensitivity in the estimates.
    - At the broadest scale, about 80% of suitable habitat or abundance of stony corals and about 90% of suitable habitat or abundance of other VME indicator taxa are outside the BTMAs. At finer geographical and taxonomic scales, and using different assessment approaches, the proportions outside the BTMAs vary quite widely, and estimates for the NW Challenger Plateau average <70%.
    - Estimates of the proportions of VME indicator taxa outside the BTMAs are lowest for the Central-South Louisville Ridge where an average of 60% of suitable habitat and 45% of abundance of the key species of stony coral are outside the BTMA, together with 52% of suitable habitat and 48% of the abundance of other VME indicator taxa. A sensitivity analysis assuming VME indicator taxa significantly deeper than bottom trawl fisheries are not exposed to fishing disturbance increases these values by 20–30 percentage points in these areas.

- A Relative Benthic Status (RBS) assessment has been undertaken with the results indicating that RBS for most taxa across the two scales assessed (whole Evaluated Area and orange roughy stock management areas) is >0.8 for most fishing effort and abundance sensitivity scenarios, with a number of clear exceptions at the smallest scale (orange roughy management areas, FMAs) and within some BTMAs.
- The RBS results indicate that status under the current and future fishing effort scenarios will be higher than status under the historical fishing effort scenario, and that status under the current fishing effort scenario will be higher than under the hypothetical future fishing effort scenario.
- A range of additional analyses have been undertaken to explore uncertainty in the habitat suitability index (HSI) modelling, including potential model over-prediction, as well as analyses of the relationships between HSI and abundance of VME taxa on the seafloor and the catchability of VME taxa in trawl gears. These analyses should be considered when interpreting results provided in the VME impact assessment and making inferences about the performance of CMM03-2020 (bottom fishing).

1.2 DESCRIPTION OF FISHING ACTIVITIES

Fishing gear and activity using the methods of bottom trawl (mostly targeting orange roughy), midwater trawl (targeting benthopelagic species like alfonsino), and bottom line fishing methods (mostly targeting bluenose or wreckfish but with more fishing recently for subtropical and tropical species) are described for Australian and New Zealand-flagged vessels separately.

1.3 MAPPING AND DESCRIPTION OF FISHING AREAS

Fishing areas for the methods of bottom trawl (mostly for orange roughy), midwater trawl (for benthopelagic species like alfonsino), and bottom line-fishing methods are described for New Zealand-flagged and Australian-flagged vessels, and maps are provided for New Zealand-flagged vessels.

1.4 IMPACT ASSESSMENT METHODS

A range of impact and risk assessment methods are applied to the various assets and hazards relevant to bottom fisheries in the southwestern portion of the SPRFMO Convention Area where bottom fishing currently occurs. Largely expert-based qualitative or semi-quantitative assessments have been completed for non-target fish stocks and marine mammals, seabirds, reptiles and other species of concern that are occasionally caught in SPRFMO bottom fisheries. Fully quantitative or semi-quantitative assessments have been completed for orange roughy, the main target species (by weight) for bottom fisheries, and for benthic habitats and taxa indicative of VMEs.

1.5 STATUS OF STOCKS

Fully quantitative stock assessment modelling has been completed only for orange roughy in a range of areas thought to represent separate stocks. All such assessments for non-straddling stocks are data-limited and have broad uncertainty. The Scientific Committee considered at its 5th meeting in 2017 that, although the data were limited and none of the methods was ideal for the assessment of SPRFMO orange roughy stocks, these assessments are, collectively, indicative of stock status and potential yields. Based on these models, advice on catch limits was developed for the first time in 2017 for groups of stocks in the Tasman Sea (excluding the Westpac Bank area) and on the Louisville Seamount Chain (LSC). The proposed catch limits were more precautionary for the Tasman Sea stocks than the LSC stocks, based on the relative risk of these stocks being below 20% of the unfished biomass (a common limit reference point for commercial fisheries). Catch limits for orange roughy have been unchanged since the proposed limits were adopted, except for an increase for the Westpac Bank area based on a fully quantitative stock assessment undertaken in 2019 that suggested that the stock biomass had continued to increase since the fishery was re-opened in 2011.

1.6 Monitoring, management and mitigation measures

All fishing pursuant to CMM03-2020 (bottom fishing) and CMM03a-2020 (deepwater species) requires flag States to provide detailed information on the time and location of each fishing event, the catch of target and non-target species of fish, interactions with marine mammals, seabirds, reptiles and other species of concern, and benthic invertebrates, including VME indicator taxa. There is also a requirement to carry observers, with coverage specified as 100% for trawling and at least 10% for bottom line methods for each fishing year. Observers collect complementary and sometimes more detailed information (for example measuring fish lengths and collecting otoliths for age determination). The information requirements are detailed in CMM02-2020 (data standards). The measures in place to mitigate bycatch of seabirds in SPRFMO bottom fisheries is close to world best practice (as defined by Agreement on the Conservation of Albatrosses and Petrels (ACAP)). These are specified in CMM09-2017 (seabirds). Species- and area-specific catch limits for orange roughy and aggregate limits for all other fish species combined are specified in CMM03a-2020. Minimum levels of observer coverage, spatial management (open areas by fishing method) and a VME encounter protocol are specified in CMM03-2020.

2 DESCRIPTION OF FISHING ACTIVITIES

2.1 GENERAL HISTORY AND CHARACTERISTICS OF THE FISHERIES

The SPRFMO Convention Area has historically been fished by vessels from various nations using pelagic and demersal fishing gear. The main high-volume commercial fisheries resources managed by the SPRFMO are Chilean jack mackerel (*Trachurus murphyi*) and jumbo flying squid (*Dosidicus gigas*). The SPRFMO also manages fisheries for lower-volume demersal species such as orange roughy and alfonsino, which are caught using bottom and midwater trawl gears, and a variety of demersal species caught using bottom line gears. These demersal fisheries are the focus of this assessment. Historically, these demersal fisheries have targeted species associated with seamounts, ridges and plateaus in the southern Pacific Ocean. Penney et al. (2016) reported that it is thought that virtually every underwater topographical feature within fishable depths (<1400 m) has been explored, with the majority experiencing some fishing, but fisheries have focused on major seamounts, ridges and plateaus. In recent decades, Australian and New Zealand fisheries have mostly been confined to the western part of the SPRFMO Convention Area. There are five main fishing grounds in the region: the high seas parts of the South Tasman Rise off Tasmania, the West Norfolk Ridge, Lord Howe Rise, the Northwest Challenger Plateau in the Tasman Sea west of New Zealand, and the Louisville Seamount Chain (LSC) to the east of New Zealand. Australia and New Zealand are the only two Members currently authorised to fish in the established demersal fisheries, although some other Members are authorised to fish in exploratory fisheries outside the Evaluated Area[2]. These fisheries are assessed and managed under a separate regime.

Deep-sea features tend to attract and support fish resources because their physical and biological properties enhance local productivity. Some deepwater species form dense spawning aggregations over deep-sea features, potentially allowing high catch rates and large catches (Norse et al. 2012). Some demersal species are slow growing and long lived, and aggregations can represent the accumulation of numerous age classes recruited over many decades. Initial catch rates typically taken on these aggregations may not be sustainable and can lead to rapid declines in abundance and availability (Norse et al. 2012). Long-term sustainable yields are usually only a small percentage of initial high catches. The fishery and biological data and other information to support management are also often limited data, which poses challenges for their sustainable utilisation and exploitation (FAO 2008). Despite these challenges, sustainable and profitable fisheries for deepwater species such as orange roughy are achievable (FAO 2018) and, notwithstanding historical overfishing of several stocks globally, there are many examples of sustainable, well-managed stocks (e.g. Patterson et al. 2018, Cordue 2019).

Trawl fleets from the former Union of Soviet Socialist Republics (USSR) began fishing the high seas in the south Pacific for deepwater species in the early 1970s. These vessels fished several areas, taking pencil (or bigeye) cardinal fish (*Epigonus denticulatus*), orange roughy, blue grenadier (*Macruronus novaezelandiae*) and oreo dories (Oreosomatidae) (Clark et al. 2007).

[2] The Evaluated Area is those that 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.

Before the advent of 200 nautical mile (NM) Exclusive Economic Zones (EEZ) in 1982, it is not possible to be categorical as to whether catches came from what are now high seas areas, or from within what are now EEZs. There was some exploratory fishing by both Australian and New Zealand vessels on the Challenger Plateau and Lord Howe Rise from the mid-1980s, but it was in 1988 that the first major fishery in this region was developed on Lord Howe Rise, followed by the northwest Challenger Plateau two years later. Subsequently, commercial fisheries were developed on the Louisville Ridge (1993), the South Tasman Rise (1997), and the West Norfolk Ridge (2001). Since 1992, catches have been dominated by New Zealand and Australian vessels but other nations, including Belize, Japan, Norway, Panama, the Republic of Korea and Ukraine, also accessed these deep-sea resources (Gianni 2004).

In recent years, most of the catch of orange roughy in the SPRFMO Convention Area is taken during winter on spawning aggregations associated with underwater topographical features such as seamounts. Australian and New Zealand fishing vessels also target alfonsino using demersal and midwater trawl gears. Australian and New Zealand bottom line fishing vessels have historically targeted species such as bluenose/blue-eye trevalla (BWS, *Hyperoglyphe antarctica*), gropers/hapuku (HAU, *Polyprion* spp.), tarakihi/jackass morwong (MOW, *Nemadactylus macropterus*), yellowtail kingfish (YTC, *Seriola lalandi*), and a variety of other species.

2.2 History of SPRFMO bottom fishing management arrangements

Up until the early- to mid-2000s, most deep-sea fisheries in high seas areas of the south Pacific Ocean were regulated by domestic provisions imposed upon fishers by relevant flag states. Illegal, unreported and unregulated (IUU) fishing has also been a major historical problem in the South Pacific and southern oceans more broadly (e.g. Österblom and Bodin 2012). The first push towards contemporary international fisheries management arrangements for non-highly migratory fisheries resources in the high seas areas of the South Pacific Ocean came in 2006, when Australia, Chile and New Zealand initiated a process of consultations to enable cooperation between states to address gaps that existed in the international conservation and management of fisheries resources and protection of biodiversity of the marine environment in the area.

Shortly after this, in 2006, the UNGA adopted Resolution 61/105 that called on States and Regional Fisheries Management Organisations (RFMOs) to take urgent action to protect VMEs from destructive fishing practices, including bottom fishing, in areas beyond national jurisdiction. Key elements of Resolution 61/105 included undertaking impact assessments to determine whether bottom fishing activities would have SAIs on VMEs, identifying VMEs, establishing move on protocols, sustainably managing the exploitation of deep-sea fish stocks, and establishing appropriate monitoring, control and surveillance mechanisms[3].

[3] In 2009, UNGA adopted Resolution 64/72. While reaffirming Resolution 61/105, it asserted that measures should be implemented by flag states and RFMOs in accordance with the FAO (2009) Guidelines, prior to allowing or authorising bottom fishing in the high seas. Resolution 64/72 calls for States and RFMOs to conduct impact assessments on bottom fishing on the high seas and to ensure that vessels do not engage in bottom fishing until such assessments have been carried out.

Consistent with UNGA Resolution 61/105, the Bottom Fishing Interim Measures adopted by participants at the third international consultation to establish the SPRFMO in 2007 required participants to “Not expand bottom fishing activities into new regions of the Area where such fishing is not currently occurring” which resulted in individual ‘footprints’ for Australia and New Zealand representing the spatial distribution of effort between 2002 and 2006. The interim scientific working group subsequently recommended that areas that were ‘currently’ being fished be expressed as grid blocks of 20 minute resolution that had been fished over the period 2002 to 2006, this being the reference period subsequently chosen for limiting bottom fishing effort and catch to ‘existing levels’.

2009 was a significant year in the development of high seas bottom fishing management. Following a series of international meetings, participants decided to establish a regional fisheries management organisation and on 14 November 2009, the 8th international meeting adopted the Convention on the Conservation and Management of High Seas Fishery Resources in the South Pacific Ocean. Also in 2009, the FAO published the International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (FAO 2009), which provided recommendations on governance frameworks and management of deep-sea fisheries with the aim to ensure long-term conservation and sustainable use of marine living resources in the deep sea and to prevent SAIs on VMEs. Importantly, these guidelines also defined SAIs and VMEs, with these definitions having been used widely by demersal RFMO/As to the current day. In the same year, the UNGA adopted Resolution 66/68 reinforcing earlier Resolutions, and calling on States and RFMO to apply a precautionary approach and these FAO Guidelines.

Based on the early international agreements, UNGA Resolution 61/105 and the FAO (2009) guidelines, once SPRFMO entered into force in 2012, Australia and New Zealand set about implementing management arrangements that would satisfy the varied international obligations and objectives as manifested through the SPRFMO Convention and related non-binding instruments.

The first formal CMM for the Management of Bottom Fishing in the SPRFMO Convention Area came into force on 4 May 2014. The CMM was reviewed annually, with minor changes, while Australia and New Zealand progressed a more comprehensive review.

In 2016, the UNGA adopted Resolution 71/123 which strongly emphasised the importance of strengthening procedures for carrying out, reviewing and evaluating impact assessments, taking into account individual collective and cumulative impacts, and ensuring that any measures are based on best available scientific information, and adopt an ecosystem approach. It also noted the unevenness of implementation of the earlier resolutions. The 2016 Resolution influenced the development of a more comprehensive measure, which applied a novel approach to spatial management and consistent rules for all Members, adopted as CMM 03-2019 in 2019.

Since then there were only minor changes until the adoption of a comprehensive measure in 2019. The historical management arrangements implemented by Australia and New Zealand are summarised briefly below.

2.2.1 New Zealand’s historical bottom fishing management arrangements

In 2008, New Zealand completed a bottom fishery impact assessment for bottom fishing activities by New Zealand vessels fishing in the high seas in the SPRFMO Convention Area during

2008 and 2009. The assessment concluded that there were a variety of impacts on different 'assets' (i.e. VMEs, fish stocks, deepwater elasmobranchs, seabirds, and impacts resulting from loss of gear) and proposed a series of management and mitigation measures to minimise risks and impacts.

New Zealand established measures to manage bottom fishing in the SPRFMO Convention Area in the form of high seas fishing permit conditions, imposed from 1 May 2008. The key elements of those permit conditions included:

- Schedules designating open, move-on and closed bottom trawling areas within the historical (2002–2006) New Zealand high seas bottom trawl fishing footprint, and prohibiting bottom trawling within closed areas and everywhere else in the SPRFMO Convention Area.
- The VME Evidence Process for bottom trawling within move-on areas, with the requirement to report to the Ministry for Primary Industries and move-on 5 nautical miles from where the VME evidence threshold was reached.
- A requirement to carry at least one observer on all bottom trawling trips.
- Setting an overall catch limit for New Zealand bottom fishing vessels at the level it was during the reference period (2002-2006), including a species-specific catch limit for orange roughy.

The effect of these measures was to close bottom trawling in 41% of the total 217 463 km^2 New Zealand bottom trawl footprint area, with 30% of that made subject to a move-on rule, and 29% left open to bottom trawling. The open area represented 0.13% of the entire SPRFMO Convention Area (noting that over 90% of the western part of the SPRFMO area is too deep for bottom trawling). New Zealand modified the status of a small number of blocks within its bottom trawl footprint in 2015 such that opportunities for midwater trawling for bentho-pelagic species like alfonsino could be maintained while decreasing the risk of significant adverse impacts on VMEs.

The New Zealand VME Evidence Process incorporated weight thresholds for different taxa, based on an analysis of bycatch weight-frequency distributions in historical trawl catches, mostly within New Zealand's EEZ. This protocol also included a biodiversity threshold, summing the scores for presence of each taxon and requiring a move-on if any three of the listed VME indicator taxa were caught, even if individual weight thresholds were not breached (Parker et al. 2009). Further, a three-level weighting was applied to each of the VME indicator taxa groups based on the known importance of each group. Groups that exhibit life history characteristics that are known to contribute to higher vulnerability to fishing activities were scored high, while other groups that may be less vulnerable themselves, but indicate the presence of habitats containing VMEs, were scored low. If the total VME indicator score was three or greater, the trawl was considered to have generated evidence of having encountered a VME and the vessel was required to move away (Parker et al. 2009).

2.2.2 Australia's historical bottom fishing management arrangements

From 2007 until 2019, Australia restricted fishing to within its 2002–2006 bottom-fishing footprint (expressed as 20-minute resolution grid cells) and limited catch to the average annual levels during this same period. All areas within that footprint were open to Australian vessels; and all areas outside that footprint were closed. Australia implemented a VME encounter protocol where if combined catch of coral or sponge in any one shot exceeded 50 kg of corals and sponges in a trawl shot or 10 kg bycatch of corals and sponges in a 1000 hook section of line for automatic longline operations, then fishers were required to stop fishing immediately and not fish using the same method at any point within a 5 NM radius of any part of the shot until the Australian Fisheries Management Authority (AFMA) notified otherwise. Any evidence of a VME such as coral or sponges in a fishing shot was required to be recorded in logbooks. These measures also required 100% observer coverage for all trawl operations, and for all other methods, mandatory observer coverage for the first trip of each season and ongoing coverage of at least 10% annually.

In 2011, Australia completed a bottom fishery impact assessment in the SPRFMO Convention Area to examine whether individual bottom-fishing activities by Australian vessels would have significant adverse impacts on VMEs (Williams et al. 2011). The study concluded that the overall risk of significant adverse impacts on VMEs by Australian bottom trawl and bottom longline operations was low, and the impact caused by midwater trawling and drop-lining was negligible (Williams et al. 2011).

2.2.3 Contemporary bottom fishing management arrangements (CMM03-2019 and CMM03-2020, CMM03a)

Following a recognition by the SPRFMO Commission that the different implementation of SPRFMO bottom fishing measures by members was sub-optimal, Australia and New Zealand initiated discussions to agree and implement a revised bottom fishing measure so that consistent management arrangements would apply to all SPRFMO Members engaged in established bottom fisheries in the SPRFMO Convention Area. There were also ongoing concerns expressed by the international community, in particular environmental non-government organisations, that the measures in existence (and how they were being interpreted) were not meeting the intended objectives of the relevant UNGA Resolutions and associated instruments (e.g. the FAO (2009) Deep-Sea Guidelines).

In response, CMM03-2019 provided a comprehensive set of rules based on a spatial management approach that aimed to ensure the long-term conservation and sustainable use of deep-sea fishery resources. The approach aimed, through the protection of a large proportion of the predicted distribution of VME indicator taxa, to provide assurance that bottom fishing within the Evaluated Area would not have SAIs on VMEs. The measure also contained complementary measures, including VME encounter thresholds, move-on protocols and review processes within areas that are open to fishing to provide further assurance that SAIs on VMEs will be prevented. The SPRFMO Scientific Committee reviewed and agreed that the methodology underpinning the measure was appropriate. The measure included:

a) An Evaluated Area within which the distribution of VME indicator taxa has been mapped between depths of 200 m and 3000 m[4] using predictive models (Georgian et al. 2019;

[4] It is recognised that VME indicator taxa and habitat found in the deeper parts of the areas open to bottom trawling are unlikely to be impacted by bottom trawling because they are too deep to be trawled using existing technology. Analyses (e.g. Delegation of New Zealand, 2019, POLI-55-1615) indicate that bottom trawling is very rare in waters deeper than 1250 m and has never been reported deeper than 1400 m, meaning that any part of the distribution of a VME indicator taxon that is inside the areas

currently being updated) and which considers cumulative impacts of fishing, an improvement on the existing approach (which considers impacts only by individual flag State);

b) Three Management Areas[5] within the Evaluated Area in which bottom fishing may be conducted, based on spatial prioritisation using Zonation software (Moilanen et al. 2009) which are implemented consistently across the membership and differentiated by gear (bottom trawl, midwater trawl and bottom longline);
c) A VME encounter protocol within the bottom and midwater trawl Management Areas, to be implemented consistently across the membership;
d) Measures to assess, monitor and control bottom fisheries.

The revised CMM essentially allowed for two avenues for bottom fishing with a particular gear type in the SPRFMO Convention Area[6]:

(1) In a defined Management Area (within the Evaluated Area) for that gear type pursuant to the revised CMM (CMM 03-2019), or
(2) Anywhere else in the Convention Area, or within the Management Area with a gear type other than that provided for in the revised CMM, under CMM 13-2016 (Exploratory fisheries).

Recognising that there is a level of uncertainty associated with VME habitat suitability models, the revised CMM also incorporated an encounter protocol that triggers an immediate management response to the capture of defined amounts of VME indicator taxa in areas open to fishing (defined as an 'encounter'). This approach was designed to be consistent with the UNGA Resolutions noted earlier, and the FAO (2009) guidelines with respect to RFMO/As having an appropriate protocol identified in advance for how fishing vessels in deep-sea fisheries should respond to encounters in the course of fishing operations with a VME, including defining what constitutes evidence of an encounter and requiring vessels to cease bottom fishing activities at the site and to report the encounter.

In designing the encounter protocol, the threshold for the move-on rule was set at a level that would be triggered only by very unusual events that suggest the models that underpin the spatial management areas may be misleading.

The 6th meeting of the SPRFMO Scientific Committee (SC-06) noted that insufficient data from bottom longline fisheries exist to develop a data informed VME indicator taxa threshold for that method, but within this context noted that line fishing within candidate areas open to fishing is

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proposed open to bottom trawling but deeper than 1400 m is not likely to be disturbed by trawl gear in the foreseeable future. Delegation of New Zealand (2019) evaluated the performance of the proposed spatial management areas based on nominal protection (the percentage of the predicted distribution of VME indicator taxa outside the areas open to bottom trawling) and effective protection (the percentage of the predicted distribution of VME indicator taxa outside the areas open to bottom trawling plus those parts of the proposed open areas that are deeper than 1400 m).

[5] The three Management Areas are the 'open' areas, although each Management Area actually comprises several smaller, spatially discrete areas.

[6] Paragraph 15 of CMM 03-2020 refers

likely to have risks to VMEs several orders of magnitude lower than bottom trawl fishing. Therefore, SC-06 agreed that VME encounter protocols should be developed for bottom trawl fishing only and should include taxon-specific weight thresholds for key VME indicator taxa and a biodiversity threshold where several VME indicator taxa are taken. In the absence of data allowing the calculation of biomass-derived thresholds (e.g. taxa specific biomass estimates, VME patch size estimates, taxon-specific catchability, probability of encounter with bottom trawl gear, etc.), calculations were based on observed benthic bycatch of VME indicator taxa from the New Zealand bottom trawl fishery[7].

The FAO (2009) Deep-Sea Guidelines recommend that VME indicator taxa weight thresholds should ideally be specific to area and taxon. Although the Evaluated Area can be divided into two distinct geographic areas, the LSC to the east of New Zealand, and various Tasman Sea fisheries to the west of New Zealand, there was insufficient data for many taxa within each area to enable the generation of area-specific weight thresholds. Therefore, VME indicator taxon-specific weight thresholds were generated for the entire Evaluated Area. Recognising that the presence of a small amount of a single VME indicator taxon is unlikely to indicate an encounter with a VME (within the meaning of the term 'encounter' in CMM 03-2020), and that the presence of several VME indicator taxa in a single tow may indicate that the fishing event has encountered an area with a diverse seabed fauna, potentially constituting evidence of a VME, the encounter protocol includes both weight and biodiversity thresholds.

Weight and biodiversity thresholds were identified from taxon-specific plots of the cumulative distribution of historical non-zero catch weights using the points at which each curve begins to flatten. Thresholds indicating unexpectedly large catches should ideally fall to the right of such points, whereas "biodiversity weights" indicating increasing numbers of taxa in a single tow at weights below the threshold trigger might occur to the left. The choice of a percentile to the left or right of the threshold value depends on the desired sensitivity of the encounter protocol and is largely a management question relating to the desired level of precaution.

For CMM03-2019, the Commission adopted weight thresholds for Porifera, Gorgonacea, Scleractinia, Antipatharia, Actiniaria and Alcyonacea equal to the 99th percentiles of ordered values of bycatch weight from New Zealand bottom trawl tows conducted in the evaluated area of the SPRFMO Convention Area over the period 2008-2018 (with some rounding), which fell to the right of taxon-specific "inflection points" on the curves. This choice of threshold was intended to ensure that the encounter protocol is not too sensitive and responds only to very unusual events that suggest the models that underpin the spatial management areas may be misleading.

Following the initial implementation of the measure in 2019, additional work was done to explore uncertainties in the modelling and the management approaches that had been agreed. This work (e.g. Pitcher et al. 2019) identified uncertainties in the model predictions of habitat suitability and other outputs that underpinned the spatial management approach adopted in CMM03-2019, as well as providing advice on the appropriateness of the VME encounter

[7] Australian data were not included in this analysis because benthic bycatch records are not captured in databases with the same precision and resolution as New Zealand benthic bycatch data. Inclusion of these lower-resolution data would reduce the overall quality of the data set.

thresholds specified in the measure. Following review of this work, the 7th meeting of the SPRFMO Scientific Committee (SC-07) agreed (amongst other things) that uncertainty in the predictions of the habitat suitability models for VME indicator taxa may be higher than previously thought and that this leads to increased uncertainty in estimates of the proportion of VME indicator taxa, in particular stony corals, protected across the modelled region. Specifically, the Scientific Committee noted the results might indicate that CMM03-2019 may provide less protection than previously thought. SC-07 also agreed that the VME indicator taxa thresholds outlined in CMM03-2019 were likely to correspond to high coverage and biomass of VME indicator taxa on the seabed and that further work was required to establish whether the thresholds specified in CMM03-2019 were consistent with the objectives of the measure to prevent SAIs on VMEs, and that it was important to evaluate whether bycatch of VME indicator taxa that correspond to these thresholds would result in SAIs. Further, SC-07 agreed that given these increased uncertainties, lower encounter thresholds for VME indicator taxa would help to mitigate risks of SAIs on VMEs until key uncertainties with the performance of the spatial management measures could be resolved. Subsequently, the SPRFMO Commission reduced the threshold for Scleractinia (stony corals) from 250 kg to 80 kg in CMM03-2020. CMM03-2020 (and its predecessor, CMM03-2019) includes a mandatory annual review process for VME indicator encounters and benthic bycatch data.

In relation to fish stocks, prior to the implementation of CMM03-2019, demersal fish stocks were managed as part of the various historical bottom fishing CMMs by limiting catch to that taken by a flag state in the defined reference period between 2002 and 2006. In 2019, management measures for deepwater fish stocks were separated into the CMM for Deepwater Species in the SPRFMO Convention area (CMM03a-2019), which has subsequently been updated (CMM03a-2020). This measure sets specific catch limits for orange roughy stocks, and general catch limits for all other species caught by SPRFMO Members' vessels fishing in the SPRFMO Convention Area (currently only Australia and New Zealand). Despite the separation of the CMMs 03 and 03a to reduce complexity, both measures share the same overarching objectives.

There is currently a large body of work underway leading up to full review of CMM03-2020 in 2021. Much of this work will be considered as part of this bottom fishery impact assessment, including:

- updating and reassessing VME habitat suitability modelling, including model testing and updating using new data
- review of the 'naturalness' condition layer (a spatial representation of the current status of a taxon after the effects of all historical trawling)
- analysis of the relationship between habitat suitability probability and actual occurrence and/or abundance
- analyses of the catchability of VME indicator taxa in trawl gears
- reassessment of the performance of the spatial management measure.

2.3 NEW ZEALAND BOTTOM FISHERIES

New Zealand has managed activities of its vessels fishing on the high seas by means of high seas permits since at least 2001 before the Interim Measures were adopted. SPRFMO management measures have been implemented through conditions on the high seas permits, which are updated regularly. Since specific conditions have been imposed for pre-SPRFMO or SPRFMO requirements (from 2008), between 16 and 31 vessels annually have been issued high seas permits to fish in the SPRFMO Convention Area (Table 1). However, not all of these vessels actually fished in any given year (active vessels ranged between 8 and 11 from 2008–2019).

New Zealand fisheries in the SPRFMO Convention Area use trawl and various line methods. The number of vessels fishing using trawls declined steadily from a peak of 23 in 2002 and has been stable since 2008 at between 5 and 7 vessels (Table 1, Figure 1). The number of vessels fishing with bottom lines peaked at 11 in 2005 and has been stable between 2 and 5 vessels since (Table 1, Figure 1).

In recent years, there has been little change in the size of vessels permitted to fish (Table 2).

Table 1: Summary of the number of New Zealand vessels permitted to bottom fish in the SPRFMO Convention Area, and the number of vessels which actually fished in the Area by year with either bottom trawl or line, since 2001. The data are arranged by permit year, which is a split year from May to April.

Vessel Permit Year	Number of vessels permitted to fish the SPRFMO Convention Area	No. of vessels that actively bottom fished in the SPRFMO Convention Area	Bottom trawling	Bottom lining
2001-02	41	23	23	
2002-03	55	22	19	3
2003-04	66	24	17	7
2004-05	60	28	17	11
2005-06	58	22	12	10
2006-07	38	12	8	4
2007-08	25	7	4	3
2008–09	21	10	5	5
2009–10	24	9	7	2
2010–11	27	9	7	2
2011–12	24	9	6	3
2012–13	24	8	5	3
2013–14	24	8	5	3
2014–15	31	10	6	4
2015–16	31	9	5	4
2016–17	21	11	6	5
2017–18	16	8	5	3
2018–19	18	9	6	3
2019–20	15	10	4	6

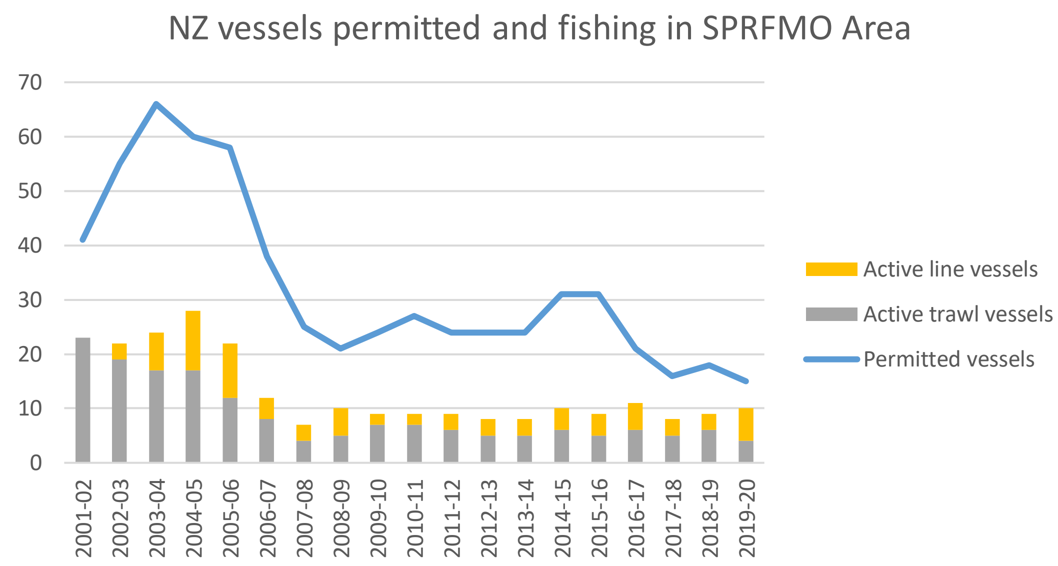

Figure 1: Summary of the number of New Zealand vessels permitted to bottom fish in the SPRFMO Convention Area and the number of vessels which were active in the Convention Area by year by method. The data are arranged by permit year, which is a split year from May to April.

Table 2: Frequency distribution of vessel size (length overall in metres, divided in 5 m classes) for New Zealand vessels permitted to bottom fish in the SPRFMO Convention Area for permit years (May–April) from 2008

	Length overall (m)									
Permit year	**≤ 11.9**	**12–17.9**	**18–23.9**	**24–29.9**	**30–35.9**	**36–44.9**	**45–59.9**	**60–74.9**	**≥ 75**	**N. vessels**
2008-09	0	0	3	3	4	8	2	6	0	21
2009–10	0	1	3	1	5	6	0	6	2	24
2010–11	0	1	3	3	4	8	2	6	0	27
2011–12	1	1	3	1	2	8	2	6	0	24
2012–13	1	1	3	1	2	8	2	6	0	24
2013–14	0	1	3	2	2	7	2	6	1	24
2014–15	0	1	8	2	3	6	3	7	1	31
2015–16	0	1	7	3	4	7	3	4	2	31
2016–17	0	1	3	2	4	6	3	2	0	21
2017–18	0	1	3	0	3	5	3	1	0	16
2018–19	0	1	2	0	4	5	3	3	0	18
2019-20	0	1	4	0	2	4	3	1	0	15

2.3.1 Trawl fisheries

2.3.1.1 General description

Trawl vessels flying the flag of New Zealand fishing in the SPRFMO Convention Area target orange roughy, alfonsino, cardinalfish and oreo species using either bottom or midwater trawl nets.

Modern deepwater trawling uses echosounders to target aggregations or plumes of fish when fishing on or near underwater features (e.g. seamounts). On flatter areas of seabed, where the fish are usually less aggregated and cannot be realistically detected using acoustic methods, more conventional "herding" trawl fishing is conducted using longer tows on flat, muddy or silty seabeds. Deepwater trawl gear has evolved in various ways towards agile net systems that minimise net size and unnecessary ground contact (particularly by non-fishing gear components such as trawl doors), including shortening groundrope lengths to reduce damage to fishing gear from hard substrates and ultimately enable nets to be more accurately aimed at fish aggregations.

Some typical deepwater trawl net designs currently used in New Zealand feature-based fisheries are shown in Figure 2. The nets are designed to provide net mouth width between wing-tips of 15–20 m under optimal towing conditions, with headline heights of 5–6 m above the footrope. Net headropes are equipped with hard floats to provide the buoyancy needed to maintain the net open during trawling (see Figure 2). Nets are also equipped with netsounders and headline sensors to monitor the net opening, to determine position of the net relative to the seabed, and to facilitate accurate targeting of nets on acoustic fish targets. Nets are composed of panels of decreasing mesh size, made from braided nylon twines typically ranging 4–5 mm in diameter (wings vs end sections), doubled twines for areas of the net belly subject to abrasion and with heavier rope meshes in the codends. Codends and ground-gear (footropes designed to work on the sea bed, often including bobbins disks, weights, etc) can be rigged specifically, depending on the seabed type to be trawled and the species targeted.

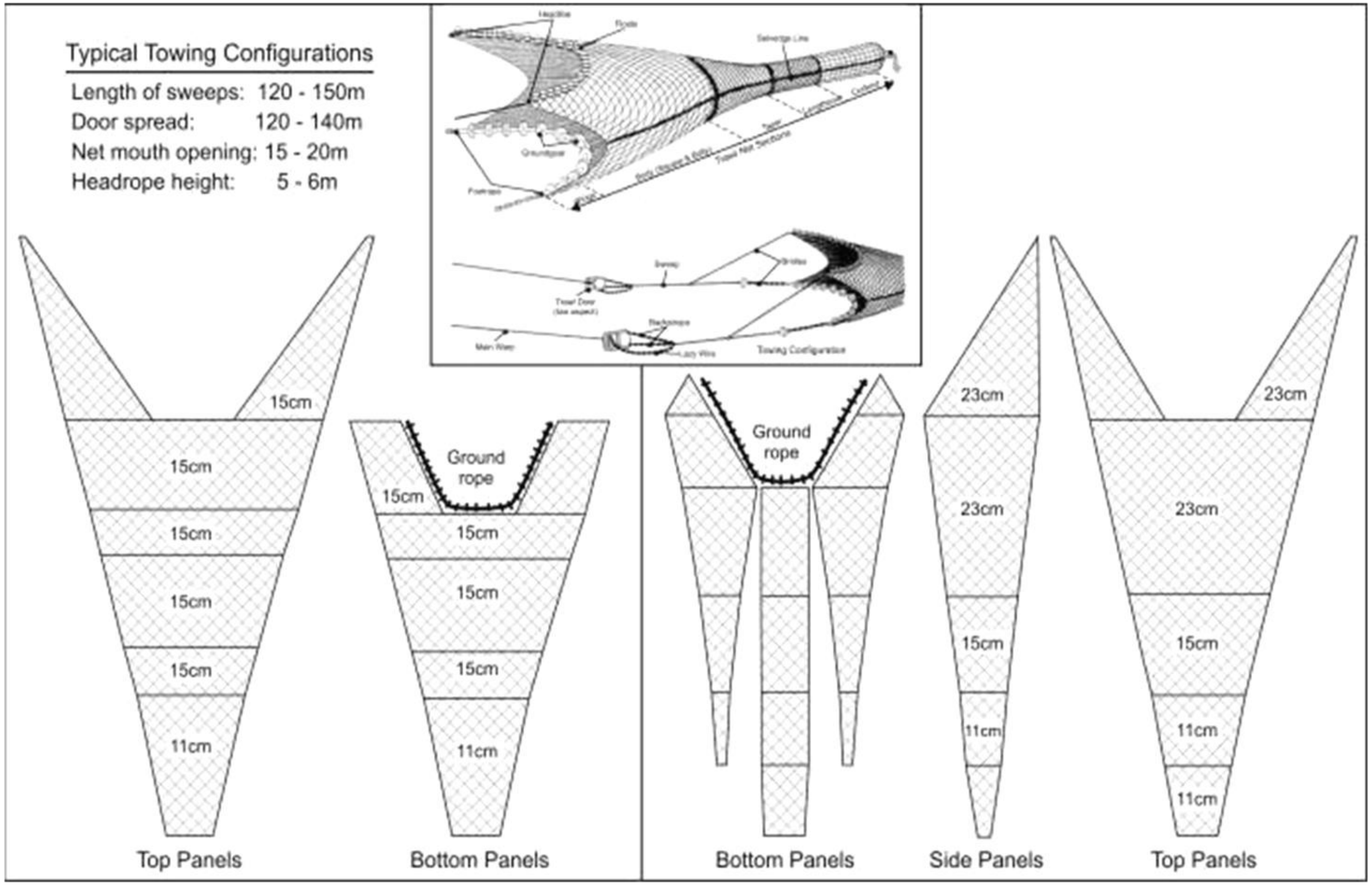

Figure 2: Stylised net construction diagrams for typical bottom trawl nets used in the New Zealand deepwater orange roughy targeted bottom trawl fishery. Numbers over the net describe mesh sizes of each panel. Two alternate simplified net designs are shown, using different mesh sizes and net wing configurations. Inset shows an illustration of the configuration of a typical bottom trawl net during trawling.

New Zealand deepwater bottom trawl fisheries initially used ‘vee-doors’, which have a low aspect ratio (i.e., their length is greater than their height, Figure 3a) and maximise the stability of doors during towing, but depend on bottom contact (ground sheer forces) to create their net spreading force. However, high aspect ratio doors (i.e., height 1.5 to 1.8 times length, see Figure 3b) were developed in parallel with better winch systems and increased use of electronics to accurately target fish aggregations. These doors do not require bottom contact and depend solely on hydrodynamic forces to generate spread. Efforts to reduce drag and increase control of trawl doors has also resulted in a move to smaller trawl doors (e.g., Nichimo, Hampidjan and Morgere high-technology doors).

The trawl doors currently used by New Zealand deepwater bottom trawlers typically weigh 1 200–2 000 kg and have an area of 4–8 m^2, depending on the vessel engine power and net design. Modern doors (such as the Morgere WX and WV doors shown in Figure 4b and c) are generally designed and rigged to operate off the bottom where the seabed is rough (e.g., on or near features), and are set to minimise the risk of digging in should there be any contact with the seabed. Deepwater trawl nets rigged in this way are often towed so that the net contacts the seabed only in the area of the aggregated fish, with the doors themselves not touching the seabed.

The length of sweeps and bridles (the towing and herding wires connecting the trawl doors and the net opening) has also been significantly shortened to provide better control over the gear and further reduce seabed contact. Currently, 120–140 m long sweeps and bridles combinations are typically used to connect the doors to the nets on orange roughy targeted trawls for feature-based fishing. With these configurations, the spread between the doors during towing is, at most, 120–150 m under good conditions, achieving net openings of 15–20 m between the wingtips. In areas where operators wish to accurately target fish aggregations and require maximal control of the net, they may even operate with very short bridles and no sweeps.

For bottom trawling on hard ground, net footropes are rigged with ground-gear to protect the footrope, and to enable the net to manoeuvre over rough terrain or minor obstacles. Early deepwater trawlers used steel bobbins on the groundrope when fishing hard ground, these being standard at the time on Northern Hemisphere cod trawlers. However, it has been found that these are not necessary, and that gear efficiency is improved, and bottom contact reduced by incorporating rubber components in the ground rope. Steel bobbins were first replaced with smaller 40–60 cm diameter rubber bobbins (Figure 5a) and, more recently, with 50–80 cm diameter rubber discs separated by spacers along the footrope (Figure 5b, the so-called ‘rockhopper’ gear). Whereas bobbins are designed to allow the footrope to roll over rough ground, the groundrope in a rockhopper system is rigged under tension, causing the net to ‘hop’ over encountered obstacles, rather than attempting to drag through or roll over them.

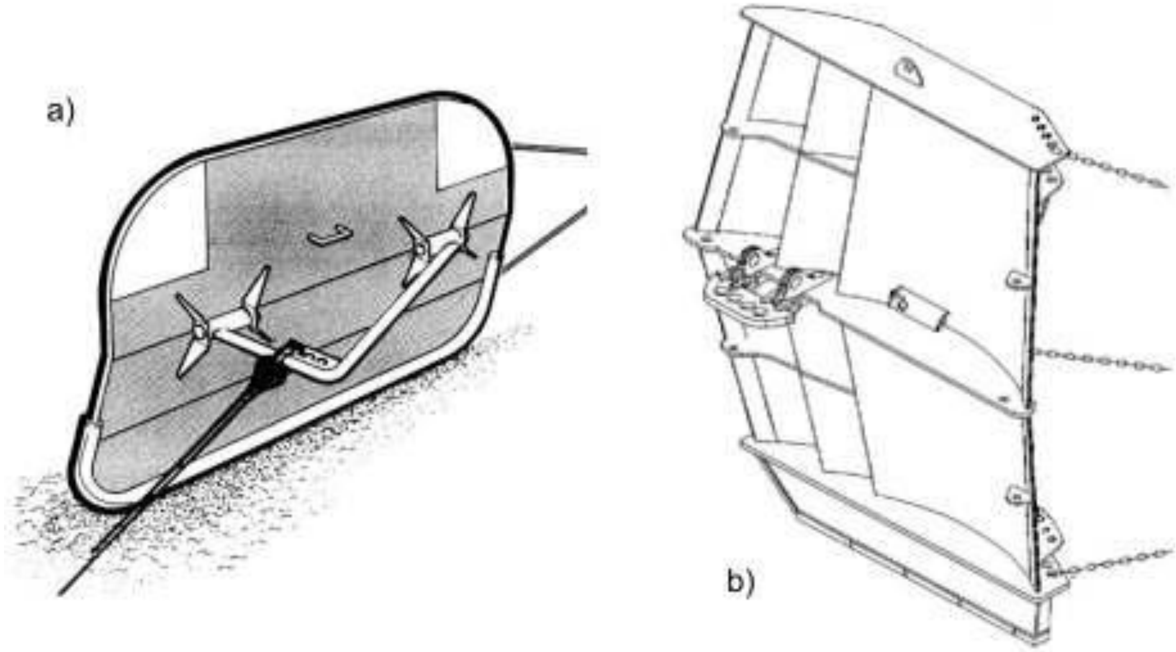

Figure 3: Illustrations of trawl doors used in New Zealand bottom trawl fisheries showing a) Older style low aspect-ratio 'vee' door, and b) More recent high aspect-ratio hydrodynamic door.

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Figure 4: Examples of trawl doors in use on New Zealand-flagged vessels using bottom trawls for orange roughy and midwater trawls for benthopelagic species like alfonsinos. a) Nichimo Super-Vee doors rigged on a trawler stern, b) a Morgere WX door and c) a Morgere WV door.

Figure 5: Typical ground-gear configurations used by New Zealand-flagged vessels when bottom trawling for orange roughy and oreos showing ground-ropes equipped with a) 50–60 cm rubber bobbins separated by rubber spacers, and b) with more closely spaced 60–80 cm 'rockhopper' rubber discs plus leading end steel bobbins.

Bentho-pelagic species like alfonsino and bluenose have also been taken using midwater trawls fished close to the bottom. This method is included in this bottom fishery impact assessment because the gear can occasionally come into contact with the bottom during normal fishing operations (Tingley 2014) and is therefore defined as bottom fishing by SPRFMO (CMM 03-2019). Midwater trawls are of lighter construction than bottom trawls, although the same doors are used to deploy them (see a representative net plan in Figure 6). Midwater trawls are generally not rigged with ground gear and the footropes are constructed of a relatively light chain or wrapped wire rope (Figure 7). Such trawls are towed in such a way that they should not touch the bottom. However, the footrope does sometimes contact the seabed and may break if the gear becomes snagged.

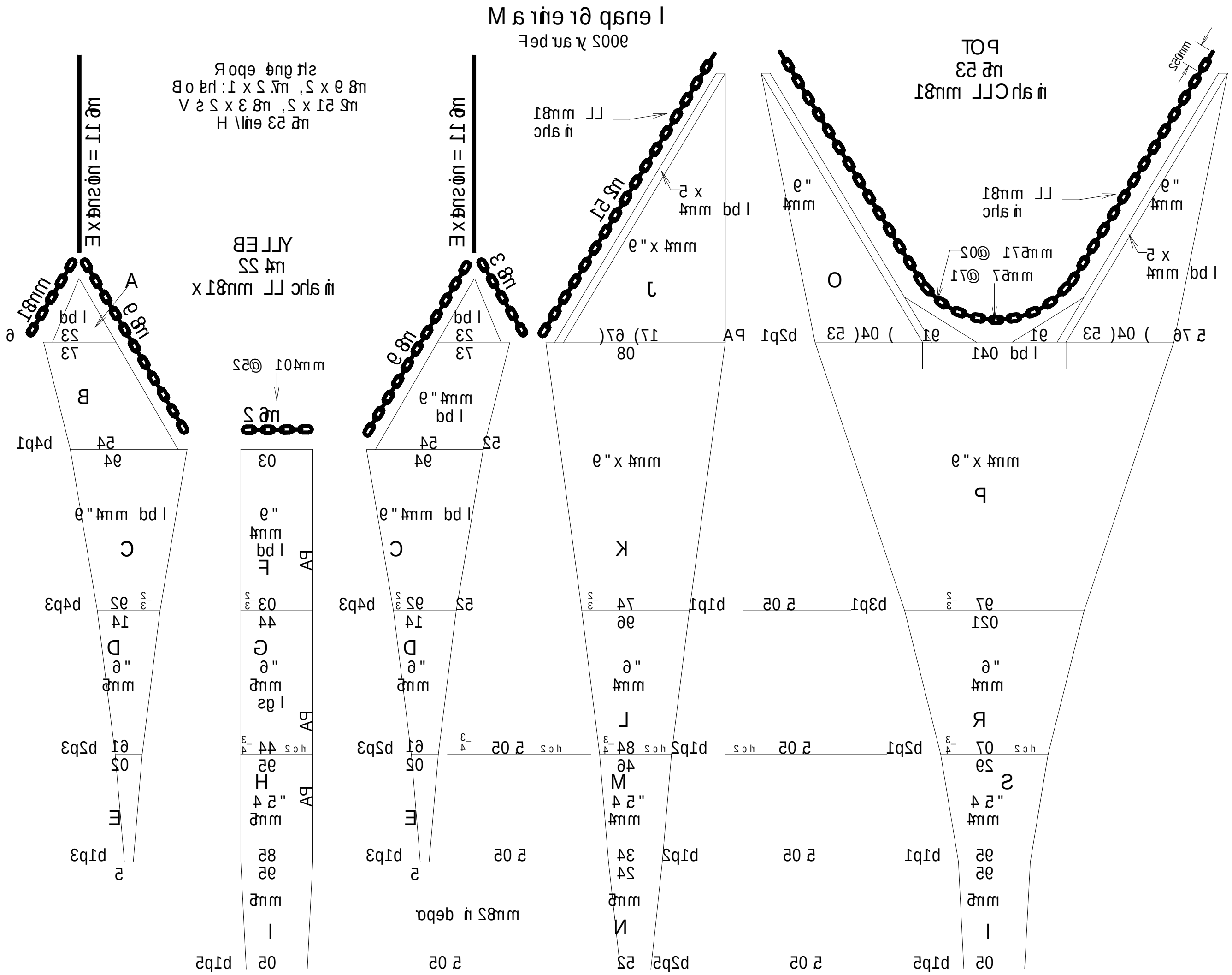


Figure 6: Net construction diagram for typical midwater trawl net used by New Zealand-flagged vessels targeting benthopelagic species like alfonsino in the SPRFMO Convention Area. Numbers over the net describe mesh sizes of each panel.

Figure 7: Wrapped wire rope used as footrope (top) and typical midwater trawl with light ground gear (bottom) used by New Zealand-flagged vessels when targeting alfonsino. Footropes can also be constructed using chains. Photos courtesy Talleys Ltd.

2.3.1.2 Fishing effort

The annual bottom trawl fishing effort by New Zealand vessels in the SPRFMO Convention Area declined from a maximum of 23 vessels completing over 3 500 tows in 2002 to 5 or 6 vessels completing 400–1 400 tows each year over the most recent 5 years (2015–2019) (Tables 3 and 4).

Table 3: Recent bottom trawl effort (number of tows) in the main areas fished by New Zealand bottom trawl vessels fishing in the SPRFMO Convention Area by calendar year. Reported effort for the Westpac Bank only includes effort on the high seas since 2013.

Year	Challenger Plateau	Westpac Bank	West Norfolk Ridge	Lord Howe Rise	Louisville Ridge	Other Areas	All Areas
2009	156		252	229	–	11	648
2010	409		58	388	303	12	1 170
2011	437		84	379	258	–	1 158
2012	166		58	121	296	11	652
2013	189	7	27	238	299	7	760
2014	64	6	–	70	263	6	403
2015	582	24	32	124	221	–	959
2016	706	92	–	197	40	–	943
2017	421	44	25	583	352	-	1 423
2018	309	183	13	232	77	44	858
2019	74	23	1	87	36	30	251

Table 4: Annual fishing effort (number of vessels and tows) and fisher-reported catch (tonnes) of the top five species by weight (identified by FAO species codes – Appendix A) by New Zealand vessels bottom trawling in the SPRFMO Convention Area from 2009. Year is calendar year. The number of tows reported here is the number of tows which recorded a fish catch and excludes tows where there was no catch.

Year	No. vessels	No. tows	Tows/ vessel	ORY	ONV	BOE	EPI	ALF	SSO	RIB	RTX	SCK	Total catch (t)
2009	6	547	91	928	5	–	16	5	<1	7	<1	2	958
2010	7	1 167	167	1 474	9	12	22	24	10	15	6	13	1 864
2011	7	1 158	165	1 079	16	12	108	17	4	22	7	9	1 486
2012	6	652	109	721	10	4	2	39	3	5	7	2	805
2013	5	760	152	1 164	11	20	3	28	5	6	1	-	1 261
2014	5	403	81	998	6	7	0	0	5	2	2	<1	1 028
2015	5	959	192	1 287	11	2	48	9	10	5	32	7	1 513
2016	6	943	157	954	27	0	19	87	0	23	55	34	1 326
2017	5	1 423	285	1 093	30	22	1	29	7	36	52	20	1 641
2018	6	858	143	1 232	38	11	7	57	5	24	30	7	1 570
2019	4	251	63	460	3	8	0	33	3	8	0	0	584

Orange roughy (ORY) is the main target species and has made up 67–99% of the total catch since 2002 with 720–2 578 tonnes landed annually. Fishing effort and catch by area has varied over time, with the majority of catch since 2002 taken in the Challenger and Louisville areas. Other species that have been prominent in the catch include alfonsinos (ALF), cardinalfish (EPI), and oreos (BOE/SSO/ONV), however catch of these species from bottom trawling has fluctuated over time and catch of any particular species has never exceeded 300 t.

Most bottom trawl fishing for orange roughy by New Zealand vessels occurs between 750 and 1 000 m depth, although the maximum reported depth of tows in most years was between 1 200 and 1 400 m depth (Figure 8). Fisheries on the NW Challenger Plateau spanned the greatest depth range, while fisheries on the Westpac Bank and South Tasman Rise were concentrated on the narrowest depth interval. Disregarding obvious errors, only 22 tows between 1989 and 2019 were reported as being deeper than 1 400 m, 0.05% of the total. Some of these depths may still be reporting errors. The data for the NW Challenger Plateau fishery in 2001 and early 2002 include about 100 reported towing depths <100 m from a single vessel, distorting the lower tails of the plots for those years. These records are suspected to be reporting errors.

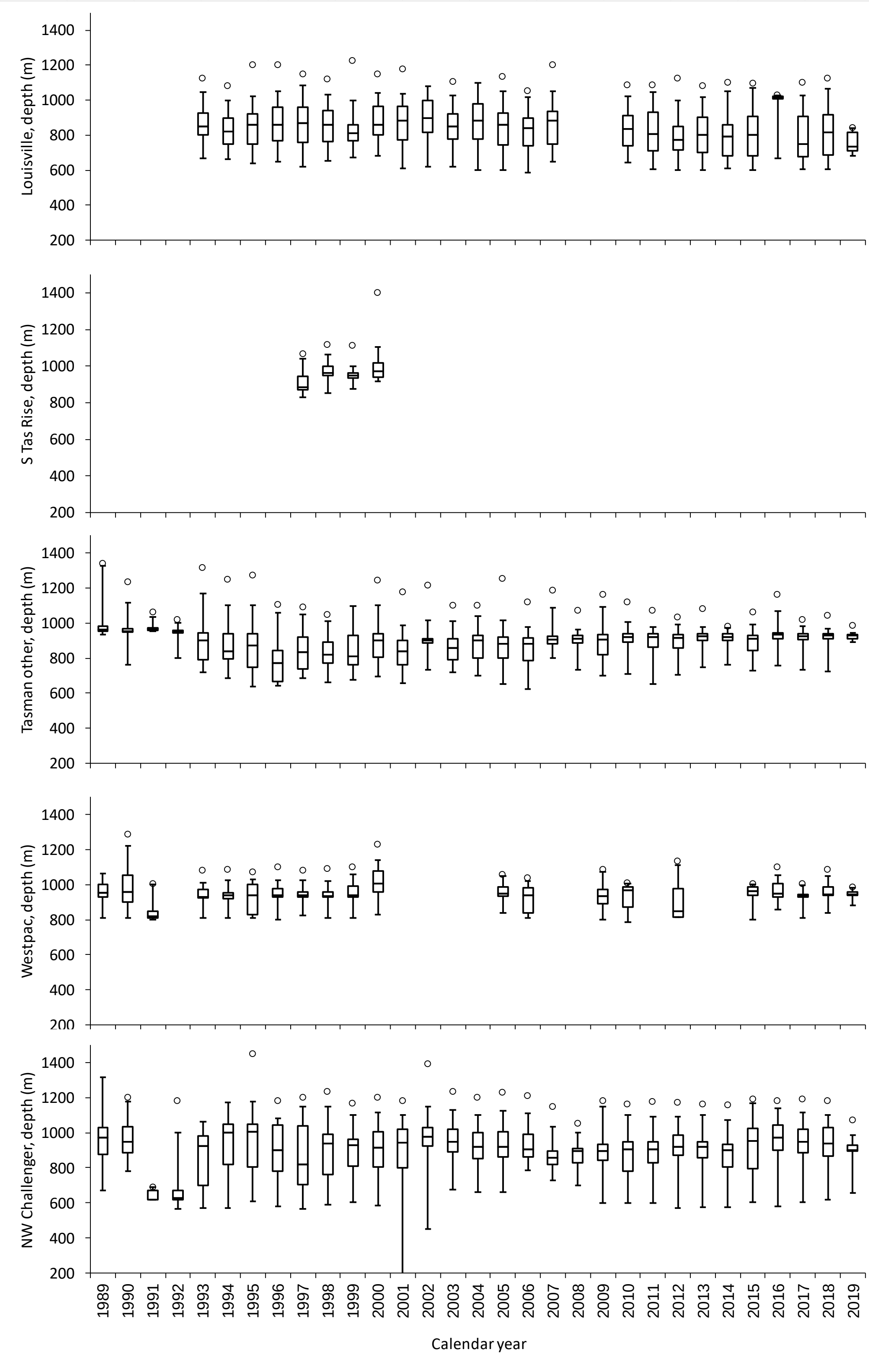


Figure 8: Depth distribution of bottom trawl tows for orange roughy in different parts of the western SPRFMO Convention Area, 1989 to 2019. The horizontal line for each year indicates the median, the boxes encompass the middle 50% of the tows, and the whiskers encompass 95% of the tows. The maximum reported depths after obvious errors have been removed are shown as open circles. Years with 10 or fewer tows excluded.

The duration of bottom trawl tows varies considerably within and between areas (Figure 9). Tows on features constitute the majority of recent tows and are typically shorter than tows on the continental slope, thus largely explaining the prevalence of tows shorter than 1 hour in most areas. This is particularly clear on the Louisville Ridge where almost all tows are on features, but there is also a strong pattern of increasing proportions of short tows in the Tasman Sea (excluding the Challenger Plateau). On the NW Challenger Plateau there have been three periods when a substantial proportion of tows exceeded 5 hours (2001–07, 2010–12, and 2015–18) but the underlying reasons for this pattern are unclear.

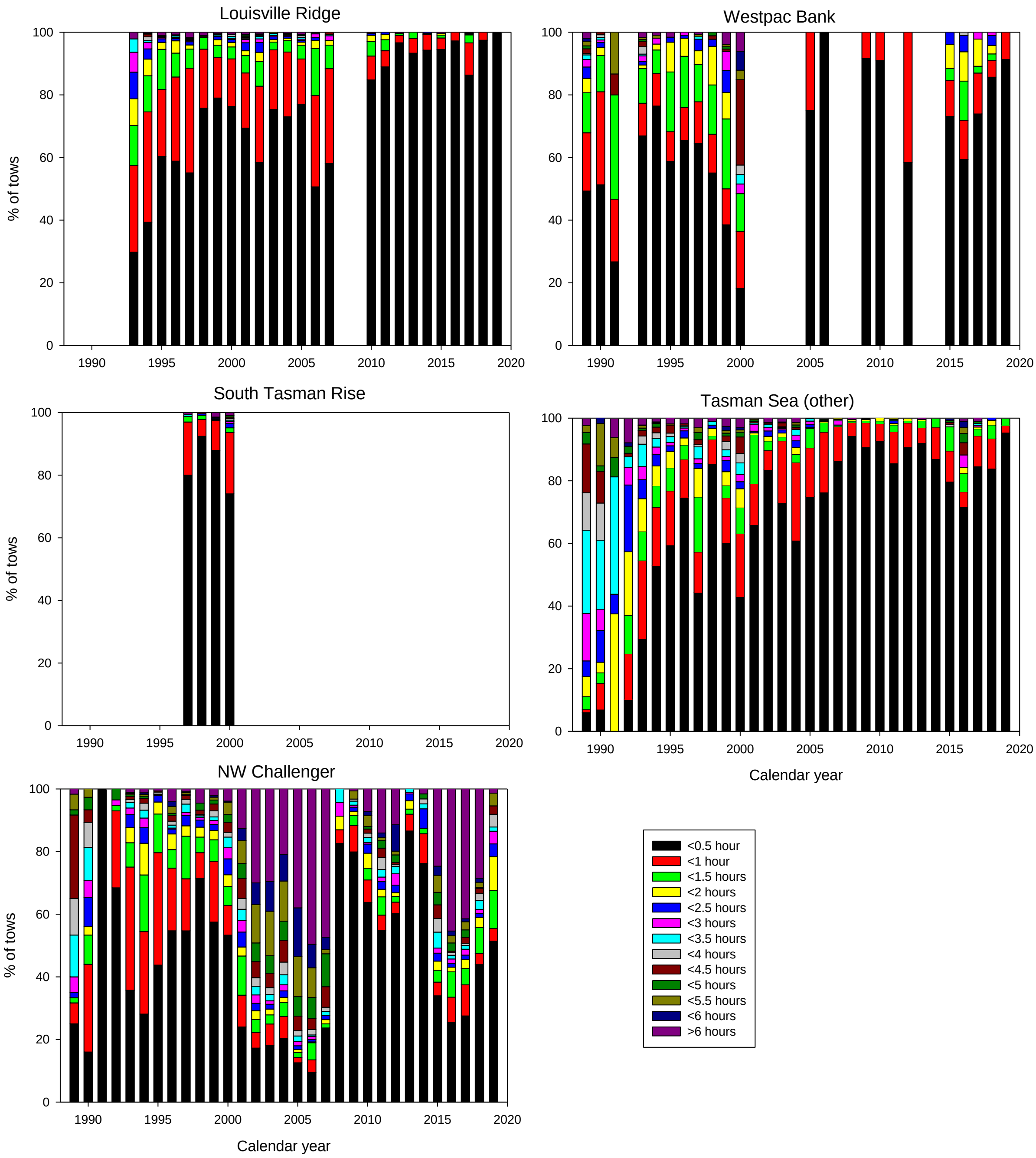


Figure 9: Distribution of reported duration of bottom trawl tows for orange roughy in different parts of the western SPRFMO Convention Area, 1989–2019. Years with 10 or fewer tows excluded.

Further information on bottom trawl effort and orange roughy catch by area is shown in Figure 10 and Tables 4 and 5.

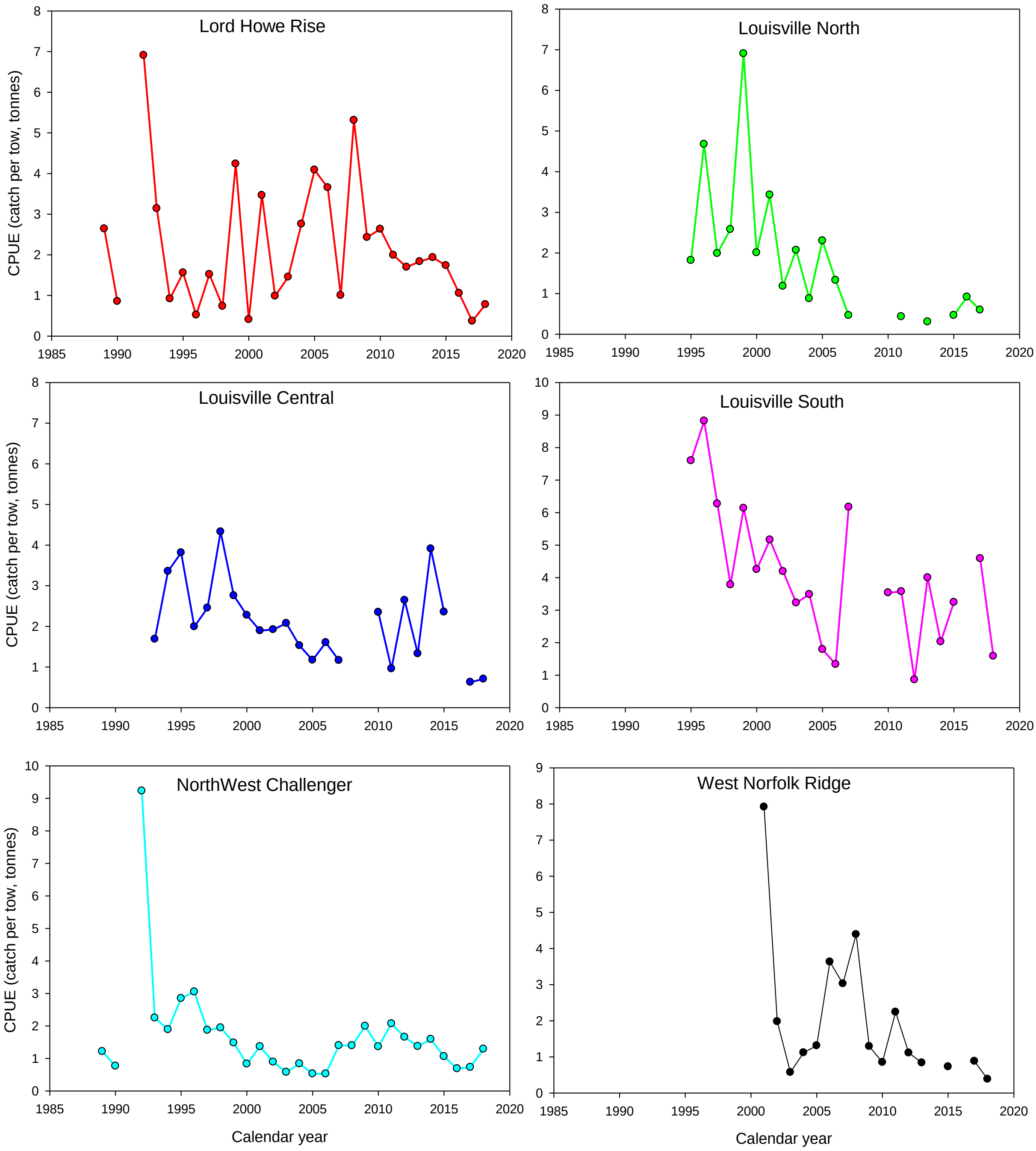


Figure 10: Nominal CPUE (estimated catch per tow) of orange roughy by New Zealand-flagged vessels in the main fishery areas in the western SPRFMO Convention Area, 1989–2019. Years with 10 or fewer tows excluded. Data up to 2015 have been groomed for errors (from Roux & Edwards, 2017), more recent data have not been extensively groomed. Note there have been substantial changes in the lengths of tows over time and that the vertical axis scales might differ.

Table 5: Total estimated catches (tonnes) of orange roughy from the main areas fished by New Zealand bottom trawl vessels fishing in the SPRFMO Convention Area by calendar year from 2009. Landings from the Westpac Bank area (part of the Challenger Plateau) are also reported against New Zealand's domestic ORH7A area catch limit. Catches from Westpac Bank between 2007 and 2010 were largely from research surveys. –, less than 1 tonne

Year	Challenger Plateau	Westpac Bank	West Norfolk Ridge	Lord Howe Rise	Louisville Ridge	Other Areas	All Areas
2009	238	23	233	403	–	31	928
2010	415	5	79	385	584	6	1 474
2011	675	5	113	1	285	–	1 079
2012	247	8	49	121	288	8	721
2013	230	3	19	344	565	3	1 164
2014	57	54	0	79	754	54	998
2015	530	118	20	157	462	–	1 287
2016	486	234	0	208	27	–	954
2017	307	129	22	215	420	–	1 093
2018	399	569	5	180	81	–	1 232
2019	171	111	0	38	139	–	460

Most tows using midwater trawls for alfonsino occur in depths of 500–600 m (Figure 11) although a few tows are carried out in considerably deeper water. Bluenose is targeted in slightly shallower water, mostly 300–600 m. A variety of other species have historically been targeted (including hoki, squid, and southern blue whiting) and the depth of these tows varied widely. About two-thirds of tows using midwater trawls are reported as occurring within about 20 m of the seabed; since 1989, the median reported distance off bottom when targeting alfonsino or bluenose has been 6.5 m.

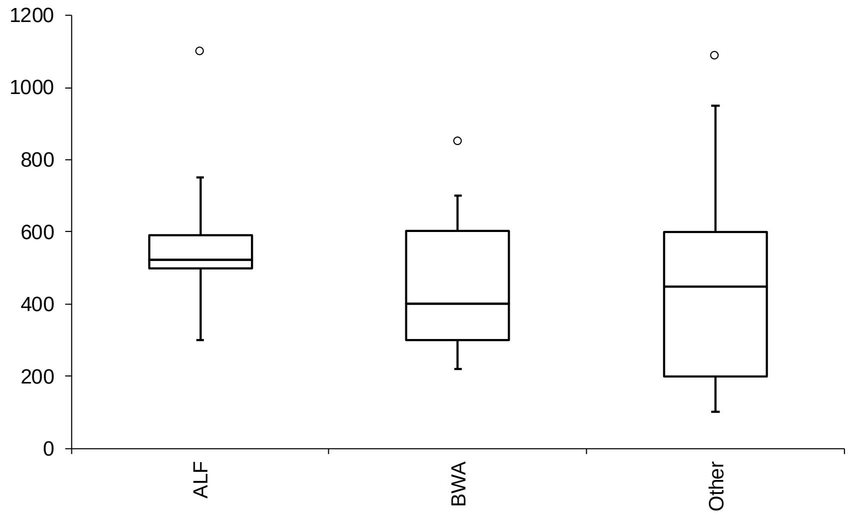


Figure 11: Distributions of bottom depth for midwater trawl tows for alfonsino (633 tows), bluenose (41 tows), and other target species (mainly hoki and squid, 251 tows), 1989 to 2019. The reported fishing depth is typically shallower than the reported bottom depth, median 6.5 m for alfonsino and bluenose target tows. The horizontal line for each year indicates the median, the boxes encompass the middle 50% of the tows, and the whiskers encompass 95% of the tows. The maximum reported depths after obvious errors have been removed are shown as open circles.

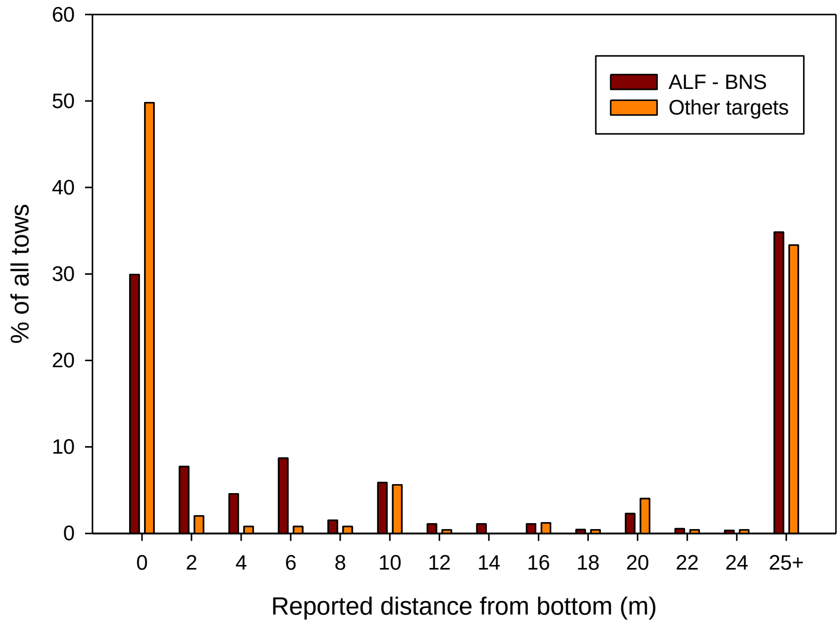


Figure 12: Distributions of distance off bottom (calculated from reported bottom and fishing depths) during fishing using midwater trawls for benthopelagic species (alfonsino and bluenose, 675 tows) and other target species (mainly hoki and squid, 251 tows), 1989 to 2019. About 38% of tows were >20 m off bottom.

Midwater trawling for bentho-pelagic species such as alfonsino by New Zealand-flagged vessels has been variable over time but has grown since 2011 and peaked in 2018 with 145 tows (Table 6). Catch from midwater trawling fluctuated around 150 tonnes per year in 2011–2013, was less than 100 tonnes in 2014–2017, and increased to over 200 tonnes in 2018. Alfonsino is the main species caught in midwater trawls, comprising over 95% of catch in the most recent three years.

Table 6: Annual fishing effort (number of vessels and tows) and fisher-reported catch (tonnes) of the top five species by weight (identified by FAO species codes – Appendix A) by New Zealand vessels midwater trawling for bentho-pelagic species in the SPRFMO Convention Area from 2009. Year is calendar year. The number of tows reported here is the number of tows which recorded a fish catch and excludes tows where there was no catch.

Year	No. Vessels	No. Tows	Avg. Tows/Vessel	ALF	EDR	ONV	BWA	All Species (t)
2011	3	61	20	64	76	21	2	164
2012	3	59	20	115	25	0	3	145
2013	1	120	120	122	9	0	10	145
2014	0	0	–	0	0	0	0	0
2015	2	21	11	34	0	0	2	37
2016	3	42	14	82	3	0	0	86
2017	1	33	33	35	0	0	0	36
2018	3	145	48	211	3	0	3	219
2019	2	9	5	12	0	0	0	12

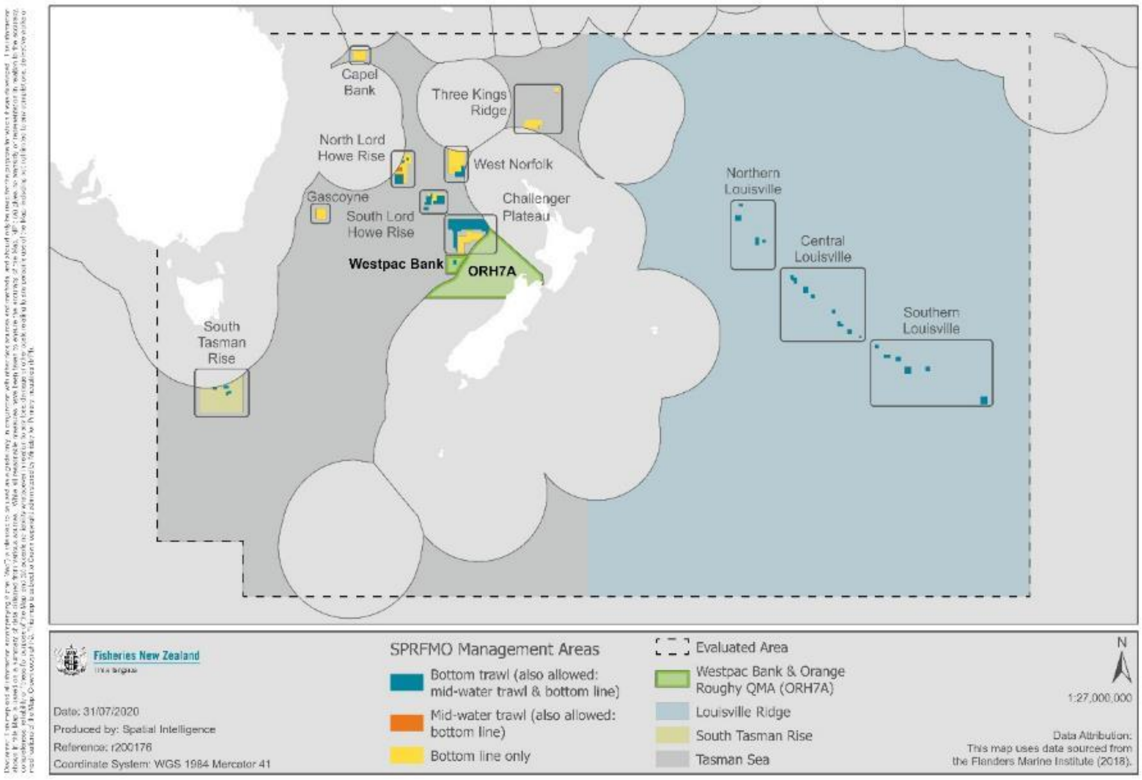


Figure 13: SPRFMO management areas open to different types of fisheries, and general fishery areas, within the Evaluated Area. Note that areas open to bottom trawling are also open to all other fishing methods and areas open to midwater trawling are also open to bottom long lines.

2.3.2 Line fisheries

Vessels flying the New Zealand flag use bottom line methods to target predominantly bluenose or wreckfish. For bluenose, the main fishing areas have been the Three Kings Ridge, the Challenger Plateau, and the West Norfolk Ridge. For wreckfish, the main are has been the West Norfolk Ridge. The annual fishing effort (number of vessels and hooks fished) and catch of the main bottom line target and bycatch species are summarised in Table 7. The number of active line vessels peaked at 11 in 2005, but successively declined in 2007 to 2–5 vessels and fluctuated on similar levels since. The number of hooks set per year has fluctuated over time, peaking at 780 000 hooks in 2014, but has been steady at around 115,000 hooks for the past two years.

Three bottom line fishing methods have been used by New Zealand vessels in the SPRFMO Convention Area: bottom longline, Dahn line, and hand line. Dahn and hand line are very similar, with both methods employing a vertical line with hooks that is either attached to a float (Dahn line) or remains attached to the fishing vessel (hand line). Given the similarities, Dahn line and hand line are treated as a single fishery, and data reporting by commercial fishers and observers is the same for both methods.

Table 7: Effort and estimated catches for New Zealand vessels bottom longlining in the SPRFMO Convention Area by calendar year from 2009. Effort is presented as the number of vessels, trips, and number of hooks set, with catches in tonnes of the target and main bycatch species (codes detailed in Appendix A).

Year	No. Vessels	No. Trips	No. Hooks (000's)	Hooks/ Vessel (000's)	BWA	HAU	DGS	MOW	RTX	Total catch (t)
2009	5	12	236	47	58	23	7	1	<1	89
2010	2	5	48	24	15	24	–	1	<1	45
2011	2	6	71	36	23	25	6	<1	<1	57
2012	3	10	90	30	44	40	2	3	<1	95
2013	3	13	479	160	64	41	6	3	<1	124
2014	4	18	784	196	33	45	4	11	<1	99
2015	4	15	179	45	35	63	4	2	<1	126
2016	4*	10	111	28	20	54	5	3	<1	87
2017	3	14	115	38	46	47	3	3	2	106
2018	3	8	110	37	34	27	10	3	0	78
2019	5		183	37	57	50	9	3	1	133

* This includes one vessel that fished only using hand lines

Bluenose (BWA) catches peaked in 2006 at 271 t but have declined and have fluctuated around 20–46 t in the most recent 5 years (Table 8). The other main species caught by bottom line are wreckfish (HAU, *Polyprion oxygeneios* and *P. americanus*), of which 27–63 t have been caught annually in the last 5 years (Table 9). Together, these species have made up around 80% of the catch in the most recent 5 years. There are no obvious directional trends in nominal CPUE for either bluenose or wreckfish (Figure 14).

Other species making minor contributions to bottom line catches in established fisheries include spiny dogfish (DGS, *Squalus acanthius*), king tarakihi (MOW), yellowtail kingfish (YTC), and sea perch (ROK, *Helicolenus* spp.).

Line fishing for bluenose occurs in three main areas on the Three Kings Ridge, the West Norfolk Ridge, and the Challenger Plateau. Most fishing is at depths of about 500 m (Figure 15). Line fishing for wreckfish by New Zealand-flagged vessels occurs predominantly on the West Norfolk Ridge, mostly at depths of 300–400 m. Line fishing for other species is dispersed and mostly at depths close to 300 m.

Bottom longline comprised most of the bottom line fishing effort (110 000 hooks in 2018, ~99.9% of total effort) and catch (78 tonnes in 2018). Effort using other bottom line methods (Dahn line and hand line) is significantly less and more variable. Table 10 shows effort and catch from fishing using other bottom line methods from 2014.

Table 8: Estimated catches (t) of bluenose in each of the main fishing areas by New Zealand vessels bottom longlining in the SPRFMO Convention Area by calendar year from 2009.

Year	Three Kings Ridge	Challenger Plateau	Lord Howe Rise	Other	West Norfolk Ridge	All Areas
2009	16	13	7	<1	22	58
2010	0	2	0	0	13	15
2011	11	0	0	0	11	23
2012	18	11	0	0	15	44
2013	24	31	0	0	10	64
2014	14	8	0	0	11	33
2015	2	23	0	0	10	35
2016	0	5	0	0	15	20
2017	3	31	4	0	8	46
2018	0	27	0	0	7	34
2019	9	31	0	<1	17	57

Table 9: Estimated catches (t) of wreckfish (hapuku and bass combined) in each of the main fishing areas by New Zealand vessels bottom longlining in the SPRFMO Area by calendar year from 2009.

Year	Three Kings Ridge	Challenger Plateau	Lord Howe Rise	Other	West Norfolk Ridge
2009	2	1	3	0	17
2010	0	0	0	0	24
2011	4	0	0	0	20
2012	2	<1	0	0	35
2013	1	1	0	0	41
2014	2	1	0	0	41
2015	3	1	0	0	59
2016	0	<1	0	0	53
2017	<1	6	<1	0	39
2018	0	3	0	0	24
2019	7	5	0	<1	35

Table 10: Effort and estimated catches for New Zealand vessels using Dahn and hand longlines in the SPRFMO Area by calendar year from 2014. Effort is presented as the number of vessels and number of hooks set, with catches in tonnes of the target and main bycatch species (codes detailed in Appendix A).

Year	No. Vessels	No. Hooks	BWA	HAU	MOW	YTC	Total catch (t)
2014	1	12 250	4	1	2	1	8
2015	3	4 861	19	10	4	-	33
2016	1	128	1	<1	1	-	2
2017	1	49	<1	<1	<1	-	<1
2018	1	120	<1	<1	<1	-	<1
2019	1	20	<1	-	<1	-	<1

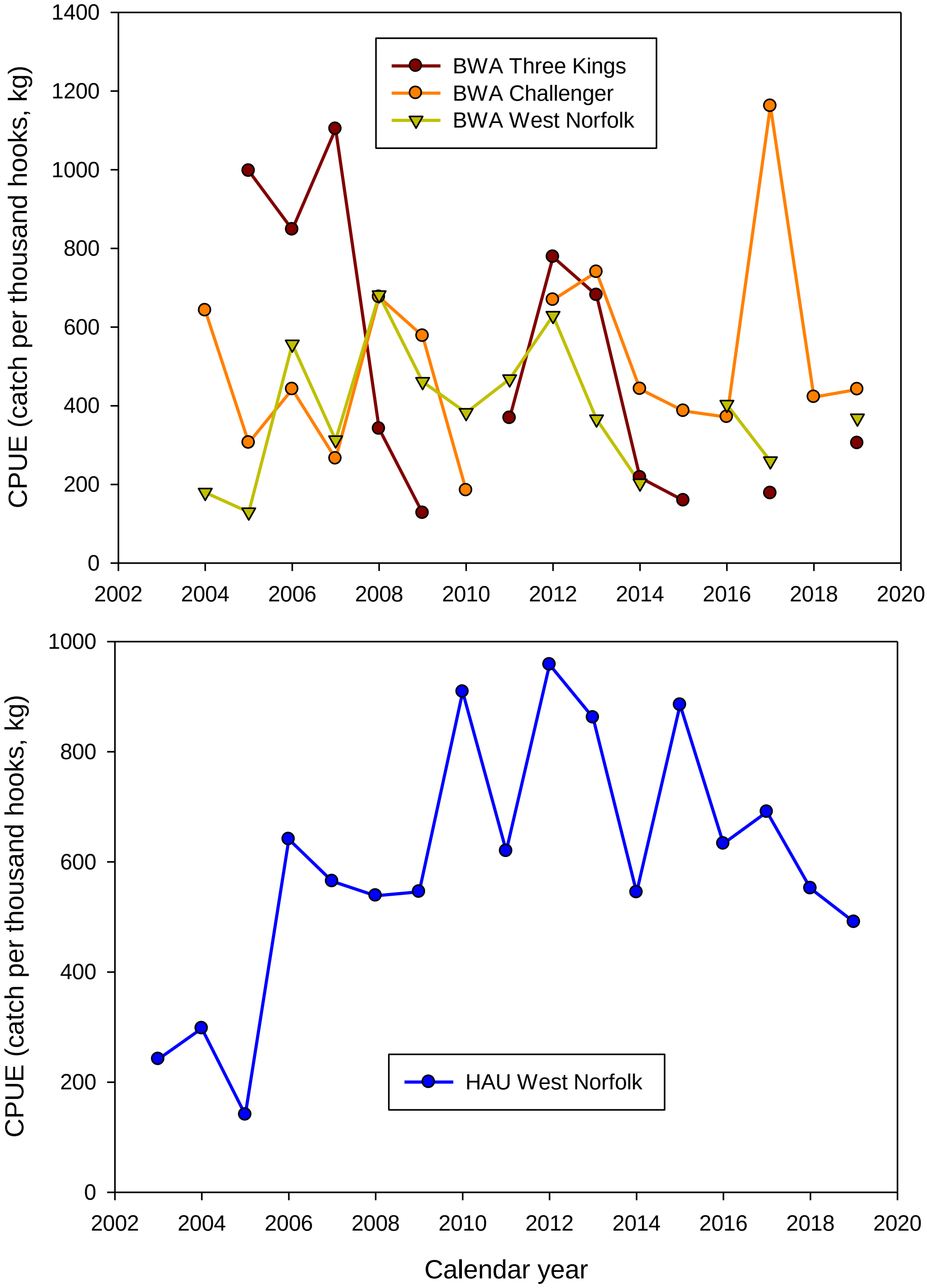


Figure 14: Trends in nominal CPUE (kg per 1000 hooks set) for bluenose (top, BWA) and wreckfish (bottom, HAU) by New Zealand bottom longline vessels fishing in the SPRFMO Convention Area, 2003–2019. Effort for each species is limited to targeted sets only. Years with 10 or fewer sets in an area are excluded.

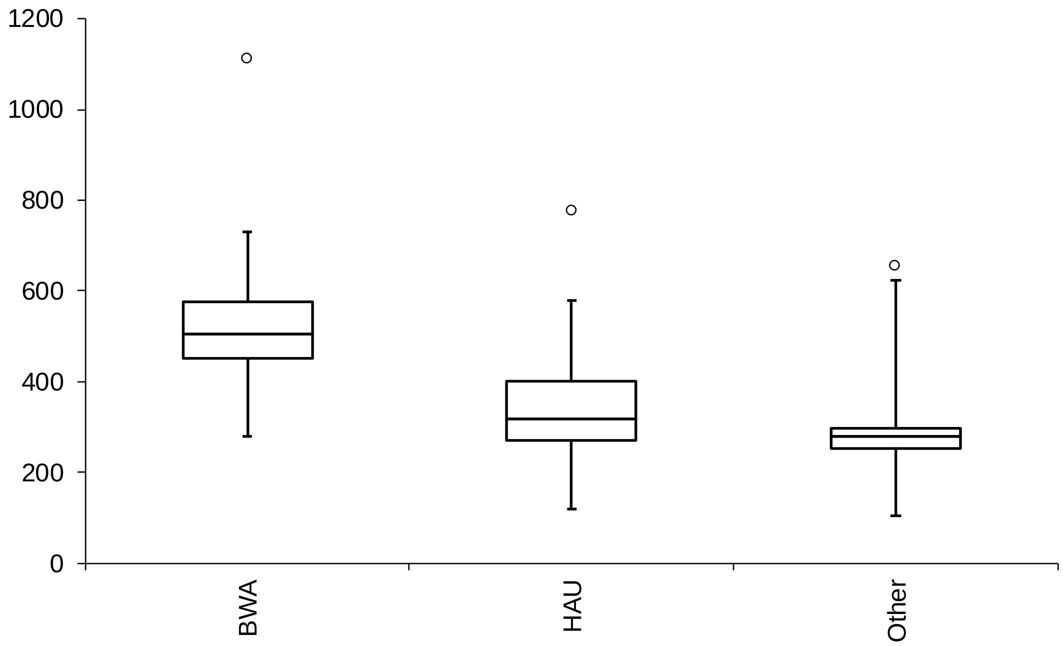


Figure 15: Depth distribution of bottom line sets for bluenose, wreckfish, and other target species, 1989 to 2019. The horizontal line for each year indicates the median, the boxes encompass the middle 50% of the sets, and the whiskers encompass 95% of the sets. The maximum reported depths after obvious errors have been removed are shown as open circles.

New Zealand has had an exploratory fishery for toothfish (using the method of bottom longlining with integrated weight line) since 2016 based on an application to the Scientific Committee in 2015 (Delegation of New Zealand, 2015) that included a detailed impact and risk assessment. The fishery was initially established under CMM4.14 for 2 years of fishing with a catch limit of 30 tonnes each year for one vessel (both species of toothfish combined: Antarctic toothfish, *Dissostichus mawsoni*; and Patagonian toothfish, *Dissostichus eleginoides*). Fishing occurred in 2016 and 2017 and, based on results from that work, the exploratory fishery was expanded spatially (Figure 16) and the catch limit increased to 140 t in each of three years, spread across two vessels (under CMM14a-2019). The initial exploratory fishing blocks were completely outside the Evaluated Area that encompasses all other recent fishing by New Zealand-flagged vessels and the expanded exploratory fishing blocks overlap only slightly with the south-eastern corner of the Evaluated Area. Impact and risk assessments for this and other exploratory fisheries[8] are not considered in detail in this BFIA but, rather, in the individual applications and CMMs.

[8] The Cook Islands has an exploratory fishery for rock lobster and deepwater crab under CMM14b-2020, and Chile has an exploratory fishery for toothfish under CMM14d-2020. Both lie outside and to the east of the Evaluated Area. The EU had an exploratory fishery for toothfish under CMM14c-2019, now expired, on the high seas areas of South Tasman Rise, within the South Tasman Rise, within the Evaluated Area.

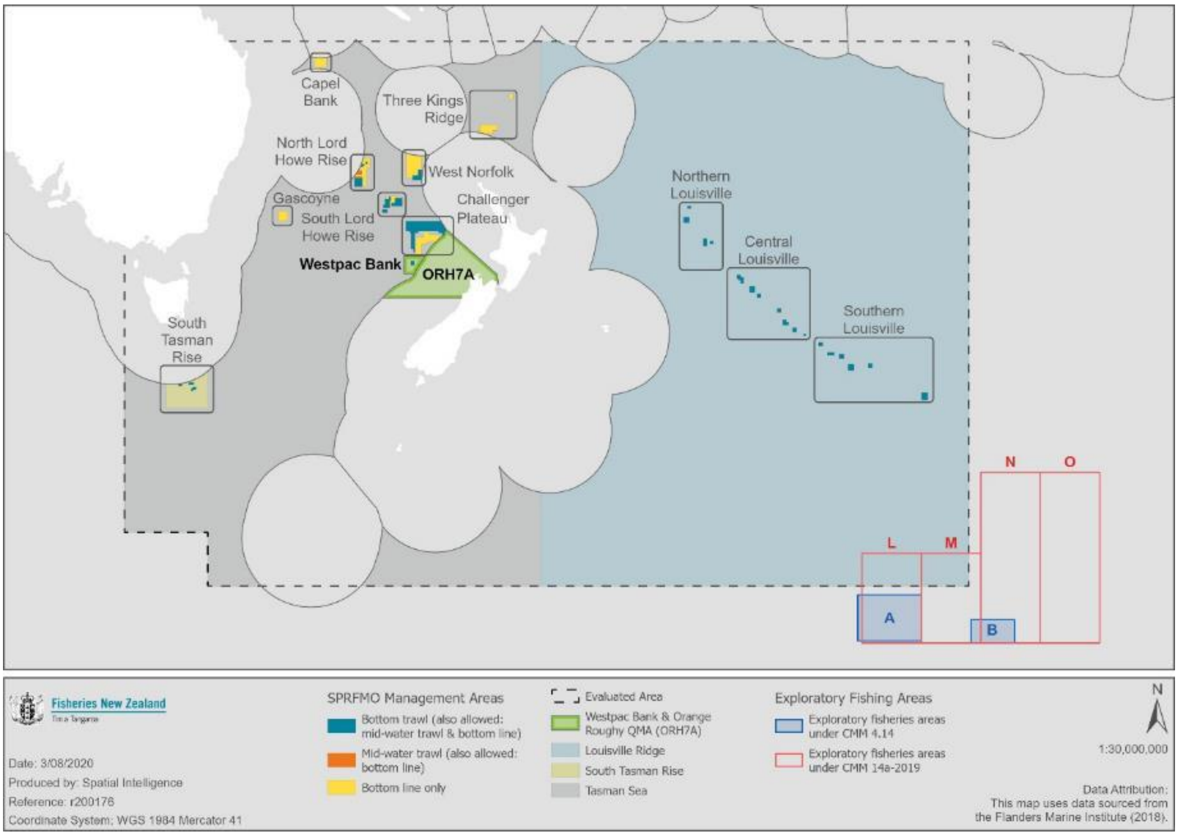


Figure 16: Locations of the exploratory fishing blocks (red boxes) for New Zealand's exploratory fishery for toothfish permitted under CMM14a-2019. The blocks for the initial 2-year exploratory fishery under CMM4.14 are shown as blue boxes and the Evaluated Area is shown as a black dashed box.

The exploratory fishery took 29 tonnes of toothfish in each of 2016 and 2017 and the results were reported in detail to the Scientific Committee in 2018 (Delegation of New Zealand, 2018). The continuing exploratory fishery under CMM 14a-2019 took 37 tonnes in 2019 and 41 tonnes in 2020. The initial results of this work will be presented to SC8 in paper SC-08-DW-09 (Fenaughty 2020).

2.4 Australian Bottom Fisheries

A small number of Australian fishing vessels target demersal fish species (those associated with the sea floor) in high-seas areas of the South Pacific Ocean. Australian operators in the SPRFMO Convention Area are authorised under permits granted by AFMA to target various species with midwater and demersal trawl, dropline, handline, automatic longline and demersal longline gears. Fishing methods have been specified on Australian high seas permits since 2008. Prior to 2008, deepwater gillnetting was allowed and used but formed a very minor part of the fishery (occurring in two years, 2002 and 2003, within a restricted area) (Williams et al. 2011). Deep-sea gillnets were prohibited in 2010 under an interim measure applicable to all fishing vessels within the SPRFMO Convention Area, prior to SPRFMO adopting a gillnet prohibition in January 2013 (SPRFMO 2013).

Permits to fish in the SPRFMO Convention Area are granted by AFMA for a period of up to five years. Australian high-seas permits require the implementation of all SPRFMO CMMs, 100% observer coverage on all trawl vessels and for the first trip of the season (for all methods) and a minimum of

10% observer coverage annually on all non-trawl vessels. At the time of writing, there were 7 permits allowing fishing in the SPRFMO Convention Area by Australian fishing vessels.

The number of Australian fishing vessels active in the SPRFMO Convention Area has decreased from a maximum of 10[9] in 2003 to three in 2019.

Detailed vessel characteristics have been provided to the SPRFMO Secretariat in accordance with the requirements in the SPRFMO Record of Vessels, (CMM 05), and are not repeated here. This assessment does not preclude Australia from issuing high seas permits and registering new and/or different vessels to fish in the SPRFMO Convention Area using the gears assessed herein in the future.

2.4.1 Trawl fisheries

A total of 16 Australian vessels trawled in the SPRFMO Convention Area between 2002 and 2019, with no trawling occurring in 2008, 2009, 2010 and 2018. Figure 17 provides the number of active Australian-flagged demersal trawl and midwater trawl fishing vessels from 2002 to 2019. Table 11 shows active Australian-flagged trawl vessels in the SPRFMO area between 2002–2019, showing the target stratum (midwater or demersal) and the number of operations (trawl shots).

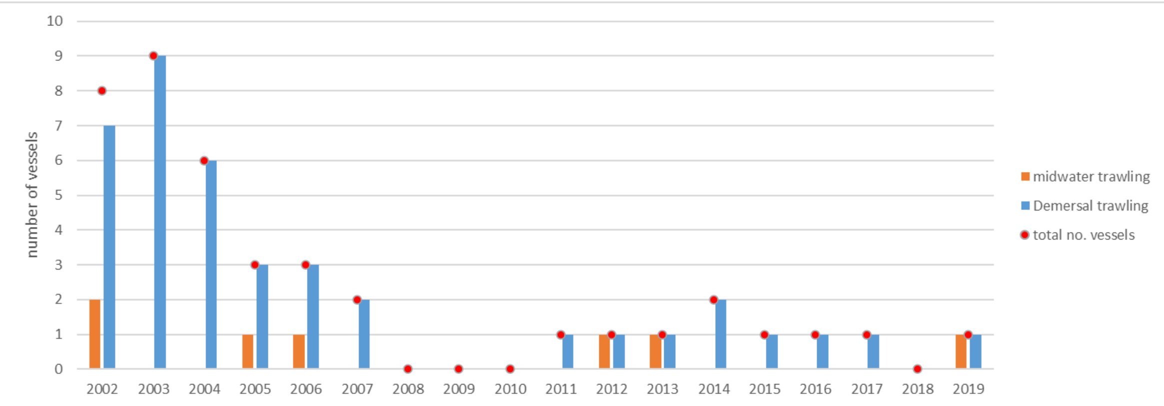


Figure 17: The number of active Australian-flagged demersal trawl and midwater trawl vessels operating in the SPRFMO Convention Area from 2002–2019.

[9] Note that this total does not match the sum of vessels shown in Figures 17 and 20 due to some vessels using multiple gear types.

Table 11. Active Australian-flagged trawl vessels in the SPRFMO Convention Area between 2002–2019 showing the target stratum and the number of operations (trawl shots).

	Stratum		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
No. active vessels	demersal		7	9	6	3	3	2	0	0	0	1	1	1	2	1	1	1	0	1
	midwater		2	0	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	1
Vessel ID	**Stratum**	**Total no. operations**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
1	demersal	2		2																
2	demersal	61		61																
3	demersal	15	10	5																
4	demersal	19		19																
5	demersal	31	25		6															
6	demersal	2		2																
7	demersal	11	10	1																
8	demersal	654	151	108	108	52	29	7							77	20	44	58		
9	demersal	17	16		1															
10	demersal	1			1															
11	demersal	63	63																	
12	demersal	234		13	4	18		199												
	midwater	25				25														
13	demersal	89					89													
	midwater	310					310													
14	demersal	101	38	26	14	17	6													
	midwater	2	2																	
15	midwater	10	10																	
16	demersal											110	85	143	18					72
	midwater												269	83						17

Species composition of catches has varied over time. Historically, Australian high-seas trawl fishing effort targeted orange roughy using demersal and midwater trawl gear. There has also been some historical effort for alfonsino using demersal and midwater trawling. Figures 18 and 19 show catch (t) of key species plus 'other' species taken by Australian-flagged demersal and midwater trawl vessels, and fishing effort (trawl-hours) in the SPRFMO Convention Area from 2002–2019.

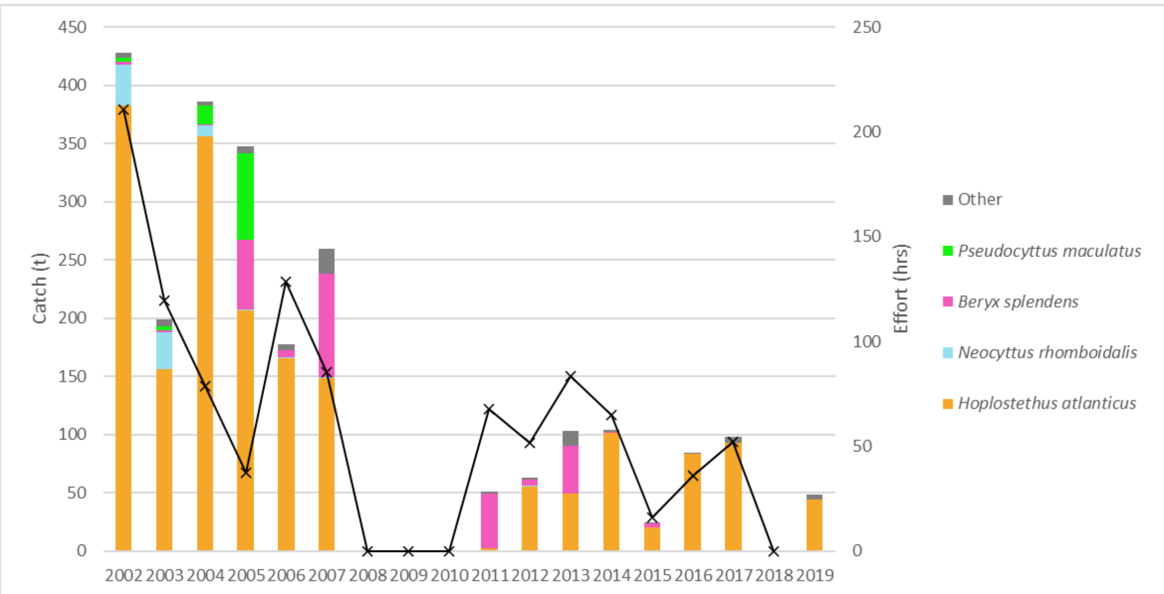


Figure 18: Catch (t) of key species and 'other' species taken by Australian-flagged demersal trawl fishing vessels, and trawl effort (trawl-hours) in the SPRFMO Convention Area from 2002–2019. Effort data for 2019 are not yet available.

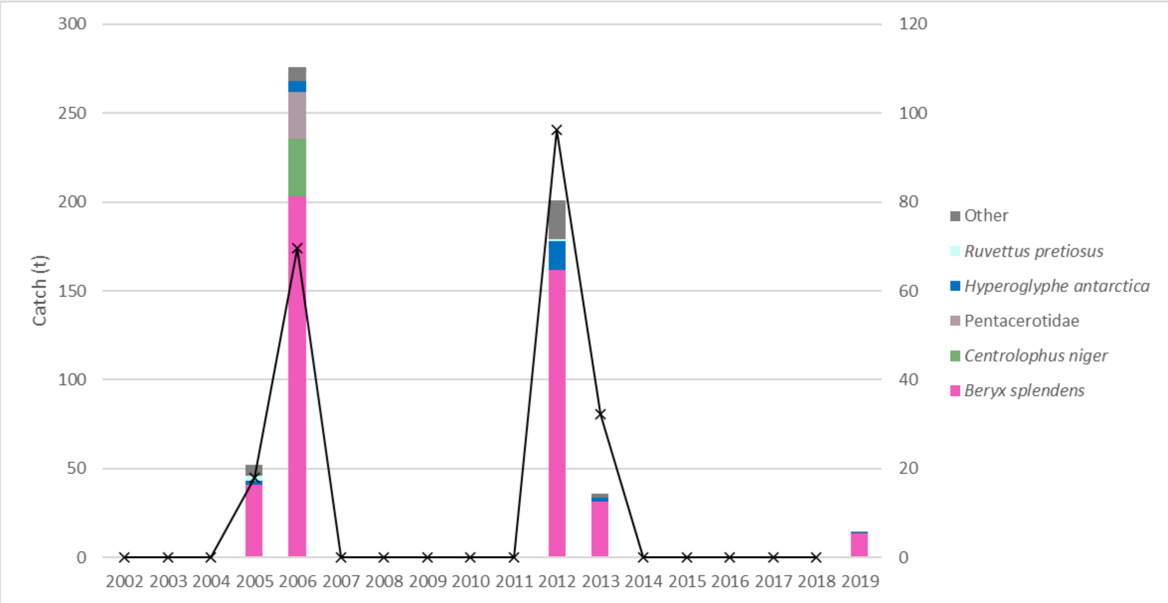


Figure 19: Catch (t) of key species and 'other' species taken by Australian-flagged midwater trawl fishing vessels, and trawl effort (trawl-hours) in the SPRFMO Convention area from 2002–2019. Effort data for 2019 are not yet available.

From observer descriptions and discussions with operators, midwater trawl operations typically use a pelagic net designed for off-bottom fishing, with large meshes (i.e. 20 metre diagonal meshes in the wings of the net). Midwater trawl nets typically have a sacrificial footrope in case the net touches the bottom. Demersal trawl operations typically use a simple 2-seam 'cut-away' orange roughy demersal trawl net with 80m sweeps and 40m bridles. The headrope and groundrope length is up to 60m and has 12-inch rubber bobbins. Fishing typically occurs in depths from 400–1100 m, depending on the target species. Demersal trawl operations typically fish with the trawl doors just off the bottom.

It is important to note that some Australian vessels have recorded fishing effort in the logbooks as 'demersal trawl' or 'midwater trawl' based on whether the net is fished on or off the bottom, with the data indicating that the same net is used. For example, one operator fishing in 2012 used a standard otter trawl net for both demersal and midwater trawl operations targeting orange roughy, alfonsino and other mixed species. Efforts are being made to resolve these and other uncertainties in the recording and reporting of logbook data.

The typical depths fished by Australian-flagged demersal and midwater trawl vessels are similar to those given for New Zealand vessels, typically ranging from ~400–1100m depending on the target species. Fishing for alfonsino typically occurs at the shallower end of this range, while fishing for orange roughy typically occurs at greater depths depending on the feature being fished.

2.4.2 Line fisheries

A total of seven Australian vessels fished with demersal line gears in the SPRFMO Convention Area between 2002 and 2019, with five active vessels in 2006 being the maximum operating in any one year. Most of Australia's line fishing effort has occurred using auto-longline and dropline gears.

Figure 20 provides the number of active Australian-flagged dropline and auto-longline vessels operating in the SPRFMO Convention Area from 2002–2019. Table 12 shows active Australian-flagged vessels using demersal line fishing methods in the SPRFMO Convention Area from 2002–2019 showing the line deployment method (dropline or auto-longline) and the number of operations (line sets).

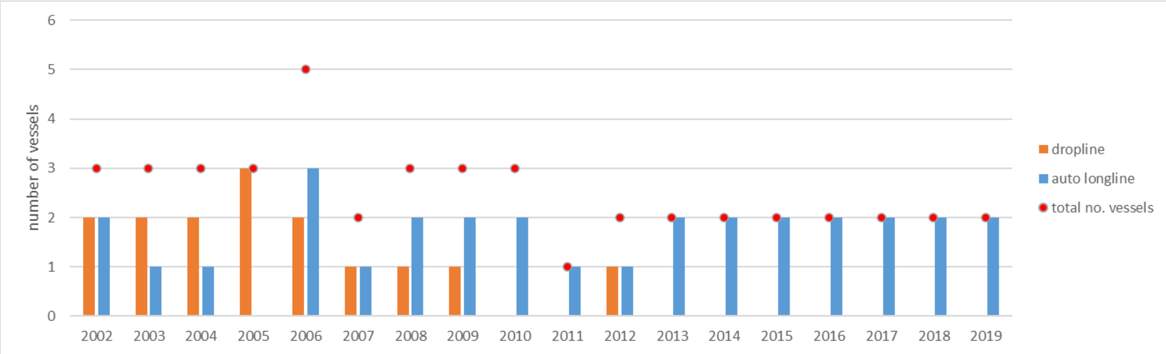


Figure 20: The number of active Australian-flagged dropline and auto-longline vessels operating in the SPRFMO Convention Area from 2002–2019.

Table 12. Active Australian-flagged vessels using demersal line fishing methods in the SPRFMO Convention Area from 2002–2019 showing the line deployment method and the number of operations (line sets). AL = Auto-longline; DL = Dropline.

	Line method	Total no. operations	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
No. active vessels	AL	4	2	1	1	0	3	1	2	2	2	1	1	2	2	2	2	2	2	2
	DL	3	2	2	2	3	2	1	1	1	0	0	1	0	0	0	0	0	0	0
Vessel ID																				
1	AL	638					9	20	68	65	41	53	58	50	40	46	67	59	62	44
2	AL	278	22	7	4		13		22	10	10			29	17	45	27	33	39	40
3	AL	3					3													
4	AL	2	2																	
	DL	45	3	2	24	10	6													
5	DL	1				1														
6	DL	39	3	4	7	8	7	4	1	2	3									
7	DL												2							

Historically, most Australian line fishing effort in the SPRFMO Convention Area has targeted species such as jackass morwong/tarakihi, yellowtail kingfish and blue-eye trevalla/bluenose. An increase in catches of emperors (Lethrinidae) and deepwater snappers (*Etelis* spp.) (as well as other more subtropical and tropical species) in Australia's line fishery in recent years reflects a change in the main fishing grounds used by some Australian line fishing vessels for part of their operations. Figures 21 and 22 show catch (t) of key species and 'other' species taken by Australian-flagged auto-longline and dropline fishing gears, respectively, in the SPRFMO Convention Area, and effort ('000 hooks) from 2002–2019.

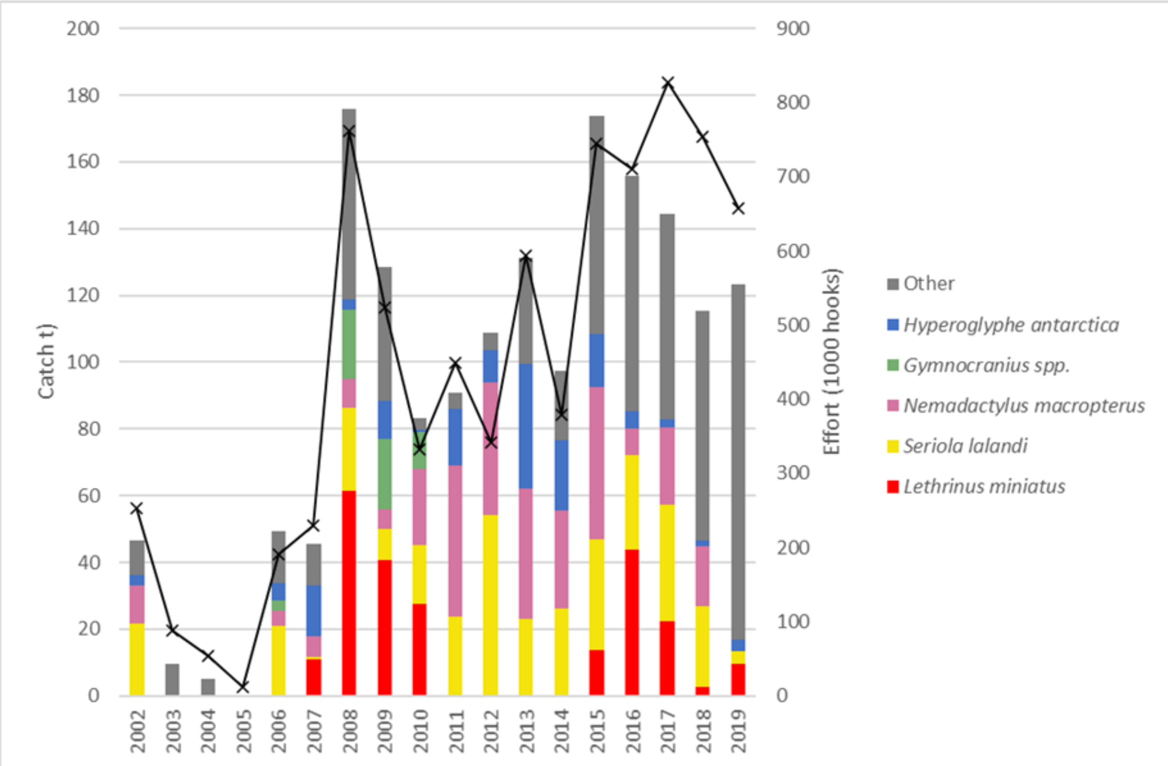


Figure 21: Catch (t) of key species and 'other' species taken by Australian-flagged auto-longline fishing vessels in the SPRFMO Convention area, and effort ('000 hooks) from 2002–2019.

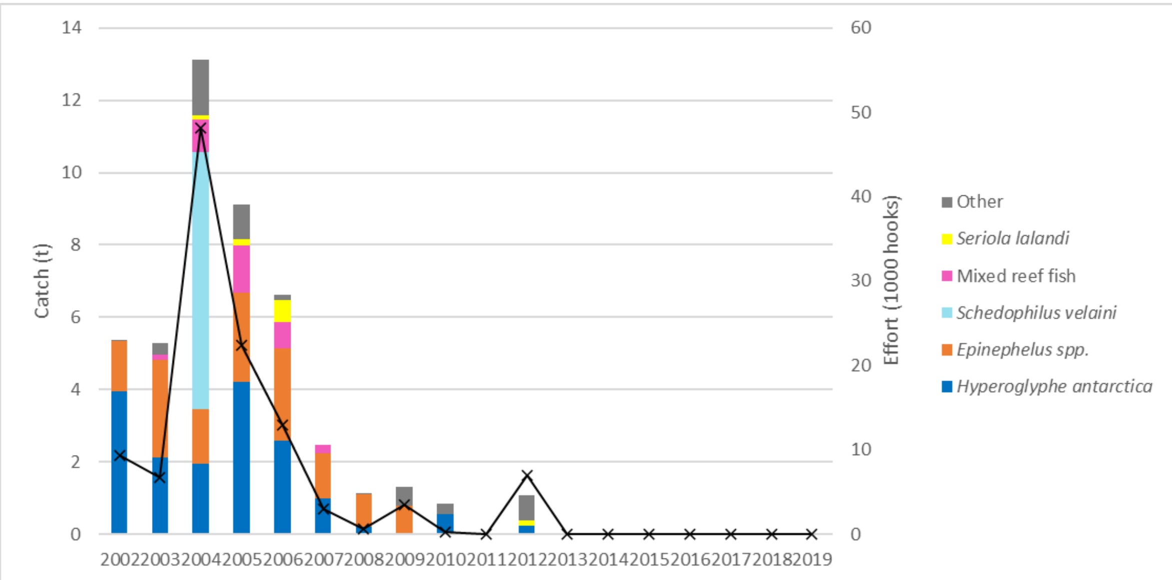


Figure 22: Catch (t) of key species and 'other' species taken by Australian-flagged dropline fishing vessels in the SPRFMO Convention area, and effort ('000 hooks) from 2002–2019.

From observer descriptions and discussions with operators, auto-longline equipped vessels use technology that allows semi-automated setting of large numbers of hooks in a short time. Part of the gear is an auto-baiter that can bait around two hooks per second while the mainline is shot from the stern of the vessel. Currently, auto-longline vessel use a bottom set mainline of 7–10 mm in diameter and can be weighted. Snoods of ~300-400mm length with a 12/0 or 13/0 hook are spaced between 1 and 1.4 m apart along the mainline. The longline is set with a 75 kg weight at each end and, depending on the target species, either floated up off the seabed using midwater floats that are clipped onto the line during deployment, or allowed to settle onto the seabed, sometimes with a weight midwater along to prevent dragging. Droplines are set vertically with a single weight of ~40 kg at the bottom and a large float at the surface with around 100–200 hooks attached to the bottom part of the vertical line.

3 MAPPING AND DESCRIPTION OF FISHING AREAS

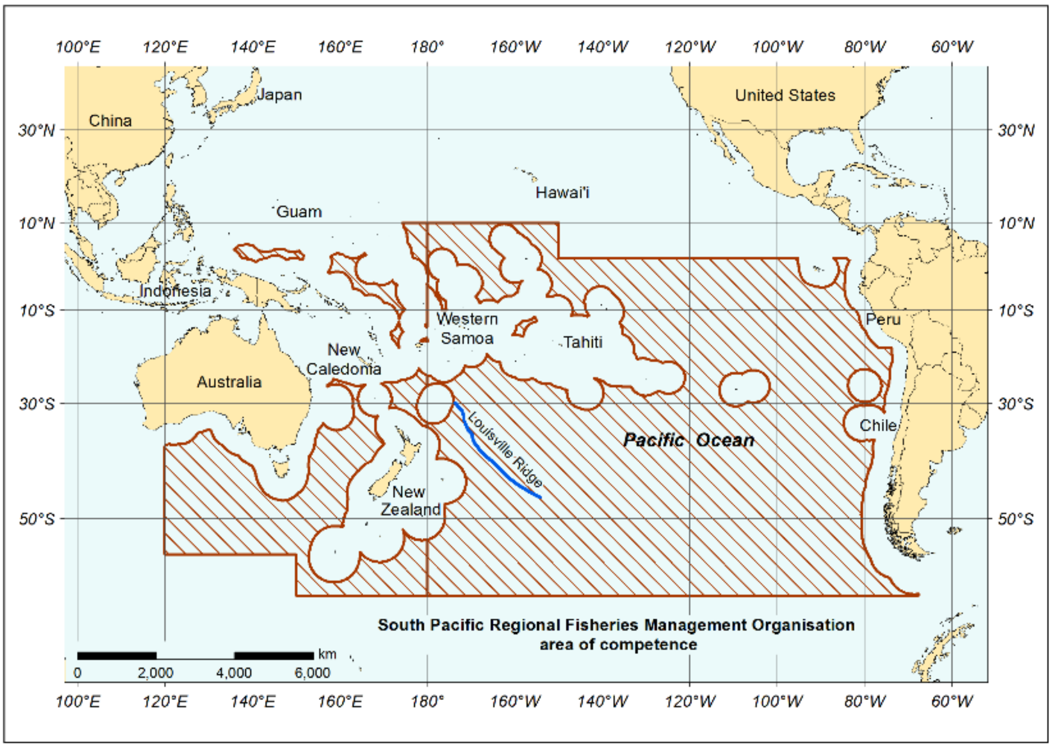


Figure 23: Map of the SPRFMO Convention area

The main bottom fishing areas for existing participants in the fisheries in the southwestern Pacific Ocean (Australia and New Zealand) are defined in the bottom fishing measure CMM03-2020 (Figure 24). Areas are defined separately for different fishing methods and bottom fishing is not allowed outside the defined areas unless authorised as an exploratory fishery pursuant to CMM13-2020. Bottom trawling is the most restricted spatially, given it has the greatest potential impact on benthic communities. Bottom line fishing is allowed in any defined management area and midwater trawling for bentho-pelagic species is allowed throughout bottom trawl fishing areas as well as in areas specific to the method.

For the purposes of CMM03-2019 and CMM03-2020, the term 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 (Figure 24).

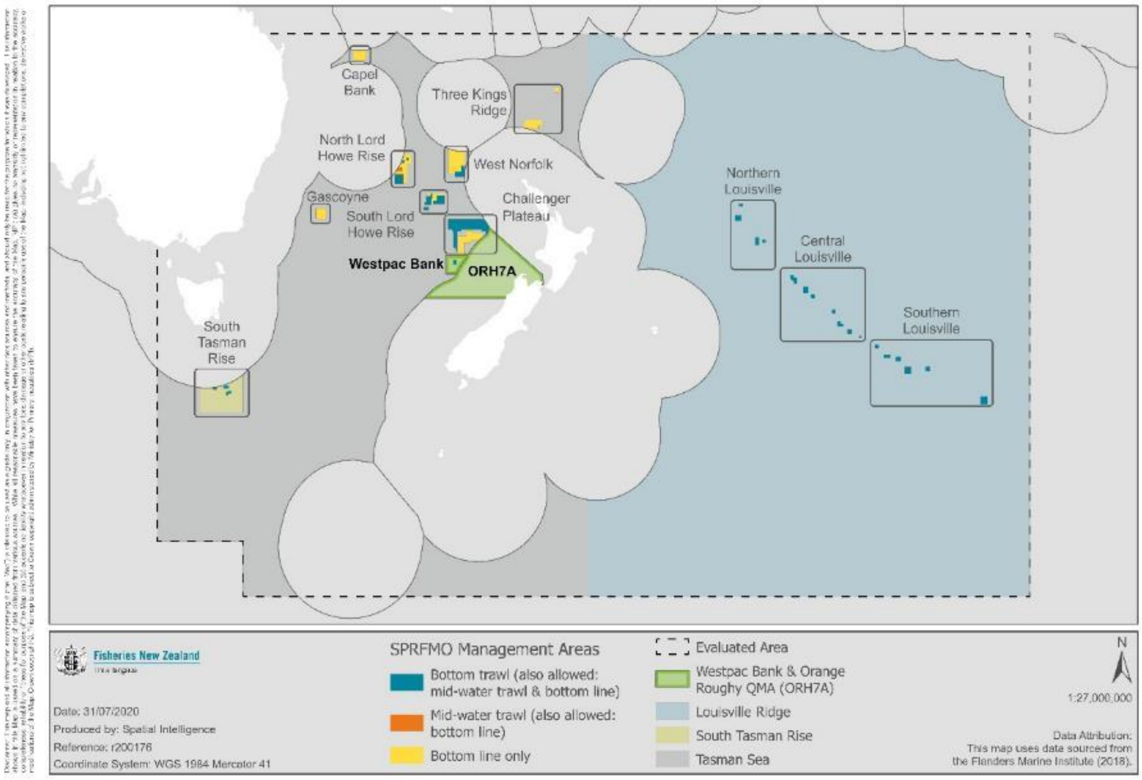


Figure 24: Areas open to different types of fisheries under SPRFMO CMM03-2020. Note that areas open to bottom trawling are also open to all other fishing methods and areas open to midwater trawling are also open to bottom long lines. The Evaluated Area is shown as a dashed line.

3.1 NEW ZEALAND BOTTOM FISHERIES

3.1.1 Trawl fisheries

3.1.1.1 Bottom trawl

The spatial extent of New Zealand bottom trawl fishing effort in the SPRFMO Evaluated Area in 1989–2019 was the largest of all gears, as well as the most intense.

Bottom trawl tracks were built from start and end tow positions, and effort was represented as the number of trawl tracks within each of the 5 minutes of arc cells. Intensity scales in the maps are consistent, to aid comparisons.

Orange roughy was the main target of bottom trawl fisheries effort and was widespread on the Louisville Ridge and on rises and plateaus alike (Figure 25). The effort targeting all other species had a lower intensity but showed a consistent spatial pattern with the orange roughy bottom trawl effort (Figure 26).

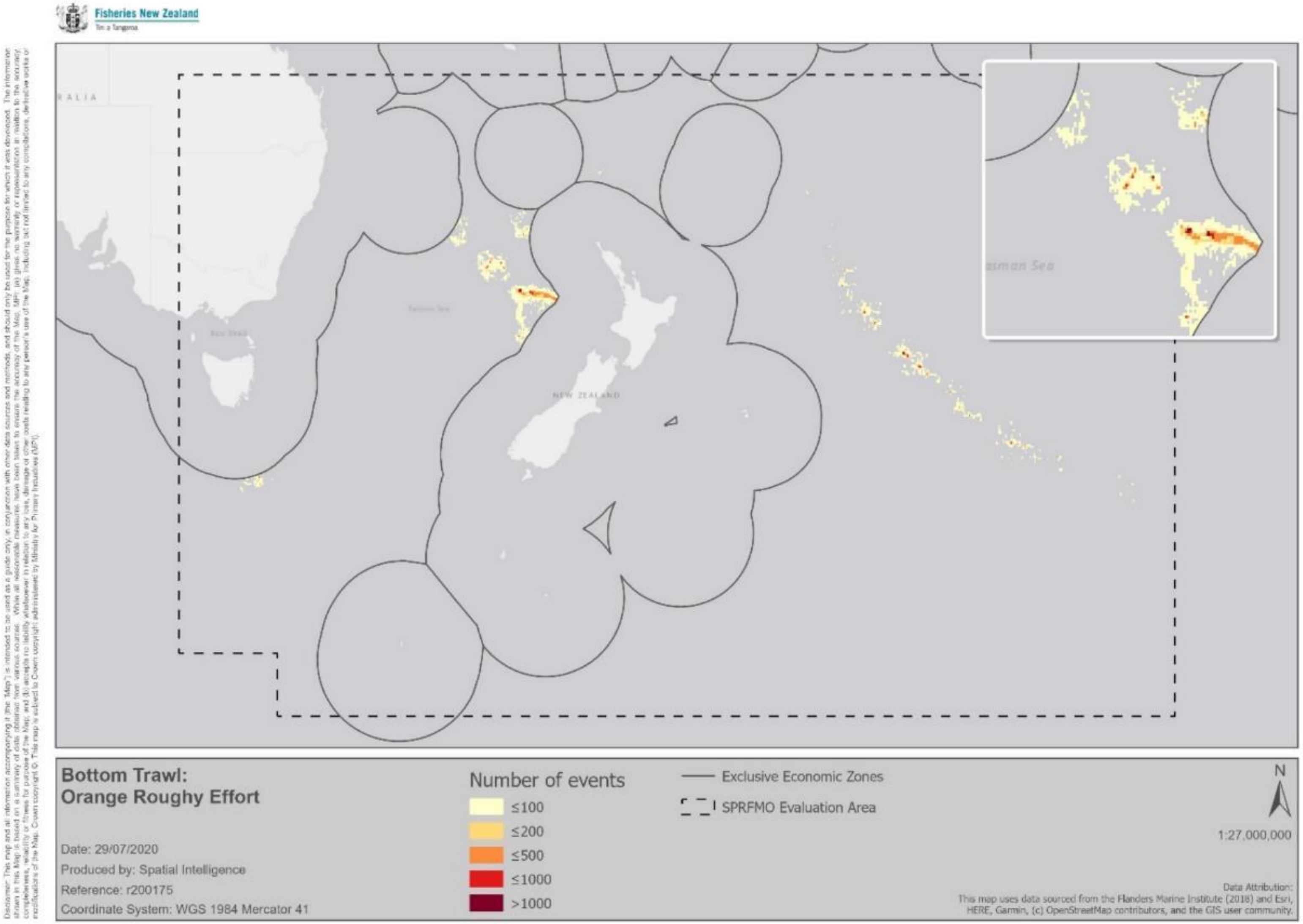


Figure 25: Map of fishing effort in the SPRFMO Evaluated Area by New Zealand vessels targeting ORH with bottom trawls, 1989–2019

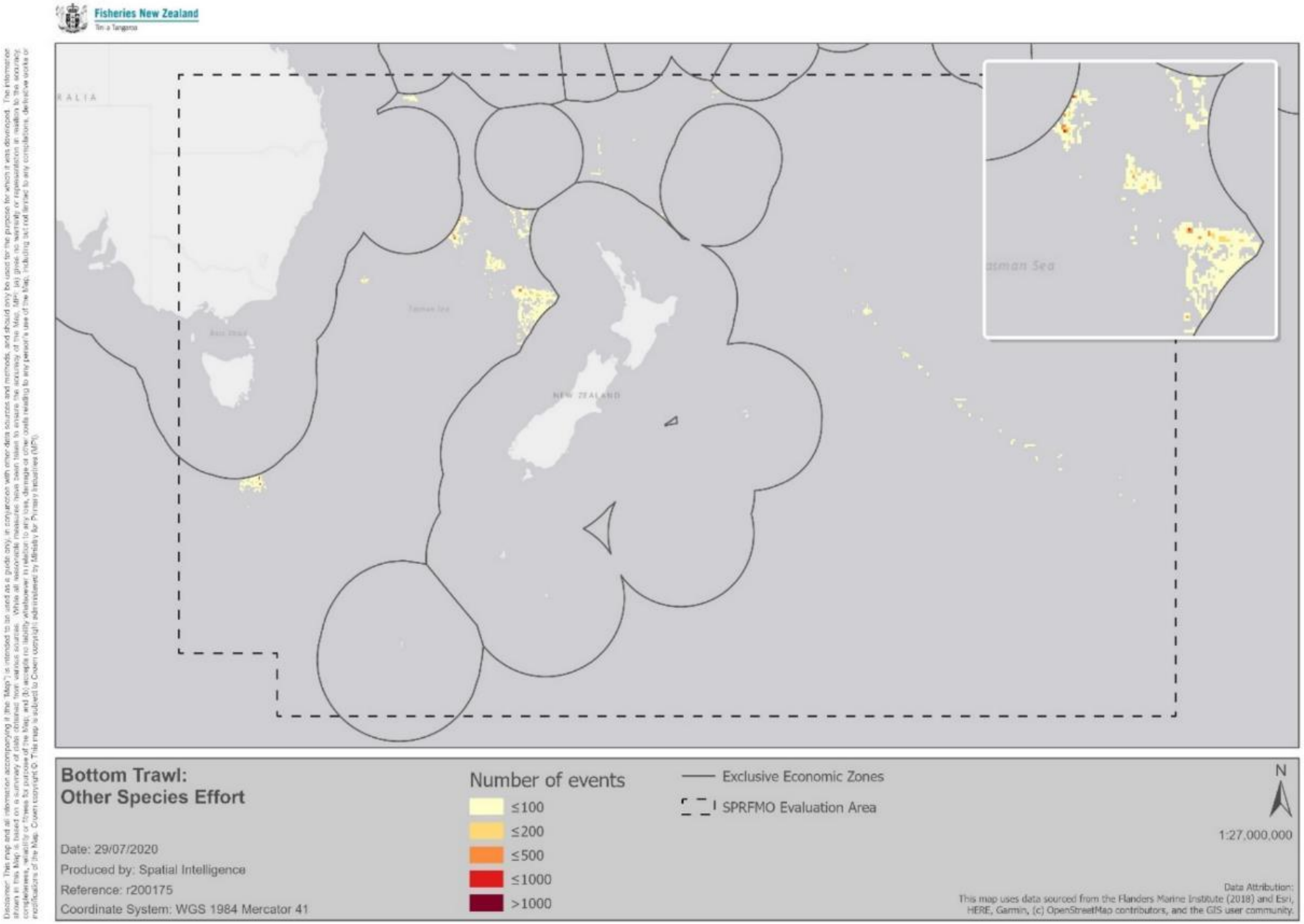


Figure 26: Map of fishing effort in the SPRFMO Evaluated area by New Zealand vessels targeting all other species with bottom trawls, 1989–2019

3.1.1.2 Midwater trawl

The spatial extent of New Zealand midwater trawl fishing effort in the SPRFMO Evaluated Area in 1989–2019 was much smaller than bottom trawl.

As for bottom trawls, midwater trawl effort was represented as the number of trawl tracks within each of the 5 minutes of arc cells. Intensity scales in the maps are consistent, to aid comparisons.

Alfonsino and bluenose / blue eye trevalla were the main target of the midwater trawl fishing effort, with a main cluster on the Lord Howe Rise (Figure 27). Effort targeting other species was relatively minor but showed a consistent spatial pattern with the main target species (Figure 28).

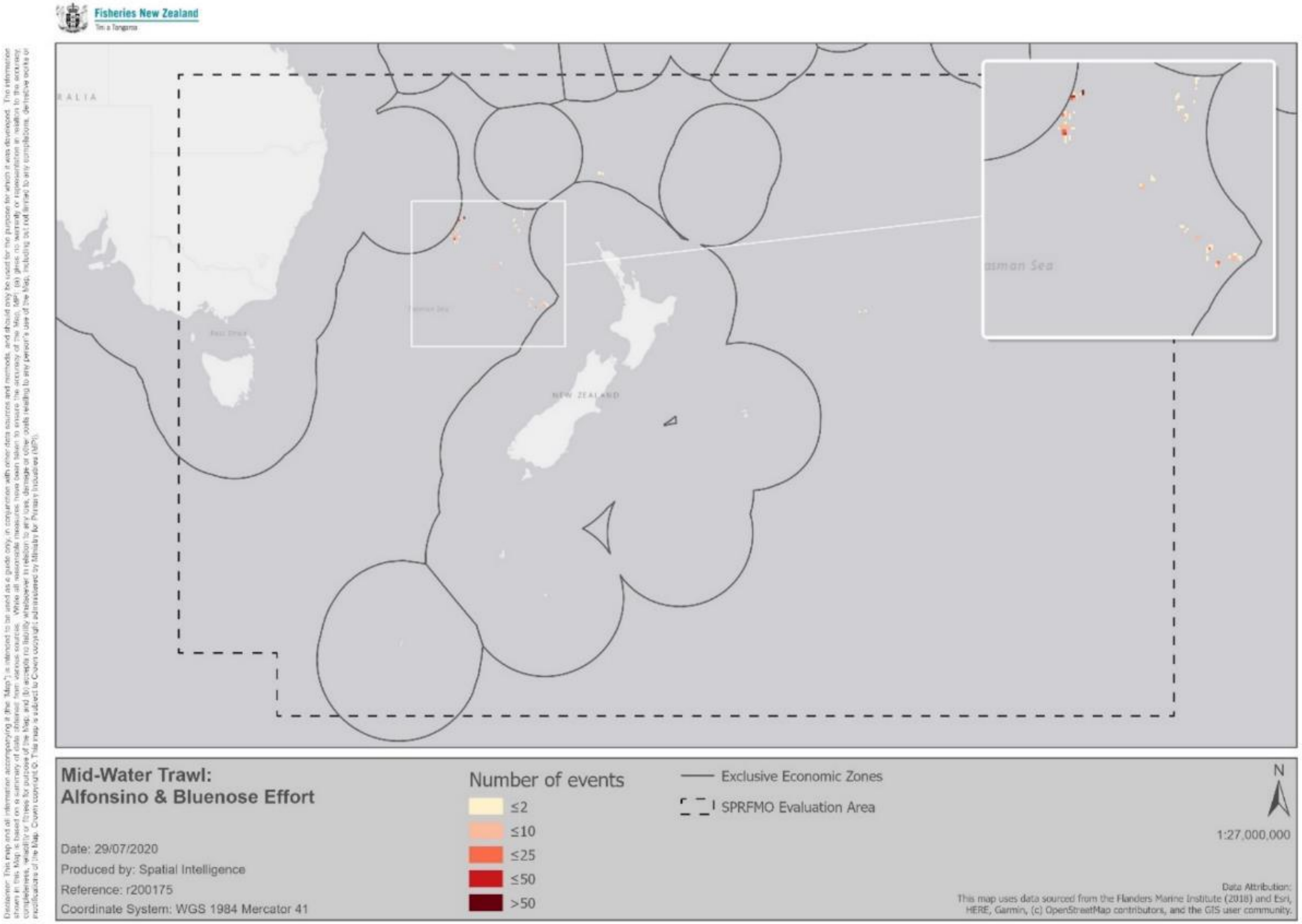


Figure 27: Map of fishing effort in the SPRFMO Evaluated Area by New Zealand vessels targeting ALF and BWA with midwater trawls, 1989–2019

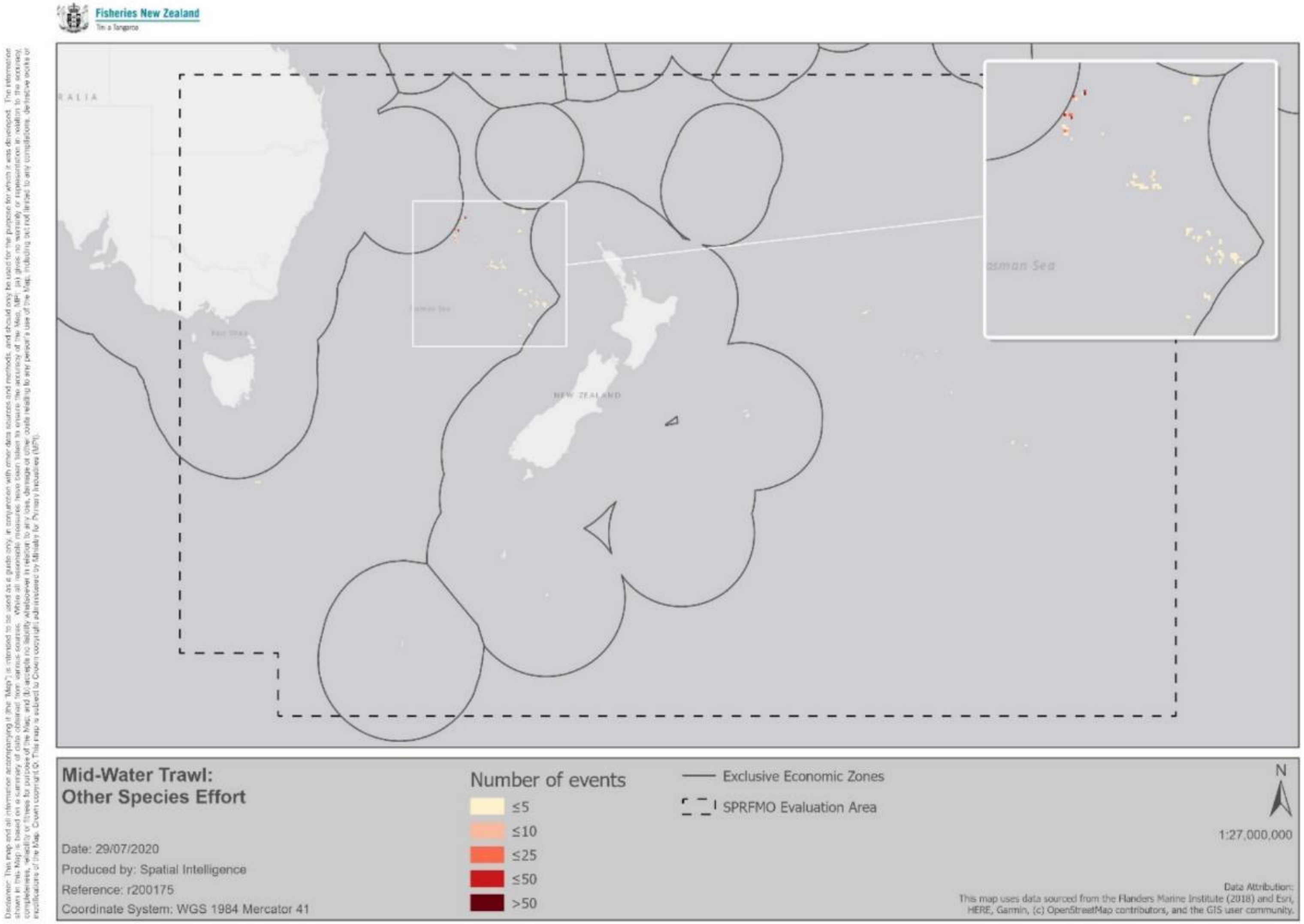


Figure 28: Map of fishing effort in the SPRFMO Evaluated Area by New Zealand vessels targeting all other species with midwater trawls, 1989–2019

3.1.2 Line fisheries

The spatial extent of New Zealand bottom longline fishing effort in the Evaluated Area in 1992–2019 was relatively minor, compared with trawl effort. Given that some of the records were missing end positions, and that longline sets are usually much shorter than trawl tracks, effort was represented as the number of starting set locations within each of the 5 minutes of arc cells. Intensity scales in the maps are consistent, to aid comparisons.

Bluenose was the main target of bottom longline fishing effort, with clusters on the Three Kings Ridge, the West Norfolk Ridge and the Challenger Plateau (Figure 29). Bottom longline fishing effort targeted at wreckfish (hapuku and bass combined) largely overlapped with bluenose effort but was most concentrated on the West Norfolk Ridge (Figure 30). Effort targeting other species was minor but showed some clustering in the Tasman Sea and in the northern part of the assessed area, including Capel Bank (Figure 31).

Figure 29: Map of New Zealand bottom longline fisheries effort targeted at BWA in the SPRFMO Evaluated Area, 1992–2019

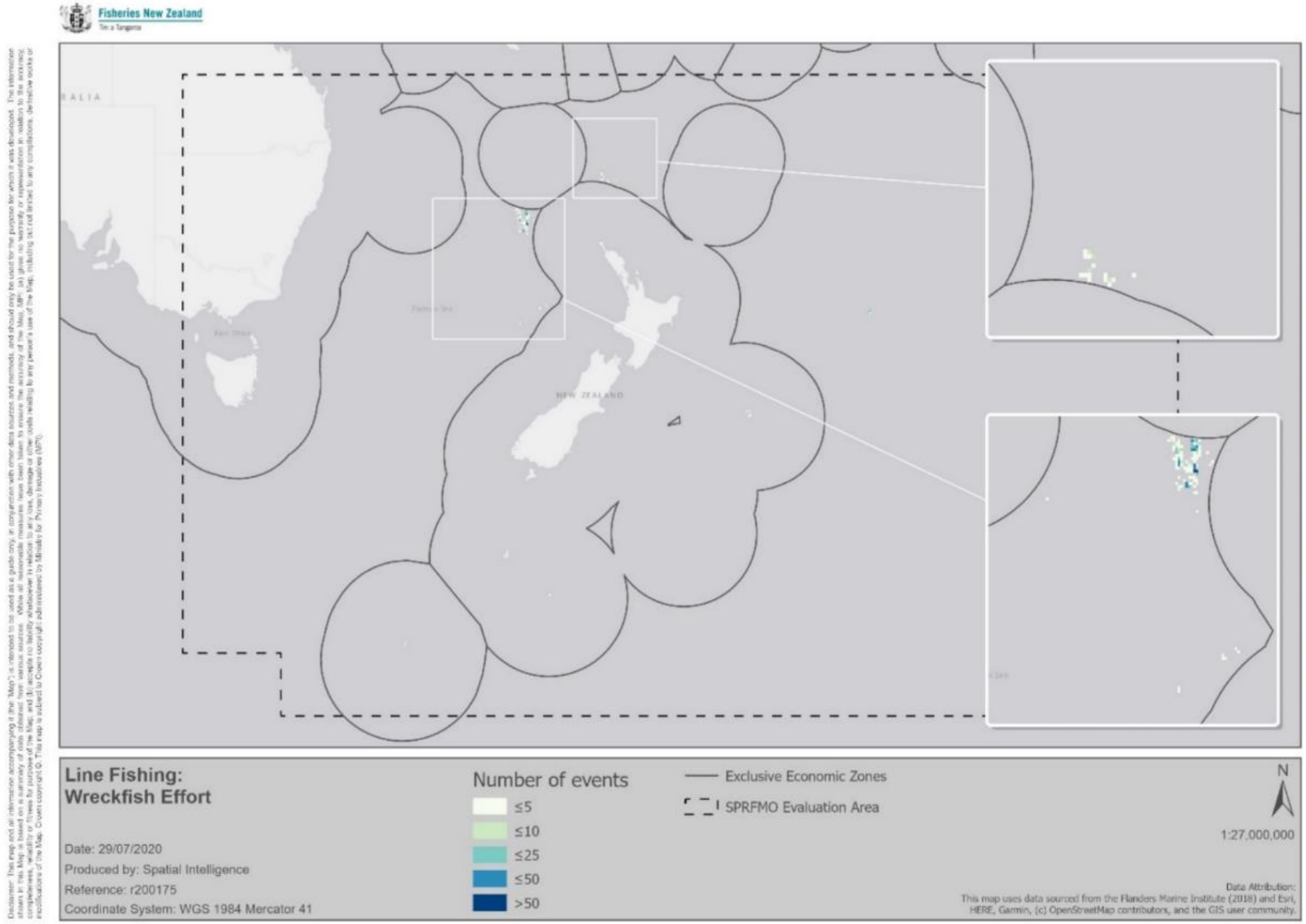


Figure 30: Map of New Zealand bottom longline fisheries effort in the SPRFMO Evaluated Area, targeted at wreckfish (HAU and HPB), 1992–2019

Figure 31: Map of New Zealand bottom longline fisheries effort in the SPRFMO Evaluated Area targeting all other species not included in the figures above, 1992–2019

3.2 AUSTRALIAN BOTTOM FISHERIES

Fine-scale maps of Australian fishing areas cannot be provided due to confidentiality and privacy constraints. Maps showing Australian fishing locations at an appropriate resolution may be provided in future updates to the BFIA. A general description of fishing areas is provided below.

3.2.1 Trawl fisheries

Most Australian demersal and midwater trawl fishing in in the SPRFMO Convention Area has occurred in the Tasman Sea, although there has been some historical effort on the South Tasman Rise and the LSC. The main Tasman Sea trawl fishing areas are the South Tasman Rise (closed since 2007), Challenger Plateau and West Norfolk Ridge.

3.2.2 Line fisheries

Historically, most Australian demersal line fishing in the SPRFMO Convention Area has occurred around the Gascoyne and Lord Howe Rise seamounts in the Tasman Sea and around the Capel Bank in the Coral Sea.

4 RISK AND IMPACT ASSESSMENT

In accordance with the SPRFMO BFIA Standard (BFIAS), this impact assessment contains the following components:

1. Identification of objectives, assets, hazards and risks using a hierarchical risk assessment approach
2. Identification and assessment of impacts
3. Identification of mitigation, management and monitoring measures relevant to impacts and residual risks
4. Iterative and adaptive review (i.e. periodic reassessment and improvement).

In this assessment, risk is assessed at each level of a hierarchy based on the uncertainty inherent in various types of assessments (e.g. benthic assessments, stock assessments, productivity-susceptibility analyses etc.). The Hobday et al. (2011) approach (Figure 32) is an ecological risk assessment approach that, in this context, has been applied within the SPRFMO BFIAS framework of impact assessment, management of impacts, ongoing monitoring and iterative review.

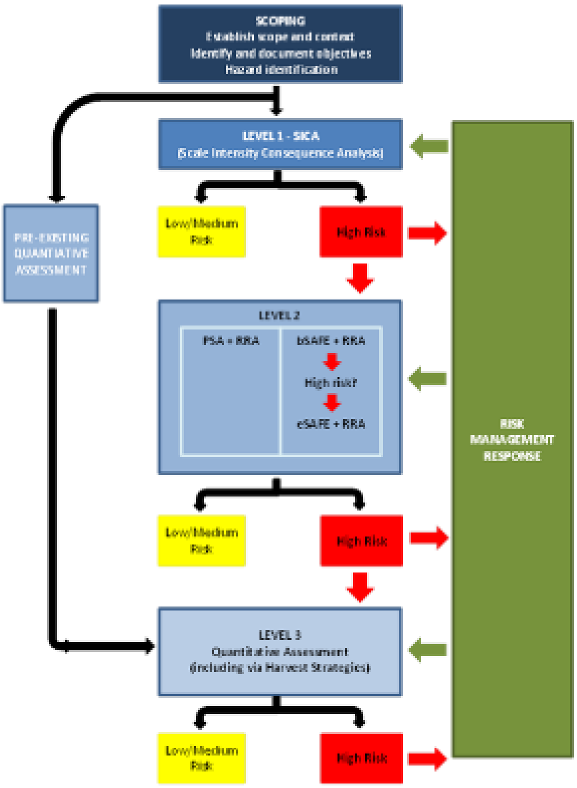


Figure 32: Structure of the three-level hierarchical methodology for the Ecological Risk Assessment for the Effects of Fishing methodology. Indicative methods available at each tier are shown, e.g. SICA – Scale Intensity Consequence Analysis; (Level 1); PSA – Productivity-Susceptibility Analysis; SAFE – Sustainability Assessment for Fishing Effects; (Level 2); Quantitative Assessment (Level 3); RRA – Residual Risk Analysis. Modified from Hobday et al. (2011).

The Hobday et al. (2011) risk assessment approach is structured around three tiers: the first is largely expert-based / qualitative assessment, the second is semi-quantitative and the third is fully quantitative estimates of the status of assets at various levels of detail. Within each tier there are various methods that can be adapted to fish stocks, other species of interest or concern, and VMEs, benthic habitats and communities. In this BFIA, we apply assessments at all levels of the hierarchy depending on the availability of information and data. Any risk that cannot be demonstrated to be low-medium with justification at a given tier needs to be assessed at the next tier or managed to reduce risk. Impacts need to be actively managed and/or mitigated and monitored.

In this assessment expert-based/qualitative assessments are applied for seabirds, marine mammals and reptiles; semi-quantitative or fully quantitative assessments for a range of fish stocks and other species of concern (including deepwater chondrichthyans); and fully quantitative assessments for VMEs.

4.1 Scoping of objectives, assets and hazards

The initial step in an assessment is to identify objectives as well as all 'assets of value' against all potential hazards the fisheries may pose.

The shared **objective** of CMM 03 (Bottom Fishing) and CMM 03a (Deepwater Species) are:

> *"through the application of the precautionary approach and an ecosystem approach to fisheries management, to ensure the long-term conservation and sustainable use of deep sea fishery resources, including target fish stocks as well as non-target or associated and dependent species, and, in doing so, to safeguard the marine ecosystems in which these resources occur, including* inter alia *the prevention of significant adverse impacts on vulnerable marine ecosystems."*

The scope of this impact assessment is constrained to historical and current fishing activities by Australia and New Zealand within the historical fishing footprints used to spatially manage fishing effort under previous bottom fishing CMMs and fishing that has occurred (and will likely occur) within the Evaluated Area and associated Management Areas specified in CMM03-2020 (Bottom Fishing).

Assessment of SAIs to VMEs is informed by the definitions and characteristics outlined in the FAO Deep-sea Fisheries Guidelines. Assessment of the impacts of fishing on fish stocks, seabirds, marine mammals and other species of concern is undertaken using a variety of methods and against various objectives depending on the asset.

The **assets** considered in this bottom fishing impact assessment are:

- Target species
- Non-target (bycatch) species, which may be retained as byproduct or discarded
- Seabirds, marine mammals, reptiles and other species of concern
- Benthic habitats, biodiversity and VMEs.

The **hazards** considered in this bottom fishing impact assessment are:

- Fishing activity: this is evaluated for each gear type used by all vessels (e.g. trawling, longlining, etc.) engaged in fishing. This assessment includes consideration of the cumulative impacts of fishing gears on VMEs and the impact of each gear type on target species, non-target (bycatch) species, seabirds, marine mammals, reptiles and other species of concern.

- Loss of bottom fishing gear, including the risk of ghost fishing and ongoing physical impact of lost gear.
- Non-gear impacts, for example bird strikes with vessels, discharge of offal or oil/fuel and other pollution, use of lights at night, noise pollution etc.

For each hazard evaluated a description of the impacts is provided in terms of what has been or may be affected and how.

Non-fishery related hazards that may result in cumulative risk and/or impacts include:

- a changing climate, including changes in oceanographic dynamics, ocean temperatures, ocean acidification, changes in oxygen, chlorophyll, carbon, salinity and other drivers of productivity
- deep-sea mining and exploration, including seismic testing
- ocean pollution, including plastics, chemical runoff, discharge from non-fishing vessels
- hazards from non-fishing vessels, including noise/light pollution and non-fishing vessel related interactions with marine fauna.

These non-fishery related hazards are not assessed in this impact assessment.

4.2 Information on status of the deepwater stocks to be fished

This section describes information on the key target and bycatch species encountered in SPRFMO deepwater fisheries. Bycatch species can be separated into those that are retained and those that are typically discarded. A list of demersal teleost and deepwater chondrichthyan species that have been assessed in SPRFMO fisheries (using a variety of methods) is included in Appendix B. This section also describes a framework for the assessment of SPRFMO deepwater stocks.

4.2.1 SPRFMO stock assessment framework

In accordance with SPRFMO CMMs 03 and 03a, the SPRFMO Scientific Committee is required to provide scientific advice to the SPRFMO Commission on the sustainability of a large number of target and non-target stocks, as well as advice on the impact of fishing on associated and dependent species with which the fishery interacts. The quantity, quality and suitability of data varies among species over time and space. This variability influences the parameters that can be estimated and associated uncertainties which, in turn, will affect the advice that the Scientific Committee can provide to the Commission. To improve the efficiency of processes run by the Scientific Committee, a tiered framework for assessing and prioritising stocks for assessment of status or other measures has been adopted based on the parameters that can be estimated given the data available. Such a tiered framework is intended to (eventually) assist the Scientific Committee with developing transparent decision rules for advice on recommended biological catches and potential buffers (e.g. 'discount factors'), or other management measures (e.g. for non-target stocks), that may be applied to account for assessment uncertainty. The tiered levels consist of:

1. Full Benchmark Assessment that utilises catch data from fishery monitoring, ideally in combination with stock abundance from independent surveys, catch rates and biological data with the purpose of estimating depletion levels and fishing mortality rates;

2. Data Limited Assessment that may utilise catch only or simple indicators to track status (e.g. CPUE, size composition, PSA);
3. No assessment necessary.

Two subsets may apply after initial classification of stocks into Tier 1 or Tier 2:

i. Research Assessment where new methods or data types are applied which may require substantive review of the methods by the Scientific Committee; and

ii. Update Assessment where previous accepted assessments are updated with new data.

A preliminary categorisation into the tiered assessment framework has been undertaken for species with records of interaction with SPRFMO demersal fisheries. A small number of stocks have been categorised into tier 1 of the assessment framework, whereby they are (or may need to be) assessed using fully quantitative assessments (e.g. Cordue et al. 2019). A number of target and non-target (but generally retained) species have been categorised into tier 2, while the vast majority of bycatch species (which are generally caught in small volumes and discarded and also include species that rarely interact with the fisheries) have been categorised into tier 3. Categorisation into tiers 2 and 3 of the hierarchy has been informed by ecological risk assessments for SPRFMO teleosts and chondrichthyans (e.g. Georgeson et al. 2019, Georgeson et al. 2020) and associated analyses of species biology and the characteristics of fishing effort and catches.

The following sections describe key target stocks that have been categorised into tiers 1 or 2.

4.2.2 Predominantly trawl fisheries

4.2.2.1 Orange roughy (Hoplostethus atlanticus)

4.2.2.1.1 Stock structure

The biological structure of orange roughy stocks in the SPRFMO Convention Area is uncertain. Research indicates that there is a greater level of genetic structure in global orange roughy populations than has previously been detected (Varela, Ritchie & Smith 2013). Analyses of biological data and various stock assessments have identified separate and geographically distinct fishing areas for orange roughy in the SPRFMO Convention Area due to substantial distances or abyssal-depth waters. These fishing areas are the high seas area of the South Tasman Rise, the northern and southern Lord Howe Rise, the Challenger Plateau and the West Norfolk Ridge.

In 2013, the first meeting of the SPRFMO Scientific Committee recommended that work be done to identify the existence and distribution boundaries of stocks of orange roughy (and alfonsino) that straddle EEZ boundaries and extend from EEZs into the SPRFMO Convention Area.

Several regional management units of orange roughy have been assumed for assessment purposes in the SPRFMO Convention Area. In addition to the South Tasman Rise stock (which straddles the Australian EEZ and the SPRFMO Convention Area), these units are Louisville North, Louisville Central, Louisville South, Lord Howe Rise, NW Challenger Plateau, and the Southwest Challenger Plateau (which straddles New Zealand's EEZ and the SPRFMO Convention Area) and West Norfolk Ridge. Work is currently underway to improve the delineation of biological stocks of orange roughy in the SPRFMO Convention Area.

Successful management of orange roughy in SPRFMO is partly contingent on the stock structure hypotheses used in the assessments (e.g. Cordue 2017, Cordue 2019) being approximately correct. In light of uncertainty, a precautionary approach to their management has been pursued.

4.2.2.1.2 Stock assessment and status

Several assessments have been attempted for orange roughy management units in the SPRFMO Convention Area (Wayte et al. 2003; Clark, Dunn & Anderson 2010; Edwards & Roux 2017; Cordue 2017; Roux et al. 2017; Cordue 2019). The first assessment models that were used by the Scientific Committee to provide advice on catch limits to the Commission were those by Roux and Edwards (2017) and Cordue (2017). Roux and Edwards (2017) used spatially structured catch per unit effort (CPUE) modelling to generate a putative biomass index and biomass dynamic modelling to assess stock status. Cordue (2017) used a catch history–based assessment that uses an age-structured population model with parameters borrowed from five stocks within New Zealand's EEZ. The method focuses on the minimum virgin biomass (B_{min}) that would allow the historical catches to have been taken, assuming a maximum exploitation rate in any given year of 67%. The assessment results indicated that, in 2015, five of the seven SPRFMO management units were very likely to have been above 20%B_0.[10] There was an indication that the NW Challenger Plateau and Lord Howe Rise management units may be below this level, and that recent exploitation rates could be very high. Cryer and Nicol (2017) compared the assessment results from these two disparate methods with very different inputs and assumptions. They focused on the lower confidence limits of estimated stock status i.e., evaluated stock status worst case scenarios that would still be consistent with the data and models. They concluded that, despite some differences, there was broad agreement on stock status for three of the four management units (where both methods could be applied). Although none of the methods is ideal for the assessment of SPRFMO orange roughy stocks, the 5th meeting of the Scientific Committee (paragraph 98 of its report) considered them to be collectively indicative of stock status and potential yields. The development of advice on catch limits for individual stocks was considered but, because of the level of uncertainty in estimates of status and yield by stock, it was considered better to group the stocks for the development of advice. Based on that advice, the 6th meeting of the Commission meeting set catch limits for orange roughy stocks on the Louisville Ridge and Tasman Sea (excluding the South Tasman Rise and the Westpac Bank).

Cordue (2019) updated the catch history-based assessment of Cordue (2017) for the three Louisville Ridge management units. The new assessment used age and length composition data from the Louisville Central orange roughy stock and assumes a maximum exploitation rate in any given year of 67%. The biological parameters and year class strengths for Louisville Central were then used to update catch-history based assessments for Louisville North and Louisville South. No biomass indices (e.g. from acoustic surveys) were available, but the composition data were adequate to rule out very high exploitation rates for Louisville Central in 1995 (when there was a spike in catches) and eliminate low values of B_0 and current stock status. The estimates of unfished and current

[10] Reference points for orange roughy have not been adopted by SPRFMO but New Zealand uses 20%B_0 as its "soft biomass limit", indicating that a formal, time-bound rebuilding plan is required. See the Harvest Strategy Standard for New Zealand Fisheries at https://fs.fish.govt.nz/Page.aspx?pk=113&dk=16543 and its operational guidelines at https://fs.fish.govt.nz/Doc/22847/Operational_Guidelines_for_HSS_rev_1_Jun_2011.pdf.ashx

biomass for the Louisville stocks remain uncertain but the new data have enabled more precise stock assessments. The new estimate of natural mortality (M) of 0.03 indicates the potential for lower yields per unit of biomass for these stocks compared with New Zealand stocks (where M~0.045 is used in assessments). Although stock status remains uncertain, the models suggest that Louisville Central is probably above 50%B_0 and Louisville North is probably above 30%B_0 (Table 13). There is a small possibility that Louisville South is below 20%B_0 but it is likely well above this level. This updated assessment gave comparable estimates of stock status and yield (calculated using the approach used in New Zealand) to the 2017 assessment for these stocks; consequently, the 8th meeting of the SPRFMO Commission agreed not to change the catch limit for the Louisville Ridge management units that was set at the 6th Commission meeting using the 2017 assessment.

Table 13 (after Cordue 2019): Estimates of initial biomass (B_0), current status (ss_{19}) and long-term yield for the three management units of orange roughy on the Louisville Ridge in 2019. Also given are the estimated probabilities (given the model assumptions) of the spawning stock being below 20%B_0 or above 30%B_0 in 2019.

	B_0 (000 t)		ss_{19} (%B_0)		Long term yield (t)		P(ss_{19}<	P(ss_{19}>
	Median	95% CI	Median	95% CI	Median	95% CI	20%B_0)	30%B_0)
Central	71	34–117	82	61–93	710	340–1 170	0.00	1.00
North	26	8–80	78	32–96	260	82–800	0.00	0.98
South	25	11–55	64	18–86	250	110–550	0.04	0.89
Total	122	53–252	–	–	1 220	530–2 520	–	–

The Southwest Challenger Plateau orange roughy stock straddles the New Zealand EEZ and the Westpac Bank area in the SPRFMO Convention Area. New Zealand has historically managed this fishery as a single biological stock, setting a domestic catch limit that applied to the New Zealand fleet across the whole range of the stock. The fishery in this area began in the 1980s and the first New Zealand catch limit in the area was set in 1986. New Zealand has completed a number of surveys and stock assessments of the area, to support the setting of catch limits for the full biological stock. The in-zone portion of the stock makes up New Zealand Quota Management Area ORH 7A, although New Zealand fishers have been required to report catch from the SPRFMO Convention Area against the domestic catch limit. The fishery was closed by New Zealand from 2000 to 2010 at which time it was re-opened with a total allowable commercial catch (TAC) of 500 t following a stock assessment that estimated there to be at least a 70% probability that the biomass had increased above New Zealand's "soft limit" of 20%B_0 (Ministry of Fisheries 2008a). The stock was assessed again in 2014, supported by trawl and acoustic surveys in 2010 and 2013 with the stock estimated to be well above the lower end of the New Zealand management target range of 30-50% B_0. The New Zealand total allowable commercial catch (TACC) was subsequently increased in 2014 to 1,600 tonnes.

The New Zealand bottom trawl footprint under CMM03-2018 before the significant changes in 2019 included two open blocks (of six within New Zealand's declared footprint) on the Westpac Bank in the SPRFMO Convention Area where the stock straddles the New Zealand EEZ. New Zealand vessels fishing in those two open blocks are required to report all catches against New Zealand's SPRFMO catch limit and also balance those catches with New Zealand Annual Catch Entitlement to ensure catches are accounted for within the New Zealand TAC for the whole stock.

In 2018, New Zealand undertook a combined trawl/acoustic survey and subsequently updated the stock assessment of the Southwest Challenger Plateau orange roughy stock. The stock assessment suggested the current biomass of the entire stock to be 47%B_0, and that a maximum catch of 2 448 t would maintain the biomass above 40%B_0 for the next 5 years (Cordue 2019b, SC7–DW-06). These estimates informed a review of New Zealand's domestic catch limit (Total Allowable Commercial Catch, TACC) for the ORH 7A management area and the New Zealand Minister of Fisheries decided to increase the TACC to from 1 600 to 2 058 t. Bock & Cryer (2019, SC7-DW-07) summarised the options presented to the New Zealand Minister of Fisheries and, based on its own consideration of these options, SPRFMO's Scientific Committee recommended to the Commission in its 2019 report that a catch limit for Westpac Bank could sustainably be set at a level up to 306 t, but that a catch limit of 258 t would represent a suitably precautionary approach. The SPRFMO catch limit for the Westpac Bank was increased from 200 t to 258 t in 2020.

SPRFMO CMM 03a-2019 was implemented in 2019 and sets catch limits based on stock assessment modelling and advice from the Scientific Committee for two groups of orange roughy management units. These catch limits are 1,140 t for the three Louisville Ridge management units combined, and 346 t for the three Tasman Sea management units combined.[11] For the Tasman Sea (which is where most of Australia's fishing has historically taken place), this catch limit has been established such that the limit could be safely taken from any of the three subunits without compromising the sustainability of any one subunit.

It should be noted that the results of the Cordue 2017 and 2019 assessments are conditional on the stock hypotheses being approximately correct and estimates of stock status have a high level of uncertainty for most management units. Nonetheless, catch limits derived from the assessment—particularly for the Tasman Sea—are likely to be highly precautionary. Additional work has been done to strengthen the assessments, including deriving age data from otoliths taken from fish in spawning aggregations and collecting acoustic estimates of aggregation biomass. Work is currently underway to update the assessments for the Tasman Sea management units.[2]

4.2.2.2 Alfonsino

4.2.2.2.1 Stock structure

Beryx splendens is a widely occurring benthopelagic species that aggregates around seamounts and features on the upper continental slope. It is likely that the majority of catches reported as '*Beryx* spp.' in SPRFMO are *Beryx splendens* although reported catches may also contain small amounts of *Beryx decadactylus*[12]. There have been taxonomic uncertainties within the *Beryx splendens* taxon (e.g. Hoarau and Borsa 2000) and evidence of extremely high intra-specific genetic diversity, even at small scales (Lévy-Hartmann et al. 2011).

FAO (2016) reviewed knowledge of alfonsino population structuring in the Pacific and identified a high level of complexity but a general lack of conclusive knowledge of distinct population

[11] The Tasman Sea management units include Lord Howe Rise, north-west Challenger Plateau and West Norfolk Ridge, but exclude the Westpac Bank on the south of the Challenger Plateau and the South Tasman Rise.

[12] New Zealand generally reports catches of *Beryx* spp. using the code ALF and this code is associated with the majority of alfonsino catches in the SPRFMO database; the FAO 3-alpha code for *Beryx splendens* is BYS.

structuring. Nonetheless, FAO (2016) presents two distinct populations relevant to the South Pacific; one for a New Caledonian population and another for a New Zealand population.

Hoarau and Borsa (2000) found evidence for two reproductively isolated sibling species (A and W) within the *Beryx splendens* taxon based on analysis of the gene composition of 250 alfonsino sampled from seamounts and continental margins in New Caledonia, New Zealand and southeast Australia and from the Northeast Atlantic. Hoarau and Borsa (2000) found no heterogeneity in the distribution of haplotype frequencies within either *B. splendens* species A or species W at the scale of New Caledonia and noted that three haplotypes from *B. splendens* sp. A in the Northeast Atlantic were also the three most common in the Southwest Pacific populations. This led to a conclusion that *B. splendens* sp. populations share a recent evolutionary history at the worldwide scale, which in turn implies genetic mixing at an interoceanic scale.

No information is available as to whether alfonsino is a single stock in New Zealand waters. Overseas data on alfonsino stock distributions suggest that New Zealand fish could form part of a widely distributed South Pacific stock (Fisheries New Zealand 2019). Horn & Massey (1989) found substantial differences in length frequency distributions between alfonsino from the Palliser Bank compared with those from other locations on the east coast of New Zealand's North Island, suggesting that there may be some age-specific migration occurring. Alekseev et al. (1986) suggested that *B. splendens* could comprise widespread populations in large oceanic eddy systems. FAO (2016) also noted that alfonsino might be contained within a large gyre system, or complex of gyres, that reach from the east coast of the North Island to the Louisville Ridge based on the presence of alfonsino on Louisville Ridge seamounts. If New Zealand alfonsino form part of such a system then the east coast North Island may be a non-reproductive zone where fish mature before leaving for a possible reproductive zone further east of the mainland (Horn & Massey 1989).

In summary, genetic studies have suggested a high level of interoceanic mixing but extremely high intra-specific genetic diversity. This may suggest that management units for alfonsino based on prevailing oceanographic currents and gyres, which may act to constrain certain populations to certain areas or influence reproductive connectivity, may be a sensible unit of assessment and management for this species. The evidence also suggests that such oceanographic dynamics may play an important role in the abundance and availability of alfonsino. It should be noted that there is very little new information on alfonsino stock structure in the South Pacific Ocean since 2000, and very limited genetic work. Given the advances in genetics since then, we may draw some very different conclusions about stock structure if more contemporary techniques were applied.

It is likely that alfonsino on northern Lord Howe Rise constitutes a straddling stock. Under the SPRFMO Convention, such stocks are subject to compatible management arrangements within EEZs and on the high seas.

4.2.2.2.2 Stock assessment and status

There is no stock assessment for alfonsino in SPRFMO and biomass status is unknown[13]. *Beryx* spp. (code ALF) is listed as the second most caught demersal fish species by volume (total ~807 t) for the

[13] A number of assessments exist for stocks that may straddle the Australian and NZ EEZs and the SPRFMO Convention area, e.g. Klaer 2013 for alfonsino in Australia's East Coast Deepwater Trawl Sector)

2014-2018 period and *Beryx* spp. comprised around 16% of the total catch of demersal species over the last 10 years (SPRFMO 2019).

4.2.2.2.3 Future workplan

The 7th meeting of the SPRFMO Scientific Committee agreed that a workplan to drive stock structure delineation efforts should be developed for *Beryx splendens* and presented to SC8 in 2020, but these efforts might be delayed.

4.2.3 Predominantly line fisheries

4.2.3.1 Bluenose/blue-eye trevalla (Hyperoglyphe antarctica)

4.2.3.1.1 Stock structure

A number of studies on population structuring of *Hyperoglyphe antarctica* have been undertaken (e.g. Horn 2003, Hindell et al. 2005, Robinson et al. 2008, Williams et al. 2017) which have relevance to SPRFMO. Earlier studies (e.g. Hindell et al. 2005, Robinson et al. 2008) indicated that genetic variation was not significant among Australian fishery regions; however, Williams et al. (2017) note that genetic homogeneity can be maintained over broad scales even where reproductive exchange and/or movement is limited. In these situations, genetically homogenous populations may be comprised of a number of subpopulations that differ in terms of growth rate, reproduction, size at maturity, fecundity, recruitment patterns, etc. (Williams et al. 2017), indicating that regional management at a subpopulation level may be important even despite genetic homogeneity.

Williams et al. (2017) used three lines of evidence—phenotypic variation in age and growth, otolith microchemistry and potential larval dispersal—and identified four geographically distinct subpopulations around southern and eastern Australia (West, South, East and Seamounts-Lord Howe). Three of these subpopulations (South, East and Seamounts-Lord Howe) were found to be interconnected through regional exchange of larvae (Williams et al. 2017). Larval dispersal modelling and other findings of this research suggest that the Seamounts-Lord Howe population is likely to straddle Australia's EEZ and SPRFMO.

Horn (2003) made inferences as to stock structure of *H. antarctica* off the north-east coast of New Zealand based on results of a detachable hook tagging programme and found that *H. antarctica* off the eastern coast of New Zealand between North Cape and Kaikōura probably comprise a single biological stock. Stock boundaries are unknown, but similarity in trends in catch and CPUE across fisheries occurring in each of the five New Zealand *H. antarctica* Quota Management Areas (QMAs) suggests the possibility that there may be a single *H. antarctica* stock across all these areas, or of some close relationship between stocks in these QMAs. Tagging studies have shown that *H. antarctica* are capable of extensive migration, i.e., from the Wairarapa coast to Kaikōura, Bay of Plenty, and North Cape (Horn 2003 in Fisheries New Zealand 2019).

Given knowledge of *H. antarctica* biology (i.e. long-lived, slow growth and late maturity), the characteristics of fishing for them (e.g. on and around seamounts), and the relatively significant catches compared to other SPRFMO demersal species, it may be prudent to prioritize the species for additional stock structure analyses in important SPRFMO fishing areas. There is evidence that targeting *Polyprion* spp. has replaced *H. antarctica* as a key focus of New Zealand line fisheries.

4.2.3.1.2 Status and/or catches

The stock status of *H. antarctica* in the SPRFMO Convention Area is unknown. The species has comprised around 3.5% of total SPRFMO demersal catches over the last 10 years (SPRFMO 2019). It was the third most caught demersal fish species by volume in SPRFMO during the 2014- 2018 period (259 t).

The eastern stock of the species is assessed domestically in Australia using standardized CPUE, which indicates biomass has varied over time, but between the relevant limit and target reference points (Haddon 2017). The species is assessed in New Zealand using a fully quantitative stock assessment. The Mean Posterior Distribution (MPD) estimates of stock size in 2016 was in the range of 17–27% B_0. Biomass was estimated to have declined continuously from the 1980s to 2011 and then to have either levelled off or increased slightly. Biomass has been below the default 40% B_0 target since around 2000 (Fisheries New Zealand 2018).

4.2.3.2 Hapuku, groper, wreckfish (Polyprion spp.)

4.2.3.2.1 Stock structure

Stock structure of *Polyprion oxygeneios* in Australian and New Zealand waters is unknown. The species has similar life history characteristics to *P. americanus* (long-lived, late age-at-maturity), which may suggest a broad population structure (Chick et al. 2018). Paul (2002) reviewed available data for New Zealand *Polyprion* spp. ('groper') and concluded that stock structure could not be described due to an absence of life history data.

4.2.3.2.2 Status and/or catches

Catches of *Polyprion* spp. (code HAU) in the SPRFMO database comprise the fourth most caught fish by volume (approx. 174 t) for the most recent five years (2014-2018). Catches of *P. americanus* (code WRF) also totalled an additional 77 t during this period.

Biomass status of *Polyprion* spp. in the SPRFMO Convention Area is unknown. In Australian waters, stock status for eastern Australian state-managed stocks of *P. oxygeneios* (New South Wales, Queensland and South Australia) is 'undefined' and the Commonwealth-managed stock is classified as 'depleting' (Chick et al. 2018). No estimates of biomass are available for New Zealand *Polyprion* spp. stocks (Fisheries New Zealand 2018).

4.2.3.3 Tarakihi/Jackass morwong (Nemadactylus macropterus)

4.2.3.3.1 Stock structure

Nemadactylus macropterus is a widely distributed species occurring around the southern half of Australia, New Zealand, southern South America, southern Africa and some islands in the Atlantic and Indian oceans. Genetic studies have shown no evidence of separate stocks in Australian waters, but found that Australian and New Zealand stocks are genetically distinct (Elliott and Ward 1994). Otolith microchemistry studies have indicated differences between Tasmanian and New South Wales/Victorian fish (Thresher et al. 1994) and larvae from New South Wales/Victoria have significantly different otolith microstructure to Tasmanian caught larvae (Bruce et al. 2001), but it is unclear if these differences indicate separate stocks. Bruce et al. (2001) found that the dispersal of long-lived larval stages is linked to offshore mesoscale oceanographic processes off south-eastern Australia.

N. macropterus stocks around New Zealand have been identified as having a long pelagic larval phase, large scale movements from tagging (e.g. Annala 1987) and a lack of genetic isolation (Annala et al. 2000). Fisheries New Zealand (2019) identifies considerable connectivity of *N. macropterus* along the east coast of the South and North Islands. The current stock hypothesis is that the Canterbury Bight/Pegasus Bay area represents the main nursery area for the eastern stock unit. At the onset of maturity, a proportion of the fish migrate northwards to recruit to the East Cape area and, subsequently, the Bay of Plenty and east Northland areas. This hypothesis is further supported by the northward movement of tagged fish from the Kaikōura coast to the Wairarapa, East Cape and Bay of Plenty areas.

It is worth noting that the recent advances in genetic approaches has enhanced the ability to evaluate population structure and may lead us to different conclusions than these previous studies.

4.2.3.3.2 Status and/or catches

Nemadactylus spp. (mostly *N. macropterus*) have comprised around 2% of demersal catches in the SPRFMO Convention Area over the last 10 years (SPRFMO 2019). Approximately 125 t was caught in SPRFMO bottom fisheries during 2014–2018. There have been some concerns around stock status in both Australia (e.g. Stobutzki et al. 2009) and New Zealand (Fisheries New Zealand 2018) in the past, but the Australian eastern stock has since recovered (Tuck et al. 2015). The New Zealand east coast stock (management units TAR 1E, TAR 2, TAR 3 and parts of TAR 7) was recently assessed to be below 20%B_0 and experiencing overfishing (Fisheries New Zealand 2020).

4.2.3.4 Yellowtail kingfish (Seriola lalandi)

4.2.3.4.1 Stock structure

Seriola lanandi is a highly mobile pelagic species with a widespread distribution that extends throughout temperate waters of the Atlantic, Pacific and Indian Oceans (Nugroho et al. 2001). Genetic analyses have shown the population off Western Australia to be genetically distinct from the *S. lalandi* found on the eastern and southern Australian coasts or within New Zealand waters (Miller-Ezzy et al. 2011). These findings confirm results from previous analyses that found no evidence of genetic differentiation between New Zealand and New South Wales *S. lalandi* (Smith et al. 1991) and results of tagging studies which show that *S. lalandi* undergo movements between Australia and New Zealand waters (Gillanders et al. 2001).

For New Zealand *S. lalandi*, a study based on meristic characteristics and parasite loads suggests two stocks of kingfish off the west and east coasts (Fisheries New Zealand 2019). These stocks are contained within the Tasman current on the west coast and the east Auckland current and east Cape current on the east coast, with little mixing between them (Fisheries New Zealand 2019). Tagging results suggest that most adult kingfish do not move outside local areas, with many tag returns close to the release site. However, some tagged kingfish have been found to move very long distances. For example, New Zealand Fisheries (2019) note reports of New Zealand tagged *S. lalandi* being caught in Australian waters and Australian tagged kingfish being recaptured in New Zealand waters.

4.2.3.4.2 Status and/or catches

Seriola spp. (mostly *S. lalandi*) have comprised around 1.5% of total SPRFMO demersal catches over the last 10 years (SPRFMO 2019). Catches from 2014-2018 totalled approximately 154 t.

Status of the eastern Australian stock is uncertain (Hughes et al. 2018). Catches in the SPRFMO Convention Area by Australian vessels in 2017 (~35 t) comprised a significant proportion of total mortality (~120 t in 2017) from commercial fishing by Australian vessels for this stock. Various indicators (CPUE, spawning potential ratio, tag recaptures and F/M estimates) suggest that the eastern Australian stock is depleted in at least part of its range (Hughes et al. 2018). For New Zealand stocks, CPUE in a variety of commercial and recreational fisheries increased considerably between 2006 to 2016 and has been relatively stable at a high level since. Overfishing is assessed to be unlikely (Fisheries New Zealand 2020). In New Zealand waters kingfish is mostly taken as bycatch while fishing for other species (Fisheries New Zealand 2018). Recreational catches in Australia and New Zealand comprise a significant proportion of overall catches.

*4.2.3.5 Toothfish exploratory fisheries (*Antarctic toothfish, *Dissostichus mawsoni*, or Patagonian toothfish, *Dissostichus eleginoides)*

Dissostichus (the toothfish) is a genus of notothen found in the Southern Hemisphere. Both Patagonian and Antarctic toothfish are distributed circumpolarly near the Antarctic, at depths between 600 and 1900 m. Both species are long-lived (up to 50 years), relatively slow growing (but reach maximum sizes exceeding 100 kg) and are benthopelagic as adults.

An exploratory bottom longline fishery started for New Zealand in 2016. This exploratory fishery used a stepwise process of ground location, ground observation for fishing feasibility, structured test fishing, and ultimately fishing in accordance with annual precautionary catch limits (SPRFMO SC03, subsequently approved with CMM 4.14). Other countries have since been granted approvals for toothfish exploratory fisheries: the EU (CMM 14c-2019, limited to 45 tonnes per year) and Chile (CMM 14d-2020, limited to 54 tonnes each year). A minimum tagging rate of three fish of each *Dissostichus* species per greenweight (live weight) tonne is implemented in these exploratory fisheries.

Toothfish exploratory fisheries are limited in spatial extent (with areas identified in the CMM for each country) and follow management measures consistent with relevant measures in force in the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Area (see CM 41-10, 2014). Bycatch species include: macrourids (*Macrourus whitsoni*, with probably lesser amounts of *M. holotrachus* and *M. carinatus*); violet cod (*Antimora rostrate)*; other morid cods; and low numbers of skates, typically *Amblyraja georgiana*. A move-on rule applies if deepwater shark bycatch exceeds 250 kg in any cluster of lines.

4.2.3.5.1 Status and/or catches

An annual retention limit (greenweight) of toothfish catch, regardless of species, is in force for this exploratory fishery. Fish that are tagged and returned alive to the sea are not counted against this limit. Catch and effort are monitored on a shot-by-shot basis and fishing operations cease once the limit is reached. The catch limit was increased from the initial 30 tonnes in 2016 and 2017 to 140 tonnes under the current measure (with additional vessel and stratum catch limits, CMM 14a-2019).

No results have yet been reported to the Scientific Committee from exploratory fisheries for toothfish by the European Union (EU) and Chile. The stock hypotheses and status of toothfish stocks in the SPRFMO Convention Area are still under investigation.

4.2.4 Priority species for stock structure delineation studies

Based on the outcomes of the 7th meeting of the SPRFMO Scientific Committee (SC-07) (and following consideration of SC-07-DW09 and the teleosts ecological risk assessment (discussed below in Section 4.2.5), SC-07 noted that stock structure delineation studies would be useful in the short to medium-term for *Hoplostethus atlanticus* and *Beryx splendens*, and agreed that a workplan to drive stock structure delineation efforts should be developed for each of these species and presented to the 8th meeting of the Scientific Committee in 2020[14]. SC-07 further noted that stock structure delineation studies could be useful in the medium to longer-term for the following species: *Hyperoglyphe antarctica*, *Polyprion oxygeneios* and *P. americanus*, *Nemadactylus macropterus*, *Seriola lalandi,* emperors (Lethrinidae) and snappers (Lutjanidae, *Etelis* spp.), and agreed that a workplan to drive stock structure delineation efforts for these species should be developed and presented to the 9th meeting of the Scientific Committee in 2021. SC-07 agreed that fish species not included above are caught in SPRFMO fisheries in such low volumes that stock structure delineation studies are a very low priority.

4.2.5 Ecological risk assessment for SPRFMO demersal teleost species

A series of ecological risk assessments (e.g. Georgeson et al. 2019, Georgeson et al. 2020) have been undertaken as part of the requirement for the SPRFMO Scientific Committee to provide advice to the Commission on a large number of target and non-target species. These semi-quantitative assessments are useful for rapidly assessing the relative vulnerability of a large number of species to fishing activities, particularly in data-limited fisheries.

The Georgeson et al. (2019) assessment used Productivity-Susceptibility Analysis (PSA) and Sustainability Assessment for Fishing Effects (SAFE) tools to assess the vulnerability of 159 teleost species to demersal trawl, midwater trawl and demersal longline gears in the SPRFMO Convention Area. This assessment is described in this section as it contains a large number of targeted and byproduct species, as well as the large number of species that are not commercially important. Methods are described in the relevant Scientific Committee papers and publications and are not repeated here.

For this assessment, PSA was run primarily to check if vulnerability rankings using the PSA and SAFE tools were comparable. Running both methods side-by-side enhanced the ability to identify potential false negatives and false positives. Given a number of methodological limitations of PSA and the fact that it is, by design, extremely precautionary, more emphasis should be given to the SAFE results. As expected, the PSA results from the Georgeson et al. (2019) assessment resulted in a large number of probable false positives (species incorrectly found to be at 'high risk'). This was largely due to the PSA assuming that species may still be at risk to fishing even if they do not overlap with fishing effort, whereas the SAFE gives a true zero (i.e. zero overlap between species distribution and fishing effort results in zero risk).

[14] Note that this task has been delayed due to the COVID-19 pandemic requiring the SC workplan for 2020 to be reduced.

It is important to note that these assessments were undertaken to prioritise species that may warrant additional attention, and not to provide absolute estimate of true risk. Consequently, the relative risk and vulnerability scores described herein should be viewed in the context of the understanding of the characteristics of SPRFMO fisheries, including the catches of each species that have been taken over time; the life history traits and biology of each species; and the additional work underway to respond to the prioritisation of certain species based on the results.

4.2.5.1 Productivity-Susceptibility Analysis (PSA)

Given the caveats describe above, we do not describe PSA results in detail here. A subset of species assessed to be at high PSA vulnerability that were also found to be at high or extreme vulnerability in the SAFE assessment for demersal trawl, midwater trawl and demersal longline gears are shown in Table 16, and PSA scores for species of particular interest or concern are also shown in Table 16.

Of the 159 teleost species assessed, 23 were classified in this assessment as PSA data deficient (i.e. missing three or more productivity and/or susceptibility attributes). Many of these data deficient species are classified as high vulnerability in the PSA (Figure 33) and most are likely to be false positives as catch records indicate they rarely interact with the fishery. They have been proposed for inclusion into Tier 3 of the SPRFMO stock assessment framework (no further assessment required).

4.2.5.2 Sustainability Assessment for Fishing Effects (SAFE)

The SAFE tool provides estimates of F_{curr} in relation to F-based reference points to determine a species' vulnerability to fishing. The tool uses three parameters: spatial overlap of fishing effort with a species' distribution, catchability (based on size- and behaviour-dependent catch rate and habitat-dependent encounterability) and post capture mortality to determine F_{curr} (Zhou et al. 2012). The SAFE tool relates life-history traits that inform natural mortality, growth rate and intrinsic rate of increase to biological reference points derived from the literature. The result is that F_{curr} can be compared with F-based reference points F_{msm}, F_{lim} and F_{crash}.

The SAFE classified several species as high ($F>F_{lim}$) or extreme ($F>F_{crash}$) vulnerability in the South Pacific Ocean. Seven species were vulnerable to demersal trawl, seven species to midwater trawl and 14 species to demersal longline fishing gears (Figure 33 and Table 14). Teleost species classified as high or extreme vulnerability across all fisheries (Figure 33 and Table 14) in the South Pacific Ocean included silver spinyfin (*Diretmus argenteus*), giant oarfish *(Regalecus glesne),* thorny tinselfish *(Grammicolepis brachiusculus),* Parin's spinyfin *(Diretmichthys parini*), narrownecked oceanic eel *(Derichthys serpentinus),* basketwork eel *(Diastobranchus capensis)* and barbeled dragonfish (*Melanostomias valdiviae).* All of these were data deficient species for which F_{msm}, F_{lim} and F_{crash} could not be calculated because of a lack of biological data to inform the productivity attributes. Out of the 159 species assessed, two additional species (*Ostracion cubicus* and *Triodon macropterus*) were missing data needed to calculate F-based reference points, meaning a total of nine species are not present in Figure 33.

The PSA and SAFE vulnerability scores for 150 teleost species are compared in Figure 33, with a subset of species assessed to be at high or extreme SAFE vulnerability and corresponding PSA vulnerability shown in Table 14. The results indicate good concurrence between the PSA and SAFE results for most species categorised as being at high or extreme vulnerability in the SAFE. However, around half of these species at the upper end of the risk spectrum were data deficient (see Table 14), resulting in higher vulnerability scores in both the PSA and SAFE. Many species classified as high or medium vulnerability by the PSA were ranked as low vulnerability by the SAFE (Table 14 and Figure 33) and many of these are very likely to be false positives (i.e. species assessed to be at high risk that are probably low risk in reality). False positives in the PSA are expected and are a design feature of the method that assigns higher rankings to species with less information. False negatives (i.e. species assessed to be low risk that may be high risk in reality), on the other hand, are often more difficult to identify. Running PSA and SAFE together provides enhanced ability to identify potential false positives and false negatives. There are some examples of species being ranked higher in the SAFE than in the PSA (e.g. *Nemadactylus macropterus* in the assessment for demersal longline gears, which was ranked medium in the PSA and high in the SAFE and may indicate a potential false negative in the PSA). Evidence of potential false positives at the medium and upper end of the PSA vulnerability rankings, include, for example, *Bassanago hirsutus* (PSA high, SAFE low), *Helicolenus percoides* (PSA medium, SAFE low) and *Rexea solandri* (PSA medium, SAFE low) for demersal trawl and midwater trawl gears (Table 14).

For demersal trawl gears, data-robust species assessed by the SAFE to be at medium vulnerability were *Bassanago hirsutus* and *Hoplostethus atlanticus*. For midwater trawl gears, data-robust species assessed by the SAFE to be at medium vulnerability were *Bassanago hirsutus* and *Pseudopentaceros richardsoni*.

For longline gears, data-robust species assessed to be at high vulnerability were *Bassanago hirsutus*, *Helicolenus percoides*, *Epigonus telescopus*, *Nemadactylus macropterus*, *Rexea solandri* and data-robust species assessed to be at extreme vulnerability were *Polyprion oxygeneios* and *Hyperoglyphe antarctica* (Table 14).

4.2.5.3 Catch of assessed species in the SPRFMO Convention Area

Table 15 provides details of the top ten species (or groups of species) caught in the SPRFMO Convention Area between 2012 and 2016[15] and their respective vulnerability ranking from both the PSA and SAFE. Of the top ten species, four (*Hyperoglyphe antarctica, Polyprion spp., Nemadactylus macropterus* and *Epigonus telescopus*[16]) were classified as high or extreme vulnerability in the SAFE (all in the assessment for demersal longline gears) (Table 15).

[15] This corresponds to the Australian and New Zealand effort dataset used in the ERA

[16] Note that this species was caught exclusively by demersal trawl gears during the 2012-2016 period, indicating a probable false positive in the demersal longline SAFE assessment.

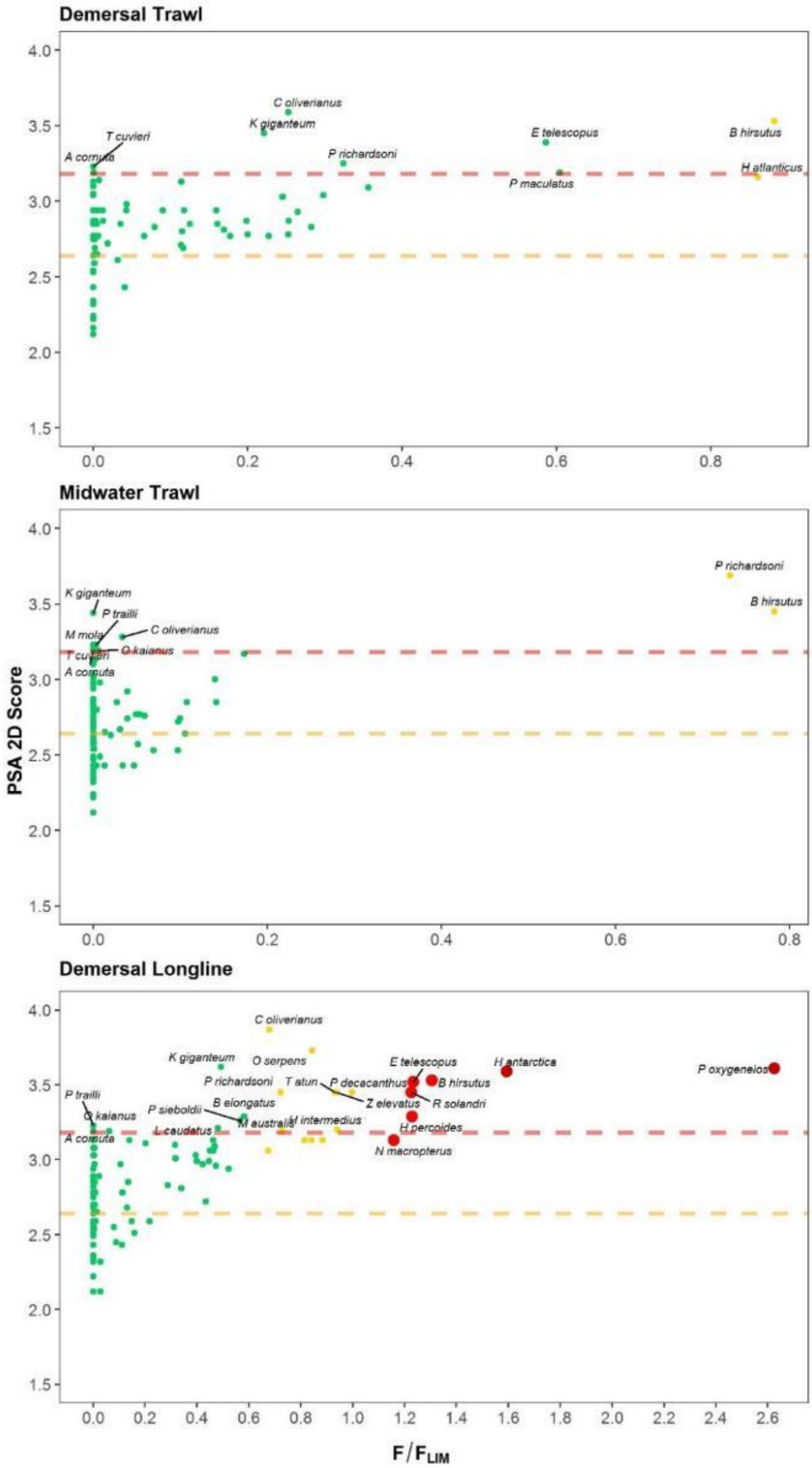


Figure 33: Relationship between SAFE and PSA results for 150 teleost species thought to occur and have the potential to interact with demersal, midwater trawl and demersal longline gears in the SPRFMO Convention Area. Points are coloured dark red, light red, yellow and green to signify species classified as extreme, high, medium and low vulnerability respectively in the SAFE. Dashed red and orange lines represent PSA risk high and medium score boundaries. Nine species could not be shown on the panels as F-based reference points could not be calculated.

Table 14. Matrix of high and extreme vulnerability teleost species from the SAFE and their respective PSA score for each fishery along with 2012-2016 catch totals in the SPRFMO Convention Area. Proportion of catch by gear type for the last 5 years (2014-2018) is also included to indicate the main fishery catching each species.

Teleost species	Data deficient in PSA	2012-2016 fishing activity (kg)	Proportion of catch (last five years 2014-2018) by gear type	Demersal Trawl		Midwater Trawl		Demersal Longline	
				PSA	SAFE	PSA	SAFE	PSA	SAFE
Diretmus argenteus (DD)	Yes	0	N/A	High	Extreme	High	Extreme	High	Extreme
Regalecus glesne (DD)	Yes	6	100% Demersal Trawl	Medium	Extreme	Medium	Extreme	Medium	Extreme
Grammicolepis brachiusculus (DD)	Yes	N/A **a**	N/A	High	Extreme	High	Extreme	High	Extreme
Diretmichthys parini (DD)	Yes	0	N/A	Medium	Extreme	Medium	Extreme	Medium	Extreme
Derichthys serpentinus (DD)	Yes	N/A **a**	N/A	High	Extreme	High	Extreme	High	Extreme
Diastobranchus capensis (DD)	No	295	100% Demersal Trawl	High	Extreme	Medium	Extreme	Medium	Extreme
Melanostomias valdiviae (DD)	Yes	N/A **a**	N/A	High	Extreme	Medium	Extreme	Medium	Extreme
Polyprion oxygeneios	No	12,366[17]	72% Longline 28% Demersal Trawl	Medium	Low	Medium	Low	High	Extreme
Hyperoglyphe antarctica	No	358,260	92% Longline 5% Demersal Trawl 2% Midwater Trawl	Medium	Low	Medium	Low	High	Extreme
Bassanago hirsutus	No	930	100% Longline	High	Medium	High	Medium	High	High
Helicolenus percoides	No	26,238	99% Longline 1% Demersal Trawl	Medium	Low	Medium	Low	High	High
Epigonus telescopus	No	71,484	100% Demersal Trawl	High	Low	Medium	Low	High	High
Rexea solandri	No	2,472	100% Longline	Medium	Low	Medium	Low	High	High
Nemadactylus macropterus	No	162,591	100% Longline	Low	Low	Medium	Low	Medium	High

Notes: DD = Data deficient in SAFE, defined as species for which F-based reference points were unable to be calculated. N/A = Not applicable. **a** Interactions with these species are recorded in the SPRFMO database but there is no catch data associated with them.

[17] Note that 192,844 kg of '*Polyprion* spp.' is recorded in the SPRFMO database for this period.

Table 15. Matrix of top 10 species (or species groups) by catch volume based on 2012-2016 catch and their respective PSA and SAFE vulnerability score for each gear type assessed in the SPRFMO Convention Area.

Teleost species/group	2012-2016 fishing activity (kg)	Proportion of catch (last five years 2014-2018) by gear type	Specific species	Demersal Trawl		Midwater Trawl		Demersal Longline	
				PSA	SAFE	PSA	SAFE	PSA	SAFE
Hoplostethus atlanticus	5,427,208	100% Demersal Trawl		Medium	Medium	Medium	Low	Medium	Low
*Beryx spp.**	767,106	68% Demersal Trawl 31% Midwater Trawl <1% Longline	*Beryx splendens*	Medium	Low	Low	Low	Medium	Low
			Beryx decadactylus	Medium	Low	Medium	Low	Medium	Low
Hyperoglyphe antarctica	358,260	92% Longline 5% Demersal Trawl 2% Midwater Trawl		Medium	Low	Medium	Low	High	Extreme
Polyprion spp.	274,172	98% Longline 2% Demersal Trawl	*Polyprion americanus*	Medium	Low	Medium	Low	Medium	Low
			Polyprion oxygeneios	Medium	Low	Medium	Low	High	Extreme
Seriola lalandi	171,886	100% Longline		Medium	Low	Medium	Low	Medium	Low
Nemadactylus macropterus	162,591	100% Longline		Low	Low	Medium	Low	Medium	High
*Macrourus spp^*	97,848	99% Demersal Trawl <1% Longline	*Macrourus carinatus*	Medium	Low	Medium	Low	Medium	Low
			Macrourus whitsoni	Medium	Low	Low	Low	Low	Low
			Macruronus novaezelandiae	Medium	Low	Medium	Low	Medium	Low
Pseudopentaceros richardsoni	80,607	79% Demersal Trawl 14% Midwater Trawl 7% Longline		High	Low	High	Medium	High	Medium
Epigonus telescopus	71,484	100% Demersal Trawl		High	Low	Medium	Low	High	High
Neocyttus rhomboidalis	64,373	100% Demersal Trawl		Medium	Low	Medium	Low	Medium	Low

* Catch total is a combination of *Beryx spp., Beryx splendens and Beryx decadactylus* from the SPRMFO database. *Beryx spp*. is assumed to comprise mostly *Beryx splendens*

^ Catch total is a combination of *Macrourus spp*, *Macruronus novaezelandiae*, *Macrouridae*, *Macrourus whitsoni* and *Macrourus holotrachys* from the SPRFMO database

Table 16. Species proposed for further attention and notes on categorisation into Tier 1 or Tier 2 of the SPRFMO stock **assessment framework**

Species name	Common Name	Main gear type	SAFE risk for main gear type	PSA risk for main gear type	Catch (kgs) 2012-2016	Catch (kgs) 2014-2018	% Longline (14-18)	% Demersal Trawl (14-18)	% Midwater Trawl (14-18)	Notes
Hoplostethus atlanticus	Orange Roughy	Demersal Trawl	Medium	Medium	5,427,208	5,862,492	0.0%	100.0%	0.0%	Already regarded as a Tier 1/2 species
Epigonus telescopus	Black Deepsea Cardinalfish	Demersal Trawl	Low	High	71,484	74,440	0.0%	100.0%	0.0%	Low SAFE ranking and relatively low catches may indicate this species could be moved to Tier 3 but may require precautionary monitoring and/or management measures. Ability to apply non-standard assessment approaches unlikely.
Pseudopentaceros richardsoni	Pelagic Armourhead	Demersal Trawl	Low	High	80,607	46,061	7.1%	78.7%	14.2%	Medium SAFE ranking for midwater trawl. Relatively low catches may indicate this species could be moved to Tier 3 but may require precautionary monitoring and/or management measures. Ability to apply non-standard assessment approaches unlikely.
Beryx splendens	Alfonsino	Demersal Trawl (also MWT)	Low	Medium	244,018	3,689*	8.9%	91.1%	0.0%	*Additional 807,154 kgs of *Beryx spp.* caught between 2014-2018 Historically taken in relatively significant proportions using midwater trawl gears. Proposed for retention as Tier 1/2 species.
Mora moro	Ribaldo	Demersal Trawl	Low	Medium	52,160	100,945*	10.1%	89.9%	0.0%	*Additional 3,627 kgs of *Moridae spp.* caught between 2014-2018. Low SAFE ranking and relatively low catches may indicate this species could be moved to Tier 3 but may require precautionary monitoring and/or management measures. Ability to apply non-standard assessment approaches unlikely.
Neocyttus rhomboidalis	Spikey Oreodory	Demersal Trawl	Low	Medium	64,373	112,697	0.0%	100.0%	0.0%	Low SAFE ranking and relatively low catches may indicate this species could be moved to Tier 3 but may require precautionary monitoring and/or management measures. Ability to apply non-standard assessment approaches unlikely.
Polyprion oxygeneios	Hapuku	Longline	Extreme	High	12,366	10,408*	72.3%	27.7%	0.0%	*Additional 173,552 kgs of *Polyprion spp*. caught between 2014-2018. ERA rankings and relatively significant catch volumes suggest *Polyprion* spp. should be retained as Tier 2 species.
Hyperoglyphe antarctica	Blue-Eye Trevalla	Longline	Extreme	High	358,260	258,875	92.3%	5.5%	2.2%	ERA rankings and relatively significant catch volumes suggest *H. antarctica* should be retained as Tier 2 species.

Species name	Common Name	Main gear type	SAFE risk for main gear type	PSA risk for main gear type	Catch (kgs) 2012-2016	Catch (kgs) 2014-2018	% Longline (14-18)	% Demersal Trawl (14-18)	% Midwater Trawl (14-18)	Notes
Bassanago hirsutus	Deepsea Conger	Longline	High	High	930	930	100.0%	0.0%	0.0%	Negligible catches but ranked as high vulnerability to longline. Proposed to be moved to Tier 3 but may require monitoring.
Helicolenus percoides	Reef Ocean Perch	Longline	High	High	26,238	20,057	98.6%	1.4%	0.0%	Relatively low catch volumes. Proposed to be moved to Tier 3 but may require monitoring.
Epigonus telescopus	Black Deepsea Cardinalfish	Longline	High*	High	71,484	74,440	0.0%	100.0%	0.0%	*Ranked as high vulnerability in longline but caught exclusively in trawl during 2014-2018 period. May require monitoring.
Rexea solandri	Gemfish	Longline	High	High	2,472	2,222	100.0%	0.0%	0.0%	Relatively low catch volumes. Proposed to be moved to Tier 3 but may require monitoring.
Nemadactylus macropterus	Jackass Morwong	Longline	High	Medium	162,591	124,450*	100.0%	0.0%	0.0%	*Additional 45,656 kgs of *Nemadactylus spp*. caught between 2014-2018. Historically significant as a target species in LL fishery. Proposed to be retained at Tier 2 although ability to apply non-standard assessment approaches may be unlikely.
Seriola lalandi	Yellowtail Kingfish	Longline	Low	Medium	171,886	153,737	100.0%	0.0%	0.0%	Low SAFE ranking but of significance as a retained species. Ability to assess using non-standard assessment may be unlikely; thus, species could be moved to Tier 3 but may require catch triggers and monitoring.
Etelis coruscans	Flame Snapper	Longline	Low	Medium	41,039	61,528	100.0%	0.0%	0.0%	Low SAFE ranking but of significance as a retained species. Ability to assess using non-standard assessment may be unlikely; thus, species could be moved to Tier 3 but may require catch triggers and monitoring.
Polyprion americanus	Bass Groper	Longline	Low	Medium	68,962	76,739*	99.9%	0.1%	0.0%	*Additional 173,552 kgs of *Polyprion spp*. caught between 2014-2018. Other comments as per *P. oxygeneios*.
Lethrinus miniatus	Redthroat Emperor	Longline	Low	Low	58,330	83,734	100.0%	0.0%	0.0%	Low SAFE ranking but of significance as a retained species. Ability to assess using non-standard assessment may be unlikely; thus, species could be moved to Tier 3 but may require catch triggers and monitoring.

4.2.5.4 Discussion of teleost ERA results

The results of the SPRFMO teleosts ERA indicate that a number of demersal teleost species are potentially vulnerable to demersal trawl, midwater trawl and demersal longline fishing gears in the SPRFMO Convention Area. The results, when combined with information on catches and understanding of species' biological and life history characteristics, have been used to categorise species into the SPRFMO assessment framework. The intention is to continue using these results to aid prioritisation of species for additional data collection, research, assessment or management measures.

The results from the SAFE assessment for demersal and midwater trawl gears were somewhat surprising due to the low number of data-robust species being assessed at high vulnerability compared to demersal longline gears. Furthermore, low productivity species such as *Hoplostethus atlanticus* (orange roughy) that are targeted by the trawl fisheries and that we therefore might expect to be at the upper end of the vulnerability spectrum were assessed to be at medium vulnerability in both the PSA and SAFE. This is driven by a combination of the productivity and susceptibility attributes and how these correlate to the overall PSA and SAFE scores. To use *Hoplostethus atlanticus* as an example, out of all data-robust species, it ranked highest in terms of overall susceptibility in the PSA (i.e. AxExSxPCM), indicating that the productivity score is driving the overall vulnerability ranking down. Analysis of its individual productivity attributes reveal that the method is ranking *Hoplostethus atlanticus* as a moderately productive species. This is due to the influence of the individual productivity attributes for which *Hoplostethus atlanticus* is given a low vulnerability score (i.e. fecundity, average maximum size, average size at maturity and reproductive strategy are scored a 1), despite being given a high vulnerability score for the remaining productivity attributes used in this PSA (i.e. average age at maturity, average maximum age and trophic level are scored a 3).

The assumption that each individual productivity attribute provides a theoretically equal contribution to the overall productivity score has been challenged by Hordyk and Carruthers (2018), with their study showing a complex non-linear relationship between individual attributes and over-parameterisation caused by irrelevant or correlated attributes. In a statistical exploration of productivity attributes Griffiths et al. (2017) showed a number of productivity attributes were redundant for species assessed in a purse seine fishery in the Eastern Pacific Ocean, with a clear correlation between attributes such as age at maturity and maximum age. They postulated that the use of these redundant attributes would create an implicit weighting and positive bias in productivity scores, leading to an overestimation of species productivity and underestimation of the effects of fishing.

Consequently, the example of *Hoplostethus atlanticus*, despite being somewhat 'surprising', is not unexpected as the original Hobday et al. (2011) attributes and risk cut-off scores were based on a large database of teleosts and chondrichthyans with a very broad productivity range, with an intention to allow assessment and differentiation of the relative vulnerability of very low productivity (e.g. deepwater chondrichthyans) and very high productivity (e.g. small pelagic) species.

Such an example may highlight a key limitation of ERA and suggests that: 1) where possible, species' vulnerability rankings should be considered in the context of catches by gear type and our understanding of species' biological and life history attributes; 2) relative vulnerability (within both the PSA and SAFE) is more informative than absolute vulnerability based on the limitations of the methodology when applied in this context; and 3) species overall vulnerability rankings in this assessment will likely be more sensitive to susceptibility attributes, in particular availability and encounterability, than to productivity attributes.

The results for trawl gears indicate that careful attention should be given to those species assessed to be at medium vulnerability in the SAFE assessment (i.e. not just those assessed as high or extreme vulnerability). Species ranked as medium vulnerability in the SAFE include *Hoplostethus atlanticus* and *Bassanago hirsutus* for demersal trawl, and *Pseudopentaceros richardsoni* and *Bassanago hirsutus* for midwater trawl. In the context of available SPRFMO catch data, <1 t of catch has been reported for *Bassanago hirsutus* (deepsea conger) since 1990, and consequently this species may not warrant further attention. Conversely, ~83 t was reported for *Pseudopentaceros richardsoni* using predominantly demersal trawl gears between 2012 and 2016, and 46 t was reported as caught between 2014 and 2018, which may indicate that further attention is warranted. This example highlights key challenge of interpreting these ERA results in that there are many other species or species groupings that are not assessed to be at high vulnerability to trawl gears but may be caught in relatively high volumes, such as *Beryx* spp., *Macrourus* spp. and *Oreosomatidae*, that may warrant additional attention and where more quantitative assessment and/or measures may be necessary to avoid risks of overexploitation.

In summary, for demersal and midwater trawl gears, the results of the Georgeson et al. (2019) assessment in conjunction with information on SPRFMO catch levels and existing stock assessments suggest that current efforts to assess and manage *Hoplostethus atlanticus* are appropriate. Despite *Beryx splendens* not being assessed to be highly vulnerable to trawl gears in either the PSA or SAFE, we suggest that further research into stock structure delineation (see SC7-DW09) and more quantitative assessment may be appropriate given the high level of catches relative to other demersal teleosts and the fact that they are a target species.

For demersal longline gears, the results indicate a relatively high number of species assessed to be at the upper end of the PSA and SAFE vulnerability spectrum compared to the trawl gears. For data robust species, this is likely being driven by relatively high scores for two susceptibility attributes: availability and encounterability. The authors of this study did not have access to the confidential fine-scale spatial data to investigate the contribution of the availability attribute, but for the encounterability attribute—which is informed by the level of overlap between the gear depths and core depth range of each species—it is likely that a shallower minimum depth for demersal longline gears relative to trawl gears is contributing to the higher number of species assessed to be at the upper end of the vulnerability spectrum. This is because the gear depth data that informs scoring of this attribute will include the core depth range of more species that live in shallower habitats. This could be explored further and confirmed in future analyses.

Our results suggest that there are several species assessed to be vulnerable to longline gears that should be prioritised for further research and/or assessment (see, e.g. SC-07-DW-09). Of these, *Hyperoglyphe antarctica*, *Polyprion* spp. and *Nemadactylus* spp. are of particular interest as they comprise key target stocks and are assessed to be at high or extreme vulnerability to longline gears. Several species are caught in relatively large volumes in the demersal longline fishery that may warrant further attention based on knowledge of catches, productivity, targeting characteristics and/or other information, including *Seriola lalandi*, *Lethrinus miniatus* and *Etelis coruscans*.

For other species caught in the demersal longline fisheries, including those assessed as medium vulnerability in the SAFE assessment, catches may be deemed to be so low that there is unlikely to be a measurable influence on biomass.

4.2.5.5 *Outcomes from the teleosts ERA*

In response to the ERA for SPRFMO teleosts, the 7th meeting of the Scientific Committee (SC-07; SPRFMO 2019) agreed that species listed in Table 16 could be considered for additional management measures and/or research, enhanced data collection, precautionary catch triggers and monitoring, or stock structure delineation studies, and that attempts are continued to categorise these species into Tier 1 or Tier 2 of the SPRFMO assessment framework. SC-07 also noted that species listed at Appendix B have been proposed for categorisation into Tier 3 of the SPRFMO assessment framework (i.e. no further assessment required).

4.3 INTERACTIONS WITH MARINE MAMMALS, REPTILES, SEABIRDS AND OTHER SPECIES OF CONCERN

4.3.1 Importance of interactions with marine mammals, seabirds, reptiles and other species of concern

Some marine mammals, seabirds, reptiles and other species of concern are either experiencing reductions in population size and face a high risk of extinction in the wild or are likely to be threatened in the near future (IUCN 2020). Because many of these species have extensive at-sea distributions, incidental mortality (bycatch) in pelagic and demersal longline and trawl fisheries can pose a significant species-level threat. For example, fisheries bycatch has been identified as one of the major threats to seabirds (Dias et al. 2019), which are one of the most threatened groups of birds globally (Croxall et al. 2012). Vessels participating in SPRFMO bottom line and trawl fisheries sometimes catch mammals, seabirds, reptiles and other species of concern. The objective of CMM03-2020 and CMM 03a-2020 requires an ecosystem approach to managing bottom fishing that ensures the long-term conservation of non-target and associated or dependent species (defined in the measure as marine mammals, seabirds, reptiles (turtles) (as referenced in Article 1, para f (iv) of the Convention) and other species of concern (as defined in Annex 14 of CMM 02-2020 (Data standards) and presented in Table 17). It requires vessels undertaking bottom fishing to implement existing CMMs on seabird bycatch mitigation (CMM 09-2017) and data standards (CMM 02-2020). It also seeks specific advice from the Scientific Committee on interactions of bottom fisheries with marine mammals, seabirds, reptiles and other species of concern and potential management actions. The Scientific Committee's considerations and advice may include risk assessments, identification of important bird areas or other information relating to the nontarget or associated or dependent species caught as bycatch by bottom fisheries.

Table 17: Taxa specified as "other species of concern" for the purpose of data collection (as of January 2017) by Annex 14 of CMM02-2020.

Scientific name	English name	3-alpha (FAO) code
Carcharhinus longimanus	Oceanic whitetip shark	OCS
Carcharodon carcharias	Great white shark	WSH
Cetorhinus maximus	Basking shark	BSK
Lamna nasus	Porbeagle shark	POR
Manta spp.	Manta rays	MNT
Mobula spp.	Mobula nei	RMV
Rhincodon typus	Whale shark	RHN

4.3.2 Summary of reported interactions

Fishers and observers are required to report interactions with marine mammals, seabirds, reptiles and other species of concern in accordance with CMM02-2020 on Standards for the Collection, Reporting, Verification and Exchange of Data (J.2.d). Such interactions appear to be rare in SPRFMO bottom fisheries; there have been only 14 reported instances of seabird captures, one marine mammal (subsequently determined to be a decomposing carcass), and two reptiles (Table 18, see also Appendix C for disaggregated data) since 2008. Observers report a high proportion of these interactions and many are recorded as having the animal being released alive. The prognosis of such releases is unknown.

It is likely that Table 18 underestimates the total number of interactions with marine mammals, seabirds, reptiles and other species of concern, particularly for bottom line fisheries, because fishers may not report all interactions and observer coverage in both Australian and New Zealand line fisheries is only ~10%. Additionally, not all interactions are observable by normal observer protocols; this is sometime referred to as “cryptic mortality”. For example, a proportion of seabird interactions with trawl vessels are warp strikes, where birds are hit by or fly into the trawl warps and can be injured or killed. Rarely do such incidents result in recovery of the specimen onboard where they might be recorded as bycatch. Estimates of the ratio of cryptic fatalities to observed seabird captures used in the New Zealand seabird risk assessment varied from 3 to 98, depending on the type of birds and fishery (Richard et al. 2020). Seabirds caught on longline hooks and drowned during the set may also come off the hook before the haul.

Table 18: Summary (after detailed checking and correction) of seabirds, marine mammals, reptiles, and other species of concern reported or observed captured in bottom fisheries in the SPRFMO Area in 2007–2019, together with their IUCN threat classification categories. Reports from fishers’ logbooks (2007–2019) and observers (Australia 2007–2010 and 2016–2018, New Zealand 2013–2019) combined. More details by reported event are shown in Appendix C.

Common name	Scientific name	No. captures	IUCN category
Great-winged petrel	*Pterodroma macroptera gouldi*	4	Least Concern
Flesh-footed shearwater	*Puffinus carneipes*	3	Near Threatened
White-chinned petrel	*Procellaria aequinoctialis*	1	Vulnerable
Black petrel	*Procellaria parkinsoni*	1	Vulnerable
NZ white-faced storm petrel	*Pelagodroma marina maoriana*	1	Least Concern #
Gould’s petrel	*Pterodroma leucoptera*	1	Vulnerable
Petrels & shearwaters nei	Procellariidae	2	NA
Black-browed or Campbell Island albatross	*Thalassarche melanophris or T. impavida*	1	Least Concern or Vulnerable #
Green turtle	*Chelonia mydas*	1	Endangered
Sea snakes nei	Elapidae	1	NA
Great white shark	*Carcharodon carcharias*	4	Vulnerable
Basking shark	*Cetorhinus maximus*	1	Endangered
Porbeagle shark	*Lamna nasus*	1	Vulnerable

IUCN threat classification based on a broader definition of the species than assumed in this table.

Deepwater trawling is generally not considered to pose as high a risk to seabirds given the steep angle at which the trawl warps enter the water, and the limited processing typically carried out on board (Richard et al. 2020). The small number of reported and observed captures suggest interaction rates of only a handful of individuals each year. This does not necessarily mean that the captures are inconsequential. Some marine mammals, seabirds, reptiles and other species of concern face a high risk of extinction in the wild, and even a low number of captures can present a substantial species-level threat. For example, at least three of the observed seabird captures were species classified by the IUCN as Vulnerable, and one capture was of a black (Parkinson's) petrel, a species known to be at high risk from fisheries in New Zealand's EEZ. Some observer identifications of black petrel have turned out to be other species (white-chinned petrel or great-winged petrel) when photographs have been viewed by experts. No photographs of the black petrel in Table 18 were available to confirm the identification and there remains some doubt about the actual species captured and released.

New Zealand has been working on a spatial-overlap risk assessment for seabirds since 2013 (Richard and Abraham (2013), Sharp et al. (2013)). The initial implementations of this risk assessment included commercial fisheries within New Zealand's EEZ but the analysis is being progressively extended to include commercial fishing elsewhere in the southern hemisphere. It is envisaged that information from SPRFMO bottom fisheries will be included in the southern hemisphere risk assessment for seabirds in the coming 2–3 years. Pelagic longline fisheries are being included first because those fisheries, mostly managed by the "tuna" RFMOs, are much larger than trawl and bottom longline fisheries; Francis and Hoyle (2019, see Figure 34) estimated fishing effort by method throughout the southern hemisphere and their results suggest hundreds of millions of hooks set each year in pelagic longline fisheries compared with tens of millions in bottom longline fisheries (of which only a small fraction of hooks is within the SPRFMO Convention area). Thus, it is probably reasonable to assume that pelagic longlines pose a higher risk for seabirds than bottom longlines. Abraham et al. (2017) estimated that pelagic longlines in the southern hemisphere captured 6 275 seabirds each year with a 95% credible interval (c.i.) of 4 918–8 054 birds. Abraham et al. (2019) refined the approach to incorporate data from Japan, South Africa, Australia and New Zealand, updated effort data, seabird tracking data and separate catchability estimates for each fleet, and preliminary results suggested annual fatalities of 41 078 (95% c.i.: 39 432–42 746), excluding cryptic mortality. We have not formally estimated annual captures of seabirds using data from SPRFMO bottom fisheries but, based on these estimates, the total number of seabirds killed in SPRFMO bottom fisheries would be orders of magnitude smaller than the numbers killed in pelagic longline fisheries.

Notwithstanding the apparently low risk posed by SPRFMO bottom fisheries, the *Seabird Maps and Information for Fisheries* tool (https://www.fisheryandseabird.info/) was applied to identify seabird taxa that overlap areas of either trawl or longline fisheries, and hence being at potential risk of impact. The list obtained from the tool was expanded to account for new knowledge on seabird distribution (e.g. the more widespread foraging distribution of black petrel), recent changes in taxonomy (the addition of grey-faced petrel at the species level) and to reflect the taxonomy used by the ACAP (considering shy and white-capped albatross separately). Some species were excluded based on marginal overlap (less than 1% of the species' range overlapping less than 10% of the combined fishery area). Based on knowledge of the of seabird interactions with other fisheries, such as domestic New Zealand and Australian trawl and longline fisheries, and global bycatch assessments, the species were categorised (at genus-level) into one of three categories; those known to be susceptible to bycatch in trawl and longline fisheries with bycatch being a conservation concern (highly vulnerable species), those known to be bycaught and/or attracted to vessels by light, leading to vessel strike, but where bycatch may not be the major conservation concern for the species (medium vulnerability), and all remaining species (lower vulnerability). Twenty-six species were classified as highly vulnerable, and includes species of very high concern, such as the Antipodean albatross, which is classified as Endangered and was recently listed on Appendix I of the Convention of Migratory Species. It also includes 20 species listed on Annex I of the Agreement on the Conservation of Albatrosses and Petrels (https://acap.aq/acap-agreement/206-agreement-on-the-conservation-of-albatrosses-and-petrels/file). Appendix D details the results of this work.

CMM09-2017 specifies measures that are close to global best practice for mitigating interactions with seabirds and it is encouraging that the numbers of seabirds reported by fishers and observers is low. However, given that these fisheries overlap the foraging distributions of so many highly vulnerable seabirds, it is important to continue observation and monitoring to ensure the measure is complied with and updated as new information on best practice mitigation appears.

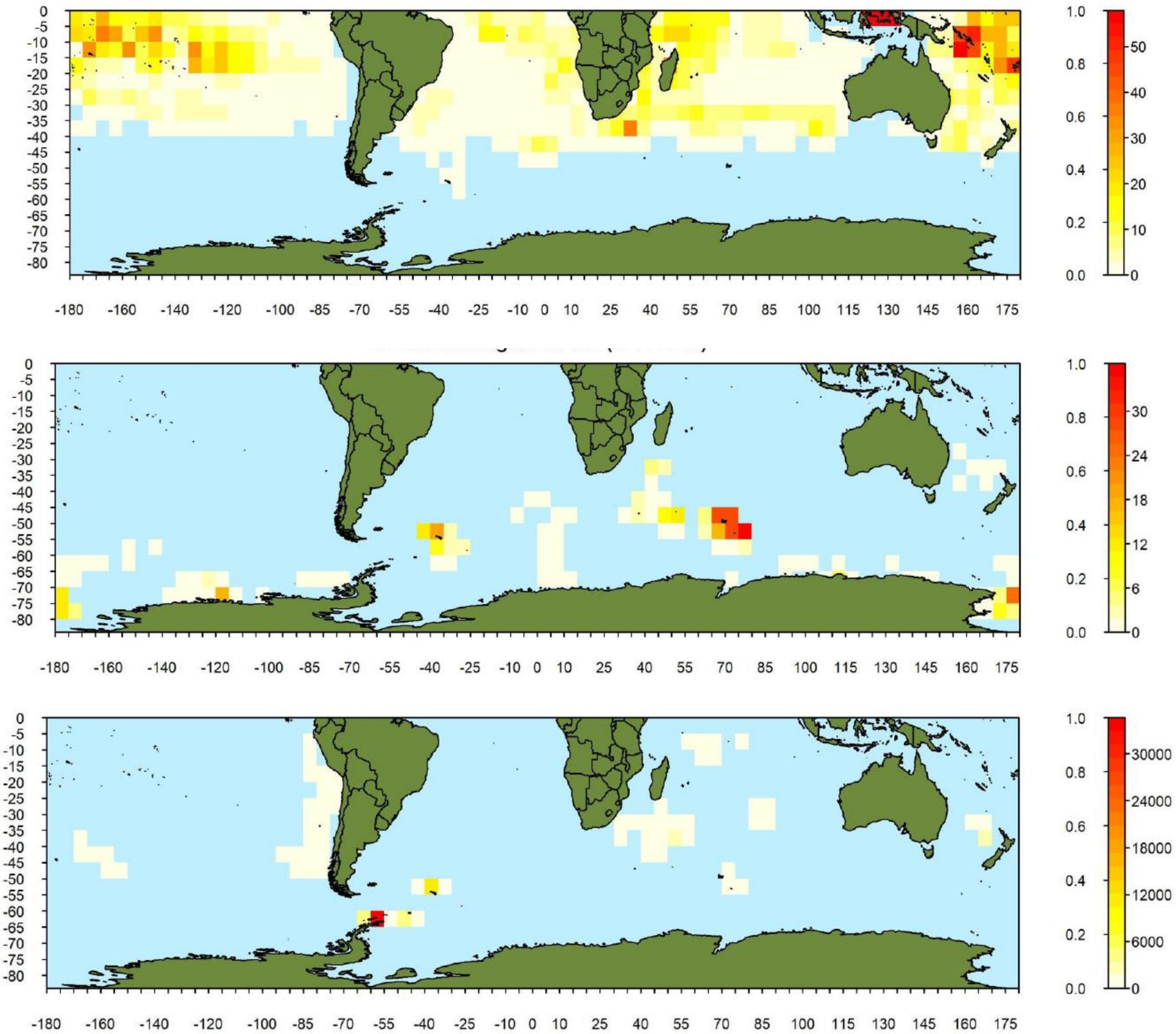


Figure 34: Southern Hemisphere reported fishing intensity in 2014–2016 for surface longline (top plot, hooks km^{-2}), bottom longline (middle plot, hooks km^{-2}) and trawl (bottom plot, tows km^{-2}). Colour legends are shown in relative (left) and absolute values (right). Summarised from Francis and Hoyle (2019).

We are not aware of similarly comprehensive and quantitative estimates of captures of marine mammals, reptiles, or the shark and ray species identified as other species of concern in the South Pacific Ocean. The observed interaction rates for marine mammals and reptiles in SPRFMO bottom fisheries are very low (no marine mammals and two reptiles observed captured in bottom fisheries in the SPRFMO Area in the period 2007–2019) and thought to pose low risk. The risk posed by the relatively few captures of sharks and rays which are classified by SPRFMO as "other species of concern" is covered in the risk assessment for chondrichthyans (see next section).

4.3.3 Ecological risk assessment for SPRFMO deepwater chondrichthyans

Risks to deepwater chondrichthyans (sharks, rays and chimaeras) from fishing are poorly understood, particularly in areas beyond national jurisdiction. Georgeson et al. (2020) adapted PSA and SAFE tools to assess the vulnerability of 173 deepwater chondrichthyans to various fishing gears in the Southern Indian and South Pacific Oceans. One hundred and twelve species were included for the SPRFMO Convention Area analyses. While a number of these species are caught as bycatch while targeting other species (and sometimes retained), the assessment is included in this section due to the life history characteristics (low productivity, late age at maturity, low fecundity etc.) meaning that many deepwater chondrichthyan species could potentially be highly vulnerable to fishing pressure and could be considered to be 'species of concern'.

As for the Georgeson et al. (2019) teleosts risk assessment, the primary objective of the Georgeson et al. (2020) chondrichthyans risk assessment was to assess the relative vulnerability of species so that those at the upper end of the vulnerability spectrum could be prioritised for additional attention. The results should not be considered as absolute estimates of risk.

4.3.3.1 Productivity-Susceptibility Analysis (PSA)

As per the teleosts risk assessment (Georgeson et al. 2019) described above, PSA results are not provided or discussed in detail here due to various methodological limitations and because they are, by design, extremely precautionary, resulting in many probable false positives (species assessed to be at risk that are not at risk in reality). Nonetheless, in the assessment for SPRFMO chondrichthyans there was good concordance between PSA and SAFE results at the upper end of the vulnerability spectrum.

4.3.3.2 Sustainability Assessment for Fishing Effects (SAFE)

In the SPRFMO Convention Area, there were a total of 20, 4 and 17 species classified by the SAFE method as high ($F>F_{lim}$) or extreme ($F>F_{crash}$) vulnerability to demersal trawl, midwater trawl and demersal longline fisheries respectively. Of the 112 species assessed in the SPRFMO Convention Area, four (*Echinorhinus cookei, Oxynotus bruniensis, Mitsukurina owstoni* and *Squalus fernandezianus*) were missing data needed to calculate the reference points F_{msm}, F_{lim} and F_{crash}.

Chondrichthyan species classified as high or extreme risk across all fisheries (Table 19) in the SPRFMO Convention Area were *Echinorhinus cookei, Mitsukurina owstoni, Oxynotus bruniensis* and *Squalus fernandezianus*. An additional seven species were classified as high or extreme vulnerability across all fisheries with the exception of midwater trawl in the SPRFMO Convention Area being *Dalatias licha, Squalus acanthias, Deania calcea, Centrophorus harrissoni, Hydrolagus bemisi, Centrophorus squamosus* and *Chimaera carophila*.

The PSA and SAFE vulnerability scores for all species in the SPRFMO Convention Area are compared in Figure 35. The results indicate good concurrence between the PSA and SAFE results for most species categorised as being at high or extreme vulnerability in the SAFE. There were three species (*Zameus* *squamulosus, Parmaturus macmillani* and *Chimaera carophila*) that were classified as medium vulnerability in the PSA but high or extreme vulnerability in the SAFE, which may indicate potential false negatives for the PSA method. Nonetheless, many species classified as high or medium vulnerability by the PSA were ranked as low vulnerability by the SAFE (indicating likely false positives in the PSA) (Table 19).

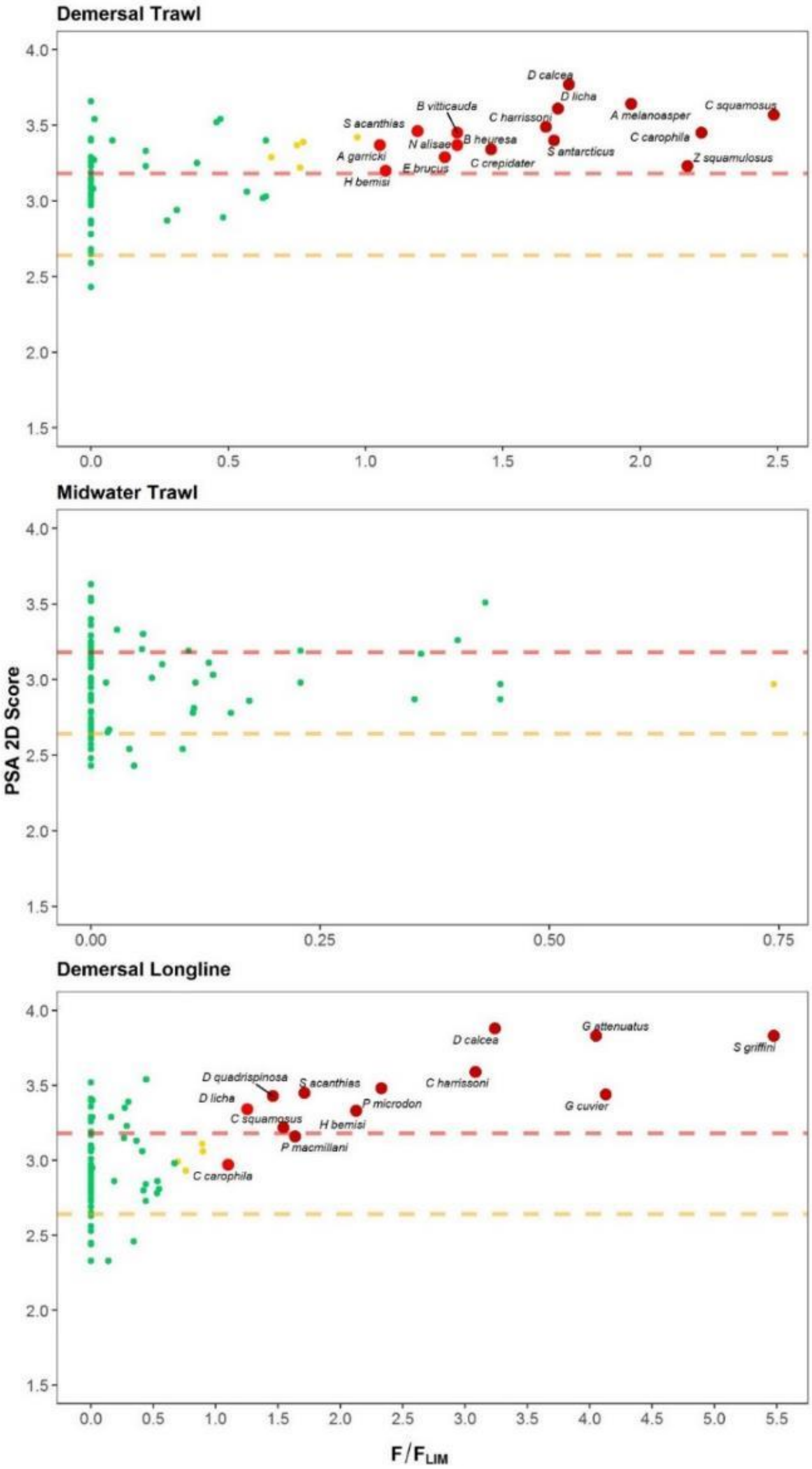


Figure 35: Relationship between SAFE and PSA results for 112 chondrichthyan species with the potential to interact with demersal longline, demersal trawl and midwater trawl fisheries in the SPRFMO Convention Area. Points are coloured dark red, light red, orange and green to signify species classified as extreme, high, medium

and low vulnerability, respectively, in the SAFE. Dashed red and orange lines represent PSA high and medium vulnerability score boundaries from the PSA. Four species are not shown on the panels because their *F*-based reference points could not be calculated.

Table 19. Matrix of high (and extreme) vulnerability species from the SAFE and their respective PSA score for each fishery in the SPRFMO Convention Area. Note that it is important to view these rankings in the context of the discussion herein and because the ERA was undertaken to prioritise species requiring additional attention. They should not be regarded as absolute estimates of risk and/or vulnerability.

South Pacific Ocean Species	Demersal longline		Demersal trawl		Midwater trawl	
	PSA	SAFE	PSA	SAFE	PSA	SAFE
Squalus fernandezianus	High	Extreme	High	Extreme	High	Extreme
Deania calcea	High	Extreme	High	Extreme	High	Low
Gollum attenuatus	High	Extreme	High	Low	High	Low
Squalus griffini	High	Extreme	High	Medium	High	Low
Centrophorus harrissoni	High	Extreme	High	Extreme	High	Low
Oxynotus bruniensis	High	Extreme	High	Extreme	High	Extreme
Mitsukurina owstoni	High	Extreme	High	Extreme	High	Extreme
Echinorhinus cookei	High	Extreme	High	Extreme	High	Extreme
Pseudotriakis microdon	High	Extreme	High	Medium	Medium	Low
Squalus acanthias	High	Extreme	High	Extreme	Medium	Low
Deania quadrispinosa	High	Extreme	High	Medium	Medium	Low
Galeocerdo cuvier	High	Extreme	Medium	Low	Medium	Low
Dalatias licha	High	High	High	Extreme	Medium	Low
Hydrolagus bemisi	High	Extreme	High	High	Medium	Low
Centrophorus squamosus	High	Extreme	High	Extreme	Medium	Low
Parmaturus macmillani	Medium	Extreme	Medium	Low	Medium	Low
Chimaera carophila	Medium	High	High	Extreme	Low	Medium
Apristurus melanoasper	High	Low	High	Extreme	Medium	Low
Brochiraja vitticauda	Medium	Low	High	High	Medium	Low
Notoraja alisae	Medium	Low	High	High	Medium	Low
Brochiraja heuresa	Medium	Low	High	High	Medium	Low
Apristurus garricki	Medium	Medium	High	High	Medium	Low
Somniosus antarcticus	Medium	Medium	High	Extreme	High	Low
Centroselachus crepidater	Medium	Low	High	Extreme	Medium	Low
Echinorhinus brucus	Medium	Low	High	High	Medium	Low
Zameus squamulosus	Low	Low	High	Extreme	Low	Low

4.3.3.3 Discussion of chondrichthyans ERA results

The results of the PSA and SAFE analyses highlight that some chondrichthyans in the SPRFMO Convention Area are likely to be vulnerable to fishing pressure due to their life-history traits (i.e. long-lived, slow growing and low fecundity), which compromises their ability to recover from fishing-induced depletion. There is a deficit of information on chondrichthyans globally, with over 50% of shark and ray species listed as data deficient on the IUCN Red List due to the taxonomic resolution of fishery catch data being too low to identify species-level trends in abundance (Cashion et al. 2019). Given the limited fisheries and biological data on deepwater chondrichthyans in the South Pacific Ocean (Duffy et al. 2017), data-poor methods such as ERA provide a useful tool for evaluating vulnerability of these species to fisheries interactions based on their biological productivity and susceptibility to the main fisheries operating across their geographic range (Zhou and Griffiths 2008, Patrick et al. 2010, Hobday et al. 2011). This approach allows those species that are at highest vulnerability to be identified and the risk either mitigated or investigated further through data collection and research prioritisation (Griffiths et al. 2017).

A key challenge when considering the results of the Georgeson et al. (2020) assessment is the availability and quality of supplementary information that can be used to critically review results in the context of the fishery or fisheries that interact with species or groups of species. In particular, information on catch and effort over time and space can be valuable in making inferences about the likely true vulnerability of species to certain gears. Catch and effort information at a suitable species resolution were only available for a subset of the fisheries assessed in the analysis.

In the SPRFMO Convention Area, deepwater chondrichthyans are caught mostly in demersal trawl fisheries targeting orange roughy and in demersal longline fisheries targeting species such as bluenose/blue-eye trevalla (*Hyperoglyphe antarctica)*, hapuku (*Polyprion oxygeneios*) and bass groper (*Polyprion americanus*) (Duffy et al. 2017), but these catches are made in relatively low volumes. Recorded total chondrichthyan catches in the New Zealand demersal trawl fishery estimated from at-sea observer data ranged from 7.7 tonnes in 2014 to 228.1 tonnes in 2016 (Duffy et al. 2017), with two species (*Deania calcea* and *Dalatias licha*) classified at extreme vulnerability to demersal trawl in our SAFE analysis contributing to a total 47% of the catch between 2012 and 2016. Observers estimate the catch weight by species for almost 100% of New Zealand bottom trawl tows. However, they were only able to identify to species level 83–94% of chondrichthyans by weight (varying between years) leaving some scope for further species at high or extreme vulnerability to have been caught in these fisheries. Commercial fishers' logbook data from the same fishery had a much greater proportion of unspecified 'deepwater dogfish' recorded (67%) compared with just 9% for at-sea observers, meaning that the observer data are preferred (Duffy et al. 2017).

Deepwater chondrichthyans were also caught in New Zealand's line fisheries, including *Dalatias licha*, which made up 8% of the total chondrichthyan catch reported by at-sea observers between 2012 and 2016 (Duffy et al. 2017). Observers estimate the catch weight by species for only about 10–20% of New Zealand bottom line sets, necessitating more reliance on commercial fishers' logbooks. Other species including *Squalus acanthias* and *Deania calcea*, which were classified at extreme vulnerability in the SAFE analysis, have been recorded as caught in the longline fishery (SPRFMO 2018). However, as identified by Duffy et al. (2017), some of these identifications (especially the commonly-reported *Squalus acanthias*) are probably errors and catches by species are therefore likely to be poorly estimated. This supposition is reinforced by 105 tonnes of unidentified deepwater sharks recorded as caught between 2012 and 2016 in the SPRFMO database. Issues with species identification, reporting and the resolution at which historical data have been collected make it very difficult to make inferences about the historical contribution of fishing to overall catches of deepwater chondrichthyans species in the SPRFMO Convention Area.

Within-species comparison of PSA and SAFE results demonstrated good concurrence between those listed at high or extreme vulnerability by the SAFE; however, the PSA estimated far more species to be at high or medium relative vulnerability than the SAFE, which classified them as low. A greater number of false positives in the PSA is to be expected (Hobday et al. 2011, Zhou et al. 2016) and in this assessment is largely driven by the PSA assuming a minimum score of 1 for the *Availability* attribute even if there is zero overlap between the species and the gears, while the SAFE gives a true zero for susceptibility (i.e. no overlap means no vulnerability and the susceptibility/*F*-estimate is zero). The number of possible false positives was less than it would have been if data on productivity attributes from congeneric species (related species from the same genus) was not used to reduce the number of species classified as data deficient (i.e. those missing three or more attributes). A bias in the vulnerability score can occur if the imputed attributes from congeneric species are incorrect but, given the limited knowledge of deepwater chondrichthyan species' biology and life history, this approach was regarded as adequate and expert-informed substitution of missing data has been used previously. Interestingly, three species were assessed to be at a high or extreme vulnerability by the SAFE that were ranked as medium relative vulnerability by the PSA. These discrepancies in vulnerability ranking, which are possibly false negatives of the PSA, were unexpected and were likely driven by the inability of the PSA to be a reliable indicator of biological risk for species within these intermediate PSA vulnerability scores. In other words, the vulnerability scores from our PSA are unlikely to be ordered correctly with respect to risk of overexploitation. Between-species comparison of PSA and SAFE vulnerability classifications indicated that differentiation was driven more by susceptibility attributes than productivity attributes. The influence of the susceptibility attributes in our results highlights the limitation of the PSA in assuming a linear and additive relationship between the productivity and susceptibility scores in the calculation of relative vulnerability scores. The assumption that each individual productivity and susceptibility attribute contributes equally to each axis has also been previously challenged.

While there were clear uncertainties and limitation in Georgeson et al.'s (2019) ERA, this should not prevent a precautionary approach being taken by SPRFMO to prioritise species at high or extreme vulnerability for further research, data collection and/or further assessment to estimate bycatch limits or sustainable yields. When coupled with information on the characteristics of fisheries (including, importantly, information on catches), such methods can be used to provide a semi-quantitative underpinning for these actions. It is clear that information on the identification, distribution, stock structure, biology and life history of deepwater chondrichthyans is lacking (Gallagher et al. 2012) and that at-sea identification protocols need to be improved in high seas fisheries to increase the accuracy of logbook and at-sea observer reporting (Duffy et al. 2017, Cashion et al. 2019, SIOFA 2019). Research on post capture mortality and gear selectivity of deepwater chondrichthyans would be useful to inform mitigation strategies to reduce or manage risk that is associated with the species susceptibility.

4.3.3.4 Outcomes from the chondrichthyans ERA

The seventh meeting of the SPRFMO Scientific Committee noted that other RFMO/As, such as the Southern Indian Ocean Fisheries Agreement, have implemented measures prohibiting targeted fishing for deepwater chondrichthyans, which it agreed could be similarly implemented by SPRFMO to discourage such practices in the absence of scientifically based assessment and management. It also recommended that identification guides be developed and used to increase taxonomic resolution and improve data collection, which can feed into future assessments and estimates of sustainable yields. The SPRFMO Commission agreed in 2020 to increase the data collection requirements in respect of deepwater sharks.

4.4 FISHERIES INTERACTIONS WITH BENTHIC HABITATS AND VMES

4.4.1 General approach to assessing benthic impacts and VMEs

All bottom-contacting fisheries impact benthic systems and modify benthic communities, although the intensity of such impacts varies substantially between fishing gears and the type of benthic fauna that the fishing gear contacts. Mobile fishing gears such as trawling generally have a more intense impact than static gears such as bottom longline (Chuenpagdee et al. 2003) (see also Table 20). Groups of species, communities or habitats that may be vulnerable to the impacts of bottom fishing activities due to slow growth, late age at maturity, long life expectancy or low or unpredictable recruitment are termed VMEs. Assessing the impacts of bottom fisheries on benthic habitats (and in particular VMEs) has been the focus of much global and regional research. The assessment of benthic impacts presented here builds on this research by developing a workflow to assess the impacts of bottom fishing on VMEs. This workflow includes determining: (1) the spatial distribution of VME taxa and bottom fishing effort; (2) changes in the status of VME taxa due to the impacts of historical fishing; and (3) evaluating the performance of management measures, including spatial management and move-on rules, taking into consideration the spatial scale at which managers may deem it necessary to prevent SAIs on VMEs, and the uncertainty associated with the data informing the assessment (Figure 36). This process was guided through one of New Zealand's standing science working groups, the South Pacific Fishery Assessment Working Group (SPACWG), which provided a forum to discuss the assessment approach collegially among scientific, policy and management representatives of Australia and New Zealand, environmental non-government organisations and fishing industry representatives. For example, discussions at the SPACWG guided decisions on the development of abundance metrics from habitat suitability models, the development of naturalness layers, the sensitivity analyses to be applied and the appropriate presentation of research outputs.

Table 20. Ranking of expected habitat impact for each fishing gear class on either physical or biological habitats on a scale of 1 (very low) to 5 (very high) (modified after Chuenpagdee et al. 2003). Gear classes commonly used in SPRFMO bottom fisheries in bold (benthopelagic trawl was not considered by Chuenpagdee et al. but we consider its impact to be intermediate between pots and traps and bottom trawl)

Gear Class	Physical habitat	Biological habitat
Gillnet – midwater	1	1
Hook and line	1	1
Longline – pelagic	1	1
Purse seine	1	1
Trawl – true midwater	1	1
Longline – bottom	**2**	**2**
Gillnet – bottom	3	2
Pots and traps	3	2
Trawl – benthopelagic	**–**	**–**
Trawl – bottom	**5**	**5**
Dredge	5	5

The main fishing methods in use in SPRFMO bottom fisheries are bottom trawl (targeting mainly orange roughy), midwater trawl (targeting benthopelagic species like alfonsino close to the seabed) and bottom longline (targeting bluenose/blue-eye trevalla, wreckfishes (*Polyprion* spp.) , and other species). Of these, bottom trawling has the most intense impact and is also the most frequently deployed and widespread fishing method in SPRFMO bottom fisheries. In recognition of this, the SPRFMO interim management measures (agreed in 2007 before the establishment of SPRFMO) and formal measures established since (starting with CMM2.03 in 2014 up to the current CMM03-2020) restrict bottom trawling more tightly than other methods. The spatial measures included in CMM 03-2019 and CMM 03-2020 for managing the impacts of bottom trawling were developed using a decision support tool (Zonation) with the intention to protect VMEs (based on habitat suitability maps for VME indicator taxa taking into account 'naturalness' condition) while providing for the utilization of high value areas for fisheries (based on a value to the New Zealand fishing industry trawl catch data supplied by the fishing industry). The result was guidance on the identification of areas to be closed to fishing (with the intention to prevent SAIs on VMEs) and areas to be opened to fishing (to provide for a viable fishery). The key metric of the likely performance of the spatial management measures was determined by calculating the proportion of suitable habitat or abundance protected for each VME indicator taxon that occur outside the areas open to fishing, and the proportion of high value areas for fishing that occur within open areas. Recognizing that the habitat suitability models that underpin the spatial management areas have associated uncertainty, CMM 03-2019 included a VME encounter protocol within areas open to fishing to provide for a rapid response to unexpectedly large benthic bycatch (relative to the predicted distributions of VME indicator taxa used to underpin spatial management measures).

Since the implementation of the spatial management measures included in CMM 03-2019 additional data has become available allowing updates to the habitat suitability models. Additionally, alternative analytical approaches for describing the current status of VME indicator taxa after the effects of bottom fishing (‘naturalness’ condition of VMEs) and for translating habitat suitability models into estimates of VME indicator taxa abundance while calculating metrics of the likely performance of the spatial management measures have been developed. These advances allow potentially improved estimates of the performance of the spatial management measures as a basis for an updated benthic impact assessment.

Six thousand new records across the whole range of modelled VME indicator taxa have become available since the first habitat suitability models were developed, and these records have been used alongside the original data to update the constituent and ensemble habitat suitability models. This BFIA presents the difference between the new ensemble models for VME indicator taxa, and their component models, and incorporates the updated models, which have improved predictive power into the assessment of the performance of the spatial management measures.

The BFIA builds on the original estimates of the performance of the spatial management measures (see COMM07-Prop03.1, Delegation of NZ 2019) by including an alternative method for describing the current status of VME indicator taxa after the effects of bottom fishing. Both the original method and the new alternative method are based on the spatial overlap between the fisheries footprint and the VME indicator taxa distributions. Both methods also account for the interaction between fishing gear and biota (mortality) and the recovery after impact, but they differ in their temporal scope. The original method is an estimate of the mortality (i.e. depletion) caused by the passing of fishing gear, coupled to an estimate of its ability to recover from the impact. This produces a spatial representation of the current status of each taxon after the effects of all historical trawling, defined as “naturalness”. As depletion and recovery values for each taxa vary, different sensitivities are tested for naturalness using pessimistic (worst combination), base (mean) and optimistic (best combination) values. The alternative method, relative benthic status (RBS), uses a similar approach but adds a dynamic component to it. The RBS assessment estimates the long-term relative abundance of biota as a fraction of its unimpacted level. The status of trawled habitats and their RBS value depend on impact rate (depletion per trawl), recovery rate and exposure to trawling, with a further sensitivity added to account for future trawling and recovery potential.

The approach to estimating the likely performance of spatial management areas used in 2018 assumed that, in effect, the relationship between habitat suitability indices and the abundance of each modelled taxon was linear; however, additional work has shown that this relationship is uncertain and variable, but unlikely to be linear. Recognizing this, estimates describing the performance of spatial management areas are made using the original approach (summing habitat suitability indices) and two alternative approaches; (1) Receiver Operator Characteristics (ROC) curves that sum habitat suitability scores above cut-off thresholds; and power curves estimated using information on the observed cover or abundance of VME indicator taxa within grid cells for which HSI predictions were available. Both new approaches are now considered superior to the sum of HSI approach used in 2018, but each has different characteristics, strengths and weaknesses.

The following sections describe each of the components of the impact assessment in detail, including differences in alternative analytical approaches. Sensitivities of the final results to different analytical approaches are summarized in tables, with the performance metrics calculated at different spatial scales to reflect the different spatial scales at which managers may deem it necessary to prevent SAIs on VMEs. These scales include (from coarsest to finest) the whole of the SPRFMO Evaluated Area; five bioregions (after Costello et al. (2017)) occurring within the Evaluated Area; several distinct fisheries administrative units within the Evaluated Area (Tasman Sea, South Tasman Rise, Louisville Seamount Chain, split into Northern, Central and Southern areas, and "other" areas); and ten finer orange roughy stock management areas (or Fishery Management Areas, FMAs).

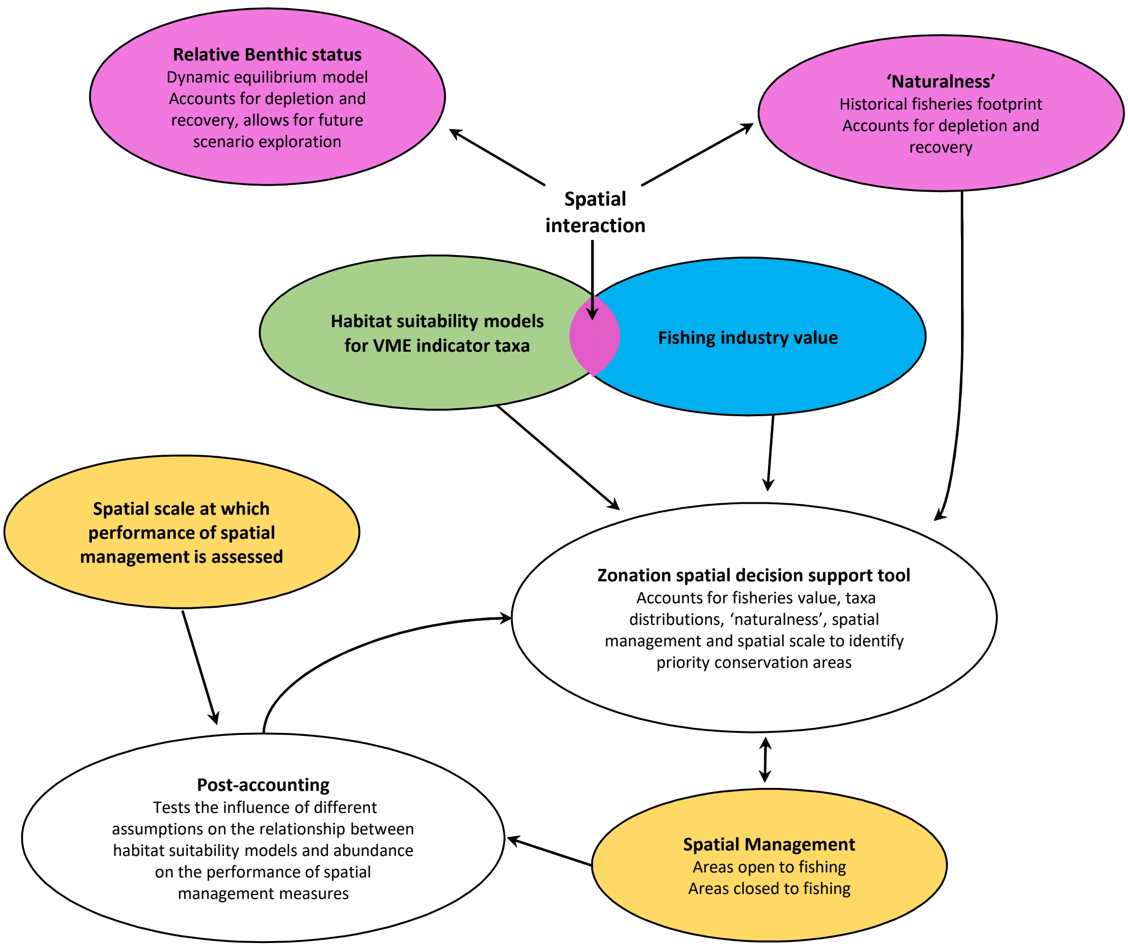


Figure 36: Schematic representation of the workflow used to assess the likely current and future state of VME indicator taxa and assess the likely performance of current spatial management arrangements.

4.4.1 International guidance on benthic impacts assessment

The impetus for RFMO/As to prevent significant adverse impacts on VMEs by bottom fisheries originated with United Nations General Assembly Resolution 61/105, which calls upon RFMO/As:

> *83 (a) To assess, on the basis of the best available scientific information, whether individual bottom fishing activities would have significant adverse impacts on vulnerable marine ecosystems, and to ensure that if it is assessed that these activities would have significant adverse impacts, they are managed to prevent such impacts, or not authorized to proceed*;

This and subsequent UNGA resolutions did not define VMEs, but referred to them as "*vulnerable marine ecosystems, including seamounts, hydrothermal vents and cold-water corals*", nor did they define SAIs. Subsequently, the FAO Deep-Sea Guidelines adopted in August 2008 have provided more specific guidance on the characteristics which could be considered to define VMEs and SAIs (numbering from the guidelines, FAO 2008):

3.3 Significant adverse impacts

17. *Significant adverse impacts are those that compromise ecosystem integrity (i.e. ecosystem structure or function) in a manner that: (i) impairs the ability of affected populations to replace themselves; (ii) degrades the long-term natural productivity of habitats; or (iii) causes, on more than a temporary basis, significant loss of species richness, habitat or community types. Impacts should be evaluated individually, in combination and cumulatively.*
18. *When determining the scale and significance of an impact, the following six factors should be considered:*
    - *i. the intensity or severity of the impact at the specific site being affected;*
    - *ii. the spatial extent of the impact relative to the availability of the habitat type affected;*
    - *iii the sensitivity/vulnerability of the ecosystem to the impact;*
    - *iv. the ability of an ecosystem to recover from harm, and the rate of such recovery;*
    - *v. the extent to which ecosystem functions may be altered by the impact; and*
    - *vi. the timing and duration of the impact relative to the period in which a species needs the habitat during one or more of its life-history stages.*
19. *Temporary impacts are those that are limited in duration and that allow the particular ecosystem to recover over an acceptable time frame. Such time frames should be decided on a case-by-case basis and should be in the order of 5-20 years, taking into account the specific features of the populations and ecosystems.*
20. *In determining whether an impact is temporary, both the duration and the frequency at which an impact is repeated should be considered. If the interval between the expected disturbance of a habitat is shorter than the recovery time, the impact should be considered more than temporary. In circumstances of limited information, States and RFMO/As should apply the precautionary approach in their determinations regarding the nature and duration of impacts.*

5.2 Identifying vulnerable marine ecosystems and assessing significant adverse impacts

42. A marine ecosystem should be classified as vulnerable based on the characteristics that it possesses. The following list of characteristics should be used as criteria in the identification of VMEs:

- *i. Uniqueness or rarity – an area or ecosystem that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems. These include:*

- *habitats that contain endemic species;*
- *habitats of rare, threatened or endangered species that occur only in discrete areas; or*
- *nurseries or discrete feeding, breeding, or spawning areas.*

45. *Functional significance of the habitat – discrete areas or habitats that are necessary for the survival, function, spawning/reproduction or recovery of fish stocks, particular life-history stages (eg, nursery grounds or rearing areas), or of rare, threatened or endangered marine species.*

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

45. *Life-history traits of component species that make recovery difficult – ecosystems that are characterized by populations or assemblages of species with one or more of the following characteristics:*
    - *slow growth rates;*
    - *late age of maturity;*
    - *low or unpredictable recruitment; or*
    - *long-lived.*

v. *Structural complexity – an ecosystem that is characterized by complex physical structures created by significant concentrations of biotic and abiotic features. In these ecosystems, ecological processes are usually highly dependent on these structured systems. Further, such ecosystems often have high diversity, which is dependent on the structuring organisms.*

45. *Where site-specific information is lacking, other information that is relevant to inferring the likely presence of vulnerable populations, communities and habitats should be used.*

Annex 1. Examples of potentially vulnerable species groups, communities and habitats, as well as features that potentially support them

The following examples of species groups, communities, habitats and features often display characteristics consistent with possible VMEs. Merely detecting the presence of an element itself is not sufficient to identify a VME. That identification should be made on a case-by-case basis through application of relevant provisions of these Guidelines, particularly Sections 3.2 and 5.2.

Examples of species groups, communities and habitat forming species that are documented or considered sensitive and potentially vulnerable to DSFs in the high seas, and which may contribute to forming VMEs:

i. *certain coldwater corals and hydroids, eg, reef builders and coral forest including: stony corals (Scleractinia), alcyonaceans and gorgonians (Octocorallia), black corals (Antipatharia) and hydrocorals (Stylasteridae);*
ii. *some types of sponge dominated communities;*
iii. *communities composed of dense emergent fauna where large sessile protozoans (xenophyophores) and invertebrates (eg, hydroids and bryozoans) form an important structural component of habitat; and*
iv. *seep and vent communities comprised of invertebrate and microbial species found nowhere else (ie, endemic).*

Examples of topographical, hydrophysical or geological features, including fragile geological structures, that potentially support the species groups or communities, referred to above:

i. *submerged edges and slopes (eg, corals and sponges);*
ii. *summits and flanks of seamounts, guyots, banks, knolls, and hills (eg, corals, sponges, xenophyphores);*
iii. *canyons and trenches (eg, burrowed clay outcrops, corals);*
iv. *hydrothermal vents (eg, microbial communities and endemic invertebrates); and*
v. *cold seeps (eg, mud volcanoes for microbes, hard substrates for sessile invertebrates).*

Table 21: List of characteristics that should be used as criteria in the identification of VMEs as determined by the FAO (2009).

Uniqueness or rarity	An area or ecosystem that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems. These include: • habitats that contain endemic species; • habitats of rare, threatened or endangered species that occur only in discrete areas; or • nurseries or discrete feeding, breeding, or spawning areas
Functional significance of the habitat	Discrete areas or habitats that are necessary for the survival, function, spawning/reproduction or recovery of fish stocks, particular life history stages (e.g. nursery grounds or rearing areas), or of rare, threatened or endangered marine species
Fragility	An ecosystem that is highly susceptible to degradation by anthropogenic activities.
Life-history traits of component species that make recovery difficult	Ecosystems that are characterized by populations or assemblages of species with one or more of the following characteristics: • slow growth rates; • late age of maturity; • low or unpredictable recruitment; or • long-lived
Structural complexity	An ecosystem that is characterized by complex physical structures created by significant concentrations of biotic and abiotic features. In these ecosystems, ecological processes are usually highly dependent on these structured systems. Further, such ecosystems often have high diversity, which is dependent on the structuring organisms.

4.4.2 Potentially impacted benthic fauna, especially Vulnerable Marine Ecosystems

4.4.2.1 Impacted species

The 7th meeting of the SPRFMO Scientific Committee (SC7) recommended to the Commission that, when it reviews CMM03-2019 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) and Bryozoa. VME indicator taxa consist of 13 of the 15 VME groups that were identified in SC7-DW13 as satisfying FAO guidelines for identifying VMEs and that met an additional two criteria related to their suitability as VME indicators. 10 of the VME indicator taxa are currently included as VME indicators in CMM 03-2020, with the remaining 3 to be added as VME indicators when the CMM is updated in 2021.

It also agreed that a broader list of candidate VME taxa for the SPRFMO Convention area should be developed. VME taxa are genera and species within each VME group that have been assessed as satisfying FAO guidelines for identifying VMEs, but which have not been evaluated for their suitability as indicators. The presence of VME taxa (or VME indicator taxa) at a location is not sufficient to identify a VME without further consideration of characteristics of those taxa at the location.

Consequently, the SC multi-annual workplan in the SC7 Meeting Report was updated to include the finalization of the list of VME taxa, to be completed in 2020-2021. In support of that workplan, New Zealand reviewed taxonomic records from within the Evaluated Area of the SPRFMO Convention Area for each of the 15 VME groups identified in SC7-DW13 (see Table A1.1), to develop lists of candidate VME taxa at a finer level of taxonomic identification.

Of the 5,300 records from within the Evaluated Area of the SPRFMO Convention Area, 44% were designated at the taxonomic level of genus or species, 54% had biomass data and 86% had depth data. The 5,300 records included 171 family, 326 genus and 248 species-level designations. Of the 15 VME groups, Porifera, Alcyonacea (gorgonians), Hydrozoa and Bryozoa had the most taxa identified, each with more than 40 taxa designated at the level of genera or species. Conversely, Alcyonacea (soft corals), Brisingida, Scleractinia, Zoantharia, and Serpulidae had the least taxa identified, each with less than 10 taxa designated at the level of genera or species, and Xenophyophores had no records identified at the level of genera or species.

The review of draft lists by taxonomic experts identified 281 genera and 231 species that, in the opinion of the expert reviewers, met FAO VME criteria and therefore could be considered candidate VME taxa. Porifera and Alcyonacea (gorgonians) had the greatest number of taxa identified as VME taxa, while Zoantharia and Serpulidae had the least. There were single records within the Evaluated Area for 41% of genera and 48% species designated as VME taxa. Most of the genera (63%) and species (79%) designated as VME taxa occurred within fishable depths (< 1400 m).

A complete and updated list of species potentially impacted is provided in Geange et al. (2020, paper SC-08-DW-11).

4.4.2.2 Vulnerable Marine Ecosystem taxa and indicators

VMEs are groups of species, communities or habitats that may be vulnerable to impacts of fishing activities. Some VME-forming taxa may be retained in fishing gear during the course of fishing activities and therefore serve as an indicator that a VME may be present within the area. However, the detection of a VME indicator taxon or component is not sufficient to identify a VME and additional evaluation taking into consideration the FAO criteria for VMEs is required.

VME indicator taxa for the SPRFMO Convention Area were first identified by Parker et al. (2009) for New Zealand-flagged vessels using bycatch data, FAO criteria for VMEs, plus two additional criteria related to retention of taxa as bycatch in deep-sea fisheries and the ability of observers to identify taxa in the field. The list of VME indicator taxa, designated variously at the level of phylum, class, order or family included 10 taxa. These taxa were subsequently incorporated into a bottom-fishing VME encounter protocol (a 'move-on rule') for New Zealand vessels (initially CMM2.03), and most recently, for vessels of all members within the SPRFMO Convention Area (SPRFMO CMM03-2020).

The SC7-DW13 paper presented a review of VME indicator taxa for the SPRFMO Convention Area in 2019 making use of a larger set of bycatch observations within the SPRFMO Convention Area since the assessment by Parker et al. (2009). That review identified 15 VME indicator taxa (at the level of Phylum, Class, Order or Family) that meet FAO criteria, of which 13 satisfied additional criteria related to their suitability as VME indicators (Table 22). Of the 13 VME indicator taxa identified by Geange et al (2019) in SC7-DW13, zoantharia, hydrozoa and bryozoa are not included as VME indicators within CMM03-2020. The Scientific Committee recommended to the Commission that when it reviews CMM03 in 2021, the list of VME indicator taxa used for the biodiversity component of the encounter protocol should be revised to include zoantharia, hydrozoa and bryozoa.

Table 22: Matrix indicating taxa identified by Parker et al (2009) as VME indicators, taxa that met FAO criteria for identifying VME taxa and assessed as VME indicators in SC7-DW13, and taxa for which habitat suitability models have been created.

Phylum	Lower taxonomic group	Identified by Parker et al. 2009 as VME indicator taxa	Identified by SC7-DW13 as meeting FAO VME criteria	Identified by SC7-DW13 as meeting VME indicator criteria	Habitat Suitability models
Porifera		X	X	X	Separate models for Demospongiae and Hexactinellida
Cnidaria	Gorgonian Alcyonacea (Tree-like forms, sea fans, sea whips, bottlebrush)	X	X	X	Modelled as a single group
	Alcyonacea (Soft corals)	X	X	X	Modelled as a single group
	Stylasteridae (Hydrocorals)	X	X	X	Modelled as a single group
	Scleractinia (Stony corals)	X	X	X	Separate models for *Enallopsammia rostrata, Madrepora oculata, Solenosmilia variabilis, Goniocorella dumosa*
	Antipatharia (Black corals)	X	X	X	Modelled as a single group
	Actiniaria (Anemones)	X	X	X	Not modelled
	Pennatulacea (Sea pens)	X	X	X	Modelled as a single group
	Zoantharia (Hexacorals)		X	X	Not modelled
	Hydrozoa (Hydroids)		X	X	Not modelled
Echinodermata	Brisingida ('Armless' stars)	X	X	X	Not modelled
	Crinoidea (Sea lilies)	X	X	X	Not modelled
Bryozoa			X	X	Not modelled
Retaria	Xenophyophorea (Xenophyophores)		X		Not modelled
Annelida	Serpulidae (Serpulid tube worms)		X		Not modelled

4.4.2.3 Predicted distribution of VME indicator taxa

The available information on biomass, depth and location of VME indicator taxa is too sparse to enable direct mapping of these taxa within the SPRFMO Convention Area, so habitat suitability models have been used to predict the niche distribution of key taxonomic groups based on the data that are available. This statistical approach relates field observations to environmental predictor variables, yielding predictions of a habitat suitability index (HSI, ranging from 0 to 1) for given taxa and the underlying environmental drivers of their geographic distribution (Anderson et al., 2016a, 2016b; Rowden et al., 2017). The spatial management measures implemented under CMM03-2019 were designed using ensemble habitat suitability models developed by Georgian et al. (2019). Ensemble models were constructed from the weighted average of model predictions of HSI from models using Boosted Regression Trees (BRT), Maximum Entropy (Maxent), and Random Forests (RF). Predictions were on a grid of 1 km^2 cells for four species of framework-building scleractinian (stony) corals, *Enallopsammia rostrata*, *Goniocorella dumosa*, *Madrepora oculata*, and *Solenosmilia variabilis*. Sponges were modelled as two groups, glass sponges (Hexactinellida) and demosponges (Demospongiae). Soft corals (Alcyonacea), sea pens (Pennatulacea), black corals (Antipatharia) and hydrocorals (family Stylasteridae) were each modelled as a single group. These represent 7 of the 15 VME taxa identified by Geange et al. (2019) (SC7-DW13), with the taxa not modelled being Actiniaria, (anemones), Zoantharia (hexacorals), Brisingida (seastars), Crinoidea (feather stars and sea lilies), Bryozoa, Xenophyophora (xenophyophores) and Serpulidae (serpulid tube worms) (Table 23). Some of these taxa are large diverse groups which previous analysis have shown to result in low model performance (Anderson et al. 2014, Rowden et al. 2014). Habitat suitability models developed by Georgian et al. (2019) were used by Winship et al. (2020) as a case study in good practice for modelling deepwater corals and sponges to support resource management and were further developed. For this assessment, an ensemble model was developed for each of the ten VME indicator taxa within the Evaluated Area for which sufficient data existed. Ensemble models use the weighted average of model predictions of HSI from models using boosted regression trees (BRT), maximum entropy (Maxent), and random forests (RF).

A review by Rowden and Anderson (2019) (SC7-DW12) identified that over 6000 new presence records had become available since the data set used by Georgian et al. (2019) was compiled, including tens of new records for *M. oculata* and *E. rostrata*, 100s for *S. variabilis*, *G. dumosa*, Antipatharia, Stylasteridae, and Pennatulacea, and >1000 for Alyconacea and the two sponge groups (e.g. Figure 37). Most new records were from commercial bycatch but a notable proportion were from image datasets, a source not accessed by Georgian et al. (2019). The expanded datasets were used for this assessment to model the same taxa except that the subset of Alcyonacea known as “gorgonians” were modelled rather than the wider group.

Alongside the presence records, Georgian et al. (2019) used a combination of the concepts of random selection and target-group background sampling (Phillips et al. 2009) to generate a spatially structured set of “pseudo absences”. This approach creates a set of background data that reflect the same bias as the occurrence data, reducing the effects of spatial sampling bias (Phillips et al. 2009). The updated models for this assessment use observed presences and a fixed number sub-set of the “target-group background data” (i.e. the presence of another species as an absence, Phillips et al. 2009). The use of target-group background data has been shown to improve average performance for regression-based models, compared with using background data, especially when the relative absences are part of the same broad biological group and have been collected using similar methods with the same sampling biases. An equal number of presence and target-group background data “absences” were used (Barbet-Massin et al. 2012, Aiello-Lammens et al. 2015).

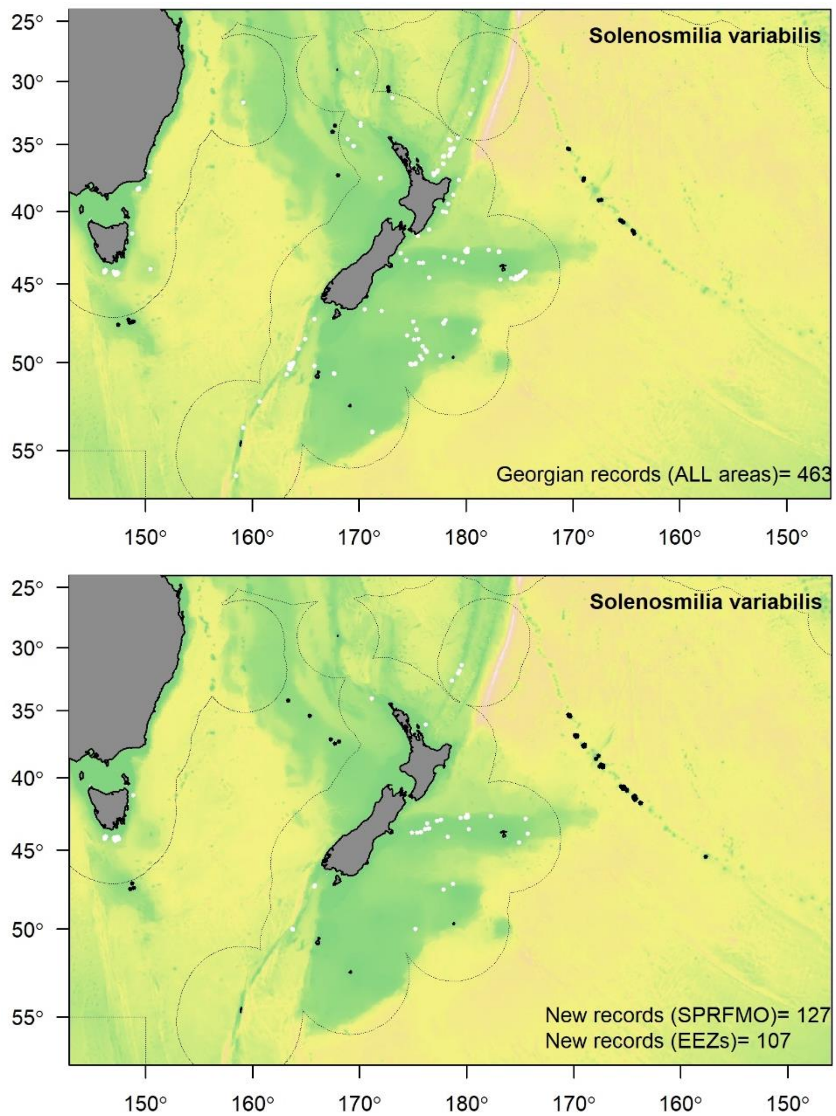


Figure 37: Presence records of *Solenosmilia variabilis* (SVA) used in the Georgian et al. 2019 paper (upper panel, 463 records) and new records used in this assessment (lower panel, 234 samples). White dots indicate records from within EEZs and black dots indicate records from the high seas. This is one example of ten VME indicator taxa.

Georgian et al. (2019) and the models for this assessment used a suite of broad-scale environmental variables to predict the distributions of each taxon, upscaled to higher-resolution regional bathymetry using a similar approach to that described by Davies and Guinotte (2011). Depth is an extremely important variable and depths for each cell were derived from the bathymetry grid for the New Zealand region derived by Mackay et al. (2015). Additional seafloor terrain metrics were derived from this bathymetry using the Benthic Terrain Modeler in ArcGIS 10.3.1.1 (Wright et al. 2012). A range of water chemistry and productivity variables were included, all gridded to 1 km^2 (Table 23). Variable selection and fitting procedures are described in Georgian et al (2019).

Table 23: Environmental variables considered for use in habitat suitability models by Georgian et al. (2019) and in this assessment (particulate organic carbon export was updated). Variables highlighted in green were used as model predictors in both Georgian et al. (2019) and the new models for this assessment.

Variable	Units	Native Resolution	Source
Seafloor Characteristics			
Depth	m	1 km^2	Mackay et al. (2015)
Percent gravel	%	–	NIWA
Percent mud	%	–	NIWA
Ruggedness[2]	–	–	Derived from bathymetry
Slope[2]	degrees	–	Derived from bathymetry
Slope SD[2]	–	–	Derived from bathymetry
Aspect	degrees	–	Derived from bathymetry
Range[2]	–	–	Derived from bathymetry
Standard deviation[2]	–	–	Derived from bathymetry
Profile curvature	–	–	Derived from bathymetry
Plan curvature	–	–	Derived from bathymetry
Curvature	–	–	Derived from bathymetry
Bathymetric Position Index – fine	–	–	Derived from bathymetry
Bathymetric Position Index – broad	–	–	Derived from bathymetry
Seamounts	–	–	Rowden et al. (2008), Yesson et al. (2011)
Water Chemistry			
Apparent oxygen utilization	ml l^{-1}	1°	Garcia et al. (2013a)
Aragonite saturation state	–	0.5°	Bostock et al. (2013)
Calcite saturation state	–	0.5°	Bostock et al. (2013)
Dissolved oxygen	ml l^{-1}	1°	Garcia et al. (2013a)
Nitrate	μmol l^{-1}	1°	Garcia et al. (2013b)
Oxygen saturation	%	1°	Garcia et al. (2013a)
Phosphate	μmol l^{-1}	1°	Garcia et al. (2013b)
Salinity	–	0.25°	Zweng et al. (2013)
Sigma theta (in-situ density of seawater)	kg m^{-3}	0.25°	Derived from temperature and depth
Silicate	μmol l^{-1}	1°	Garcia et al. (2013b)
Temperature	°C	0.25°	Locarnini et al. (2013)
Productivity			
Particulate organic carbon export	mg C m^{-2} d^{-1}	0.08°	Pinkerton (unpublished)
Vertically Generalized Production Model[1]	mg C m^{-2} d^{-1}	0.167°	Oregon State University[3]
Eppley-VGPM[1]	mg C m^{-2} d^{-1}	0.167°	Oregon State University[3]
Carbon Productivity Model-2[1]	mg C m^{-2} d^{-1}	0.167°	Oregon State University[3]

[1]-Surface data derived from MODIS–Aqua (NASA) as the mean, minimum, maximum, and standard deviation from mid-2002–2016.
[2]-Terrain metrics calculated using window sizes of 3, 5, 7, and 15 cells.
[3]-Data obtained from http://www.science.oregonstate.edu/ocean.productivity.

Georgian et al. (2019) included a residual auto-covariate (RAC) variable in their models for each taxon (sensu Crase et al. (2012)) to account for spatial autocorrelation (SAC) in the occurrence data. The presence of SAC can considerably affect model performance and the estimated importance of explanatory variables (Tognelli and Kelt 2004) and it is good practice to consider its impact (Winship et al. 2020). Data exploration for the models used in this assessment suggested that, although some significant SAC was present in the observations, tested using Moran's I (Moran 1948), it was not necessary to include RAC variables in the models to account for it because the effect on model outputs was very low. Nevertheless, the new model evaluation procedures accounted for SAC using spatial blocking (block sizes being based on distances at which SAC is no longer significant for a taxon (Figure 38). Model cross-validation (Valavi et al. 2019) was also conducted using the new (independent of the original models) records.

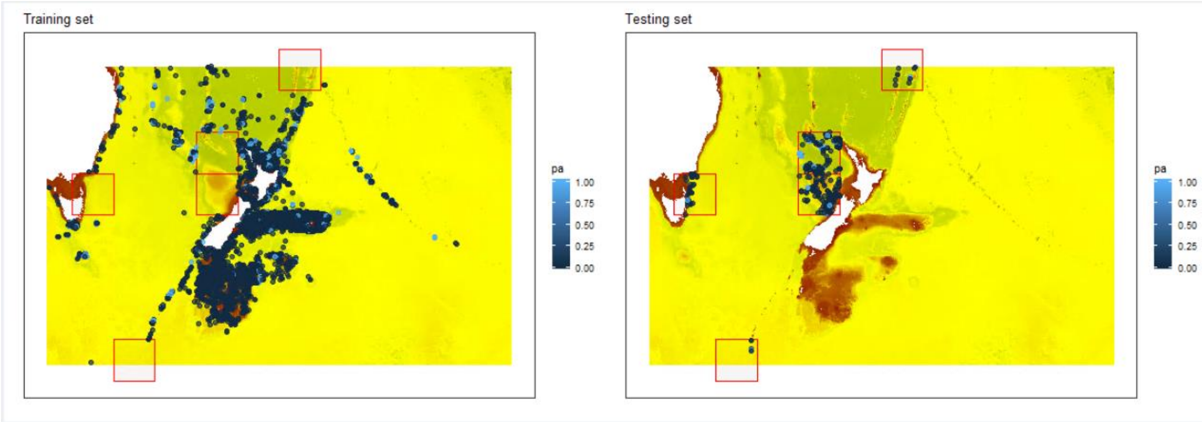


Figure 38: Training (left) and testing (right) datasets for HSI model evaluation. Dots represent data points used in either set, while red boxes represent spatial evaluation blocks.

Validation was also performed for the new models tuned using the data available to Georgian et al. (2019) by calculating the mean area under the curve metric (AUC, Table 24a) and other performance statistics (Table 24b). Evaluations were done using only the training data set (the data available to Georgian et al. (2019)) and using the completely independent new data. In these tests, AUC was consistently >0.7 for bootstrapped replicates in both training and evaluation data subsets. AUC indexes a model's ability to correctly rank occurrences above background locations; a random model has a theoretical AUC of 0.5, AUC >0.7 indicates adequate performance, and AUC >0.8 indicates excellent performance (Hosmer Jr et al. 2013). These performance statistics show that the new models tuned to data available to Georgian et al. (2019) have excellent performance at classifying both presence and (informed) pseudo absence for each VME indicator taxa.

The final RF, BRT, Maxent and ensemble models (using combination of presence data from training and evaluation datasets, Figure 39) had consistently high AUC scores for all VME indicator taxa, which were the same or higher than the Georgian et al. (2019) models. Ensemble models consistently achieve AUC in the range 0.89 to 0.99, indicating excellent performance at classifying records as presence or (informed) pseudo-absence. Final spatial predictions for each VME indicator taxa were created using all the available data (that available to Georgian et al (2019) plus the new data) and would be expected to perform even better than the AUC values in Table 24 a&b suggest.

Table 24a: Percent increase in the number of records used in 2020 models compared with those developed by Georgian et al. (2019) and mean area under the curve metric (AUC) values for each model type (RF = random forest, BRT = boosted regression tree, MX = maximum entropy, ENS = ensemble models) and each of the VME indicator taxa that were modelled. The left block of AUC values relate to tests of the new models using the data available to Georgian et al. 2019, and the right block relates to tests of the new models tuned using the data available to Georgian et al. but tested using the new, entirely independent data.

		Tested using Georgian et al. data				Tested with independent data			
Code	% increase in records	RF AUC	BRT AUC	MX AUC	ENS AUC	RF AUC	BRT AUC	MX AUC	ENS AUC
ERO	31%	0.98	0.93	0.91	0.95	0.96	0.94	0.91	0.96
GDU	28%	0.99	0.97	0.93	0.98	0.96	0.92	0.76	0.97
MOC	12%	0.98	0.94	0.91	0.96	0.99	0.98	0.97	0.97
SVA	60%	0.98	0.89	0.89	0.95	0.99	0.96	0.96	0.96
COB	41%	0.99	0.97	0.87	0.97	0.98	0.96	0.87	0.97
COR	37%	0.98	0.94	0.79	0.94	0.98	0.96	0.87	0.96
DEM	139%	0.99	0.97	0.73	0.98	0.97	0.95	0.70	0.99
HEX	118%	0.98	0.96	0.78	0.97	0.97	0.96	0.82	0.98
PTU	121%	0.99	0.96	0.88	0.97	0.98	0.94	0.87	0.97
SOC	140%	0.98	0.95	0.78	0.95	0.76	0.76	0.75	0.89
Alcy	13%	0.98	0.81	0.80	0.90	0.97	0.87	0.86	0.92

VME distribution models in Georgian et al. 2019 were combined into an ensemble model, using a weighted average of overall model performance (AUC value) for each model (see e.g. Figures 38 and 39). BRT, RF and Maxent models were bootstrapped 200 times for each VME indicator taxa. That is, a random 'training' sample of the presence-relative absence records was drawn with replacement. At each BRT, RF and Maxent model iteration, geographic predictions were made using environmental predictor variables to a 1 km^2 grid. For each VME indicator taxon, mean probability of occurrence and a spatially explicit measure of uncertainty (measured as the standard deviation of the mean (SD)) were calculated for each grid cell using the 200 bootstrapped layers. An associated measure of the uncertainty in the prediction (the SD of the mean HSI) was associated with each model (see e.g. Figure 41 for *Solenosmilia variabilis*). Building on this method, new models used spatially explicit model weightings, combining overall model performance (AUC value) and spatially explicit uncertainty estimates (SD of mean HSI predictions for each cell).

The difference between the new ensemble models for VME indicator taxa, and their component models, are illustrated in Figures 42 and 43. The principal drivers of these differences were the absence of the RAC variable, which was not required in the new models, based on analyses of autocorrelation, and the use of target group background data (and the number of these used in the models). Compared with the ensemble models, BRT and Maxent models generally predicted higher and lower indices of habitat suitability, respectively. RF models tended to predict areas of both higher and lower habitat suitability than the ensemble models. The spatial predictions of suitable habitat for VME indicator taxa did differ between the Georgian et al. (2019) models and the new models. For example, a comparison of the ensemble models indicates that the new model estimated much higher suitability for wide areas for some taxa and lower for other taxa (Figures 42 and 43).

Table 24b: Performance metrics for the new models tuned using only the data available to Georgian et al. (2019) and tested using the new, entirely independent data. Performance metrics are AUC = mean area under the curve, TSS[18] = true skill statistic, SEN = sensitivity (a measure of true positives), SPEC = specificity (a measure of true negatives). Model types are as in Table 24a. The new models tuned using all available data would be expected to perform better. ERO = *Enallopsammia rostrata*, GDU = *Goniocorella dumosa*, MOC = *Madrepora oculata*, SVA = *Solenosmilia variabilis*, COB = Antipatharia, COR = Stylasteridae, DEM = Demospongiae, HEX = Hexactinellida, PTU = Pennatulacea, SOC = gorgonian Alcyonacea, and Alcy = non-gorgonian Alcyonacea.

	Random forest				Boosted regression tree				MaxEnt				Ensemble models			
	AUC	TSS	SEN	SPEC	AUC	TSS	SEN	SPEC	AUC	TSS	SEN	SPEC	AUC	TSS	SEN	SPEC
ERO	0.96	0.90	0.95	0.96	0.94	0.82	0.94	0.89	0.91	0.72	0.87	0.85	0.96	0.85	0.93	0.92
GDU	0.96	0.85	0.96	0.89	0.92	0.76	0.94	0.82	0.76	0.47	0.67	0.81	0.97	0.77	0.95	0.81
MOC	0.99	0.95	0.95	1.00	0.98	0.92	0.95	0.98	0.97	0.85	0.88	0.98	0.97	0.92	0.93	0.99
SVA	0.99	0.92	0.99	0.93	0.96	0.79	0.91	0.88	0.96	0.81	0.92	0.89	0.96	0.84	0.94	0.90
COB	0.98	0.88	0.95	0.93	0.96	0.79	0.90	0.88	0.87	0.61	0.83	0.77	0.97	0.79	0.87	0.92
COR	0.98	0.90	0.96	0.94	0.96	0.81	0.92	0.89	0.87	0.59	0.85	0.75	0.96	0.82	0.93	0.88
DEM	0.97	0.91	0.98	0.93	0.95	0.80	0.94	0.86	0.70	0.27	0.51	0.76	0.99	0.85	0.96	0.89
HEX	0.97	0.87	0.97	0.89	0.96	0.78	0.92	0.86	0.82	0.51	0.69	0.82	0.98	0.79	0.92	0.87
PTU	0.98	0.87	0.96	0.91	0.94	0.75	0.89	0.86	0.87	0.56	0.78	0.78	0.97	0.79	0.93	0.86
SOC	0.76	0.39	0.65	0.74	0.76	0.38	0.58	0.80	0.75	0.40	0.74	0.66	0.89	0.40	0.73	0.67
Alcy	0.97	0.87	0.96	0.91	0.87	0.62	0.90	0.72	0.86	0.58	0.88	0.70	0.92	0.74	0.91	0.83

[18] TSS and AUC both measure the ability of a model to discriminate between presences and absences. TSS scales from -1 to +1; values of +1 show perfect agreement, 0 indicates no better than random, and < 0 indicates systematically incorrect prediction (Allouche, Tsoar, & Kadmon, 2006). TSS values >0.6 are considered useful to excellent. AUC is a highly effective, threshold-independent measure of accuracy; a random model has a theoretical AUC of 0.5, AUC > 0.7 indicates adequate performance, and AUC > 0.8 indicates excellent performance (Hosmer Jr et al. 2013). TSS is a threshold-dependent measure of accuracy, but is not sensitive to prevalence (Allouche et al., 2006; Komac, Esteban, Trapero, & Caritg, 2016).

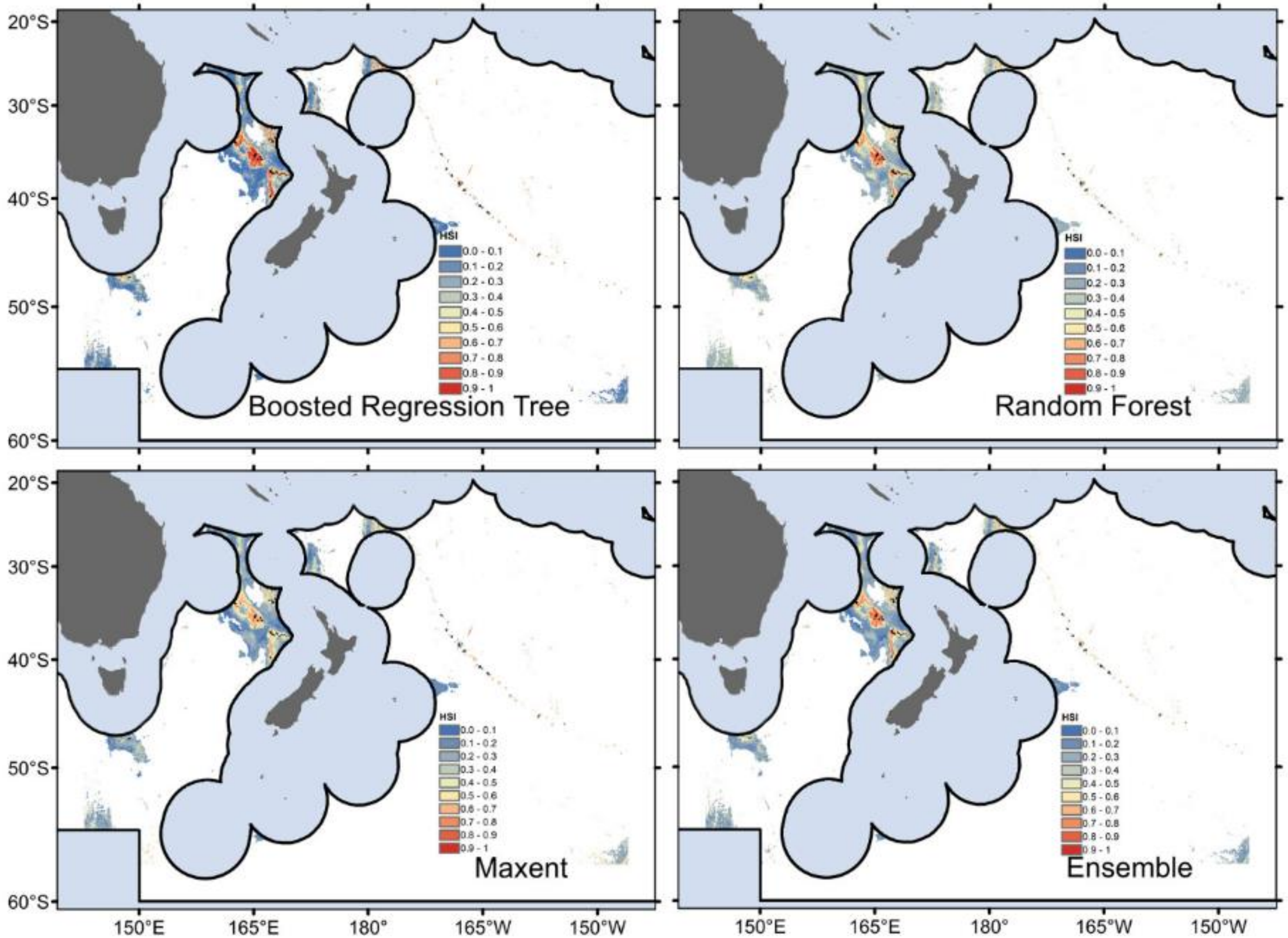


Figure 39: Habitat suitability maps derived from Boosted Regression Tree (BRT, upper left), Random Forest (RF, upper right) and Maxent (lower left) models for black coral (Antipatharia, COB). An ensemble model output (lower right panel) combines the other three models.

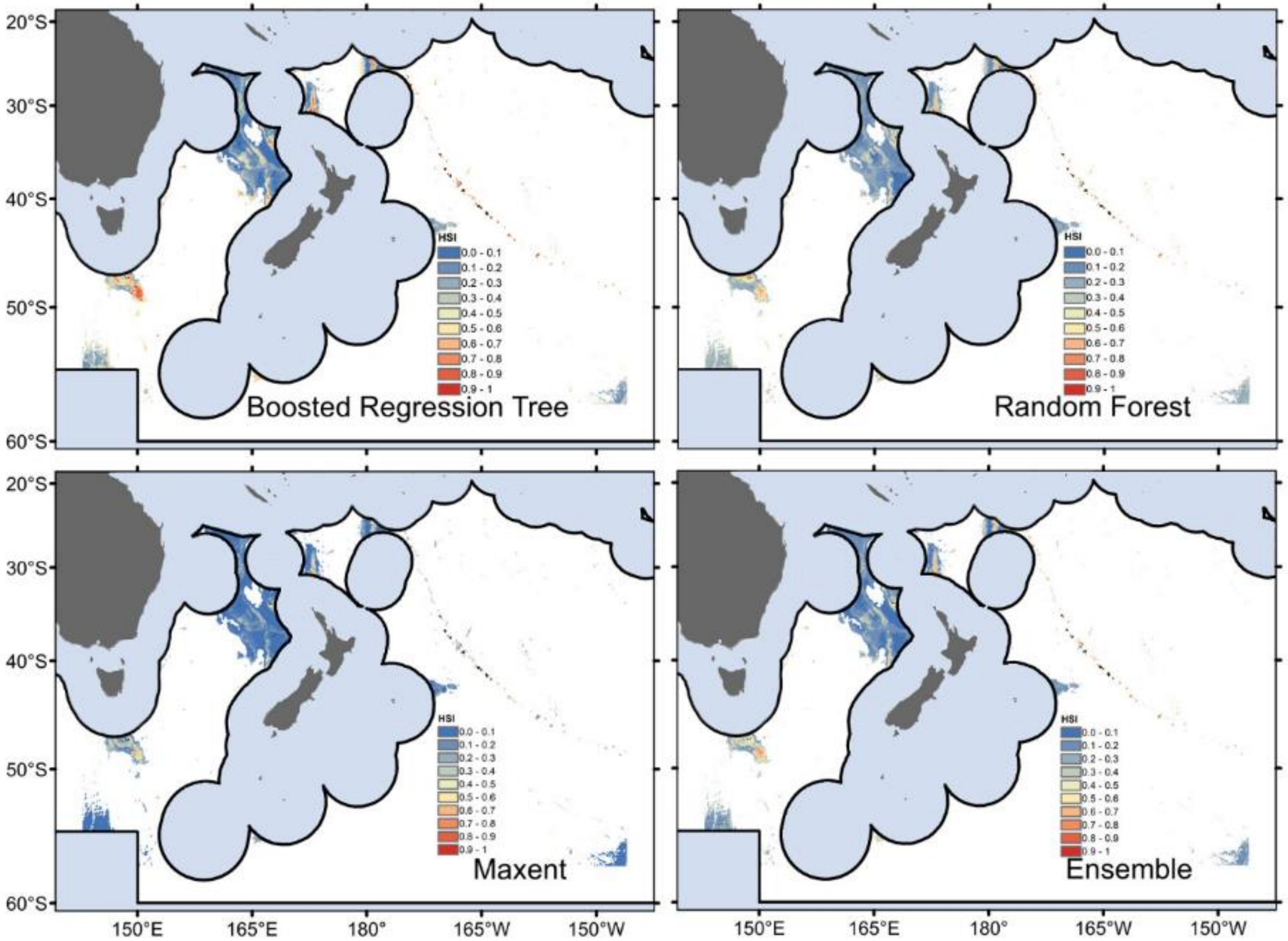


Figure 40: Habitat suitability maps derived from Boosted Regression Tree (BRT, upper left), Random Forest (RF, upper right) and Maxent (lower left) models for *Solenosmilia variabilis* (Scleractinia, SVA). An ensemble model output (lower right panel) combines the other three models.

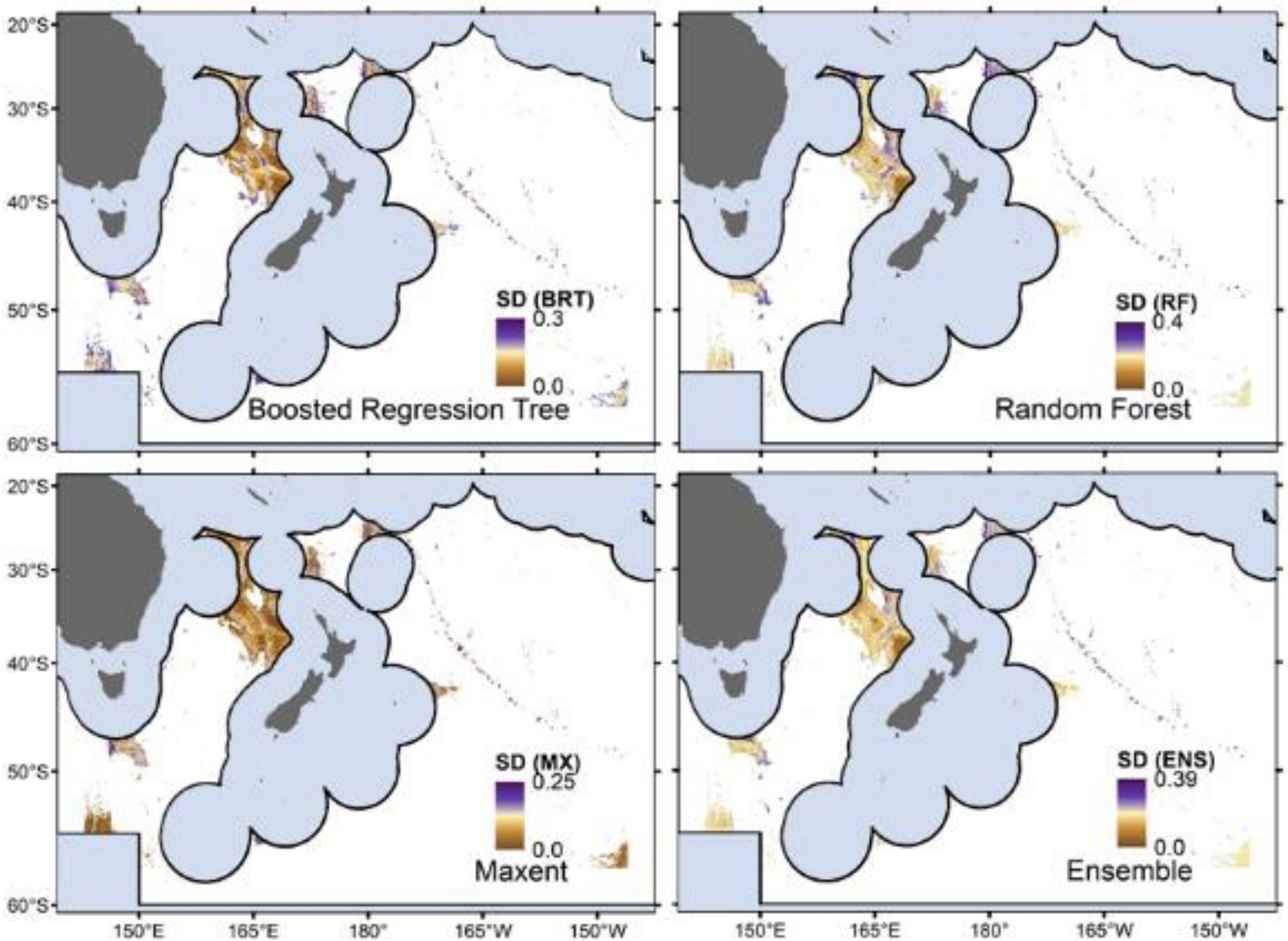


Figure 41: Spatially explicit modelled uncertainty in Boosted Regression Tree (BRT, upper left), Random Forest (RF, upper right) and Maxent (lower left) models for *Solenosmilia variabilis* (Scleractinia, SVA). Uncertainty is shown also for the ensemble model (lower right panel), combining the other three models.

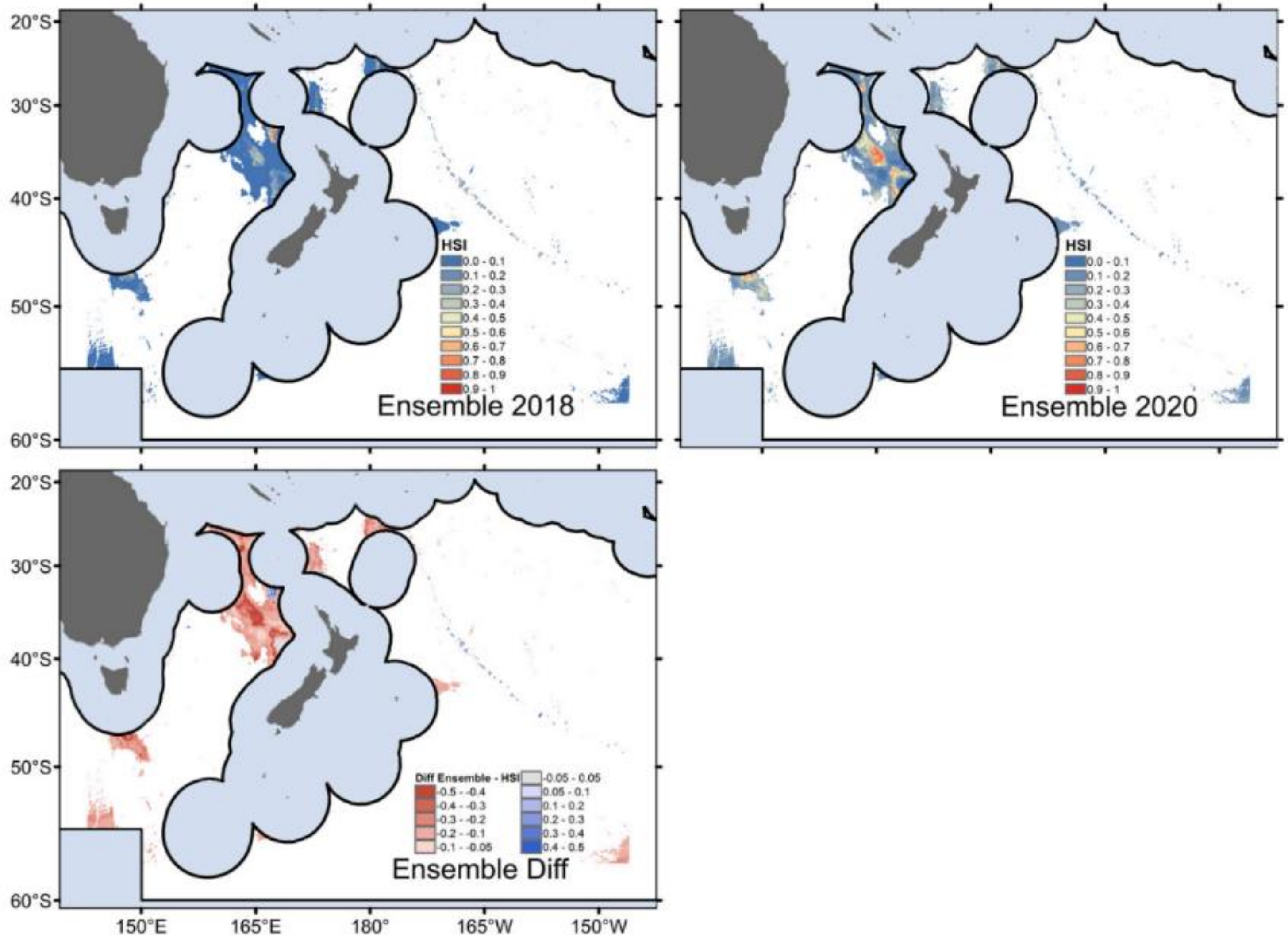


Figure 42: Degree of difference (lower left plot) between the 2018 (upper left) and the 2020 (upper right) ensemble habitat suitability estimates for deepwater branching coral (Scleractinia, ERO).

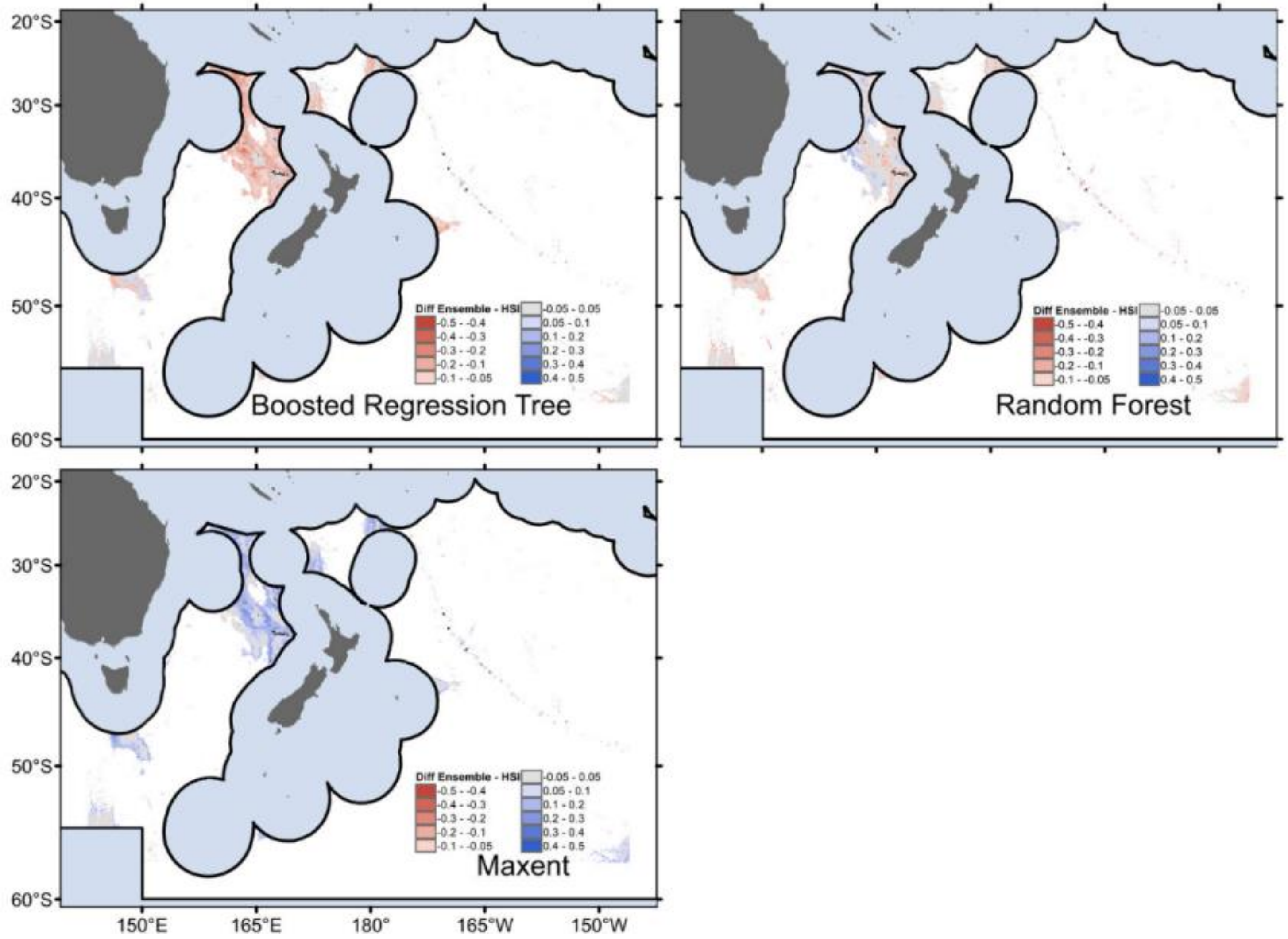


Figure 43: Degree of difference between the 2018 and the 2020 habitat suitability estimates for sea pens (Pennatulacea, PTU), derived from its single components: Boosted Regression Tree (upper left), Random Forest (upper right), and Maxent (lower left).

Both the Georgian et al. (2019) and the new models predict into areas where no occurrence data for VME indicator taxa exists. Two methods were used to assess the uncertainty that could be included in the new models because of this issue: environmental coverage (Smith et al. 2013) and Multivariate Environmental Similarity Surfaces (MESS (Elith et al. 2010)). Environmental coverage (Figure 44) indicates which parts of the environmental space contain many sighting records (across all taxa), and therefore the likelihood that the predicted relationship between the environment and taxa is more certain. MESS measures the similarity in the analysed variables between any given locality in the projection dataset and the localities in the reference (training) dataset. Generally, both these methods indicated that there is poor coverage of environmental data in the deepest waters, but that the coverage is adequate in depths where fishing takes place.

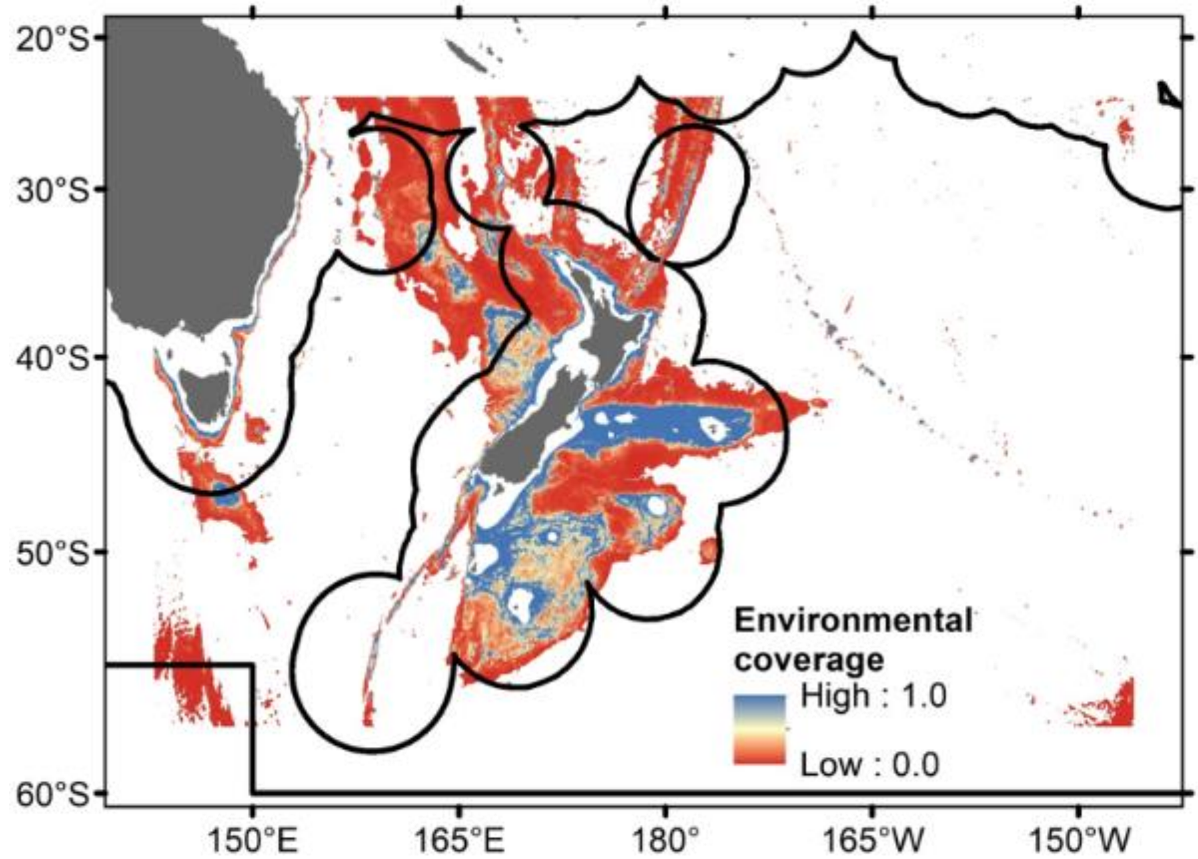


Figure 44: Environmental coverage (from low to high), i.e. spatial extent and level of detail of environmental data.

4.5 RISK ASSESSMENT FOR BENTHIC HABITATS, BIODIVERSITY AND VMES

4.5.1 Spatial footprint and intensity of fisheries

The fishing footprint was calculated following the methods outlined in Mormede et al. (2017). All available New Zealand and Australian recorded fishing events using bottom-contacting methods were obtained and assembled, the resulting dataset covering the 30-year period from 1989–2019. Data were groomed to remove or correct erroneous values and unwanted records (e.g. overly long trawls/sets, locations in too-deep water or outside of the evaluated area).

The data available included three fishing methods: bottom trawling, midwater trawling, and bottom longlining. Most of the New Zealand trawls were recorded as bottom trawls, but this distinction between trawl methods was only available for the recent Australian data (2019). The total number of recorded midwater trawls for the whole assessment period was 775 (about 1% of the total, Table 25).

The start and end locations of all sets and trawls were jittered by 0.5 minutes (using a uniform random distribution) to spatially separate records overlying due to rounding of reported positions to the nearest minute of arc. Tow positions were also adjusted using trawl geometry and depth so as to represent the position of the trawl on the seafloor rather than the vessel position.

Following Mormede et al. (2017), trawl and longline records were split into approximately 100 m long segments. For trawls the calculated tow distance, and hence the number of these segments, was based on speed and duration rather than start and end positions to account for trawls that vary off a direct course between the recorded start and end position (technically, all of them). The width assigned to each trawl segment varied, and was set according to the fishing method, bottom type, and nationality (the Australian trawlers have typically used smaller trawls) based on figures tabulated in Mormede et al. (2017) and unpublished notes from a 2017 SPRFMO trawl impact workshop (Table 26).

Because the extent and duration of bottom trawl gear contact with the seafloor depends on whether they are conducted on slopes of underwater topographical features, bottom trawls were designated as Underwater Topographical Feature (UTF) tows if the start position was within 3 n. miles of a hill, 5 n. miles of a knoll, or 8 n. miles of a seamount, and if trawl duration was less than 0.5 h; tows not meeting these criteria were designated SLOPE tows. The position of UTF trawls with end position equal to start position, or with missing end position, were adjusted back in the direction of the nearest UTF peak. Segment widths were further adjusted for UTF and midwater tows, to account for the lesser impact from the various components of the trawl (doors, sweeps/bridles, ground gear) due to the reduced period of seafloor contact by some components of the gear during the tow. For example, tows using midwater trawls to target benthopelagic species only rarely touch the bottom and only for very short time periods, and bottom trawl tows on UTFs are generally undertaken with the doors off the bottom. UTF segment widths were reduced by a ratio of 0.24/0.82 and midwater segment widths by a ratio of 0.001/0.82 (based on values in Mormede et al. 2017 and from the trawl impact workshop in July 2017).

Table 25: Number of fishing events used in the analyses; by year, method, and nationality.

			Number of trawls			Number of longlines
Year	**AUS**	**NZL**	**Total**	**AUS**	**NZL**	**Total**
1989	0	9	9	0	0	0
1990	0	254	254	0	0	0
1991	0	37	37	0	0	0
1992	0	150	150	0	2	2
1993	0	2 872	2 872	0	64	64
1994	0	3 960	3 960	0	0	0
1995	0	5 667	5 667	0	0	0
1996	52	4 219	4 271	0	6	6
1997	646	2 478	3 124	0	19	19
1998	1 504	2 002	3 506	0	5	5
1999	1 190	2 849	4 039	0	15	15
2000	930	1 960	2 890	5	8	13
2001	396	2 156	2 552	21	0	21
2002	554	3 517	4 071	22	0	22
2003	332	3 499	3 831	7	26	33
2004	251	2 741	2 992	3	102	105
2005	207	2 472	2 679	0	295	295
2006	874	1 413	2 287	28	669	697
2007	203	629	832	18	427	445
2008	0	239	239	85	245	330
2009	0	649	649	48	210	258
2010	0	1 183	1 183	49	66	115
2011	171	1 153	1 324	52	60	112
2012	393	713	1 106	58	131	189
2013	244	876	1 120	80	260	340
2014	102	403	505	49	307	356
2015	18	933	951	79	199	278
2016	49	980	1 029	90	135	225
2017	73	1 452	1 525	91	192	283
2018	0	1 041	1 041	111	172	283
2019	108	269	377	84	392	476

Table 26: Nominal swept widths (m) applied to trawls by fishing type and nationality

	Australia	New Zealand
Slope tows	100	135
Feature tows	85	115
Midwater tows	30	30

The effective width of the area impacted by bottom longlines is largely determined by the lateral movement of the backbone during retrieval and that has been shown to vary according to depth. Segment widths were estimated according to a calculation derived from Welsford et al. (2013) and Darby (2010), and based on the depth of the set:

Width=exp(2.4892514 - 0.0011380* Depth)

Impact widths thus estimated were mostly between 6 m and 10 m but were up to 12 m for some shallower sets (Figure 45). Fishing footprints for each fishing method were derived from the segment data by assigning each segment to a cell of a standard 1x1 km grid in Mercator 41 projection with an extent defined by the Evaluated Area. The total footprint in each cell was calculated by adding the areas of all segments with midpoints within the cell, assuming random overlap between segments (after Mormede et al 2017). Using this procedure, the total accumulated footprint from bottom trawling inside the evaluated area in 1989–2019 was calculated to be 17643.4 km^2. By comparison, the equivalent footprint from midwater trawling was 0.22 km^2 and the equivalent footprint from bottom longlining was 96.96 km^2. The very small footprint of midwater trawls stems from the trawl impact workshop conclusion that, on average, only 30% of midwater trawls contact the seafloor and that contact happens only twice per tow, for an average of 25 seconds each time.

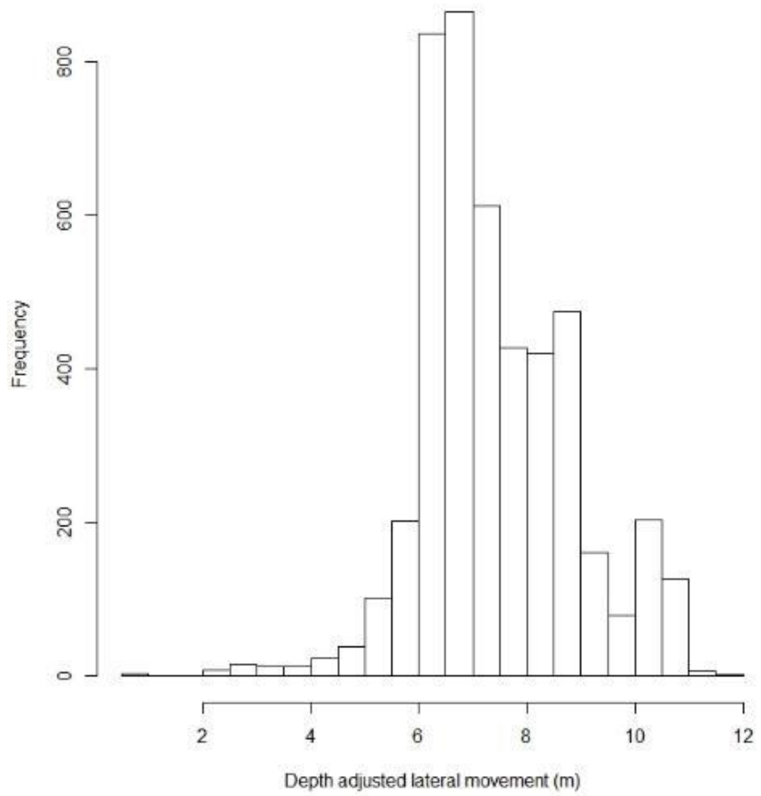


Figure 45: Distribution of estimated, depth-adjusted longline impact widths.

The footprints as a percentage of the total high-seas seafloor area within the Evaluated Area, and each of the Bioregions defined by Costello et al. (2017), the broad fisheries administrative units considered in the previous assessment, and the revised Fisheries Management Areas for orange roughy as defined by Clark et al. (2016), were also calculated (Figure 46).

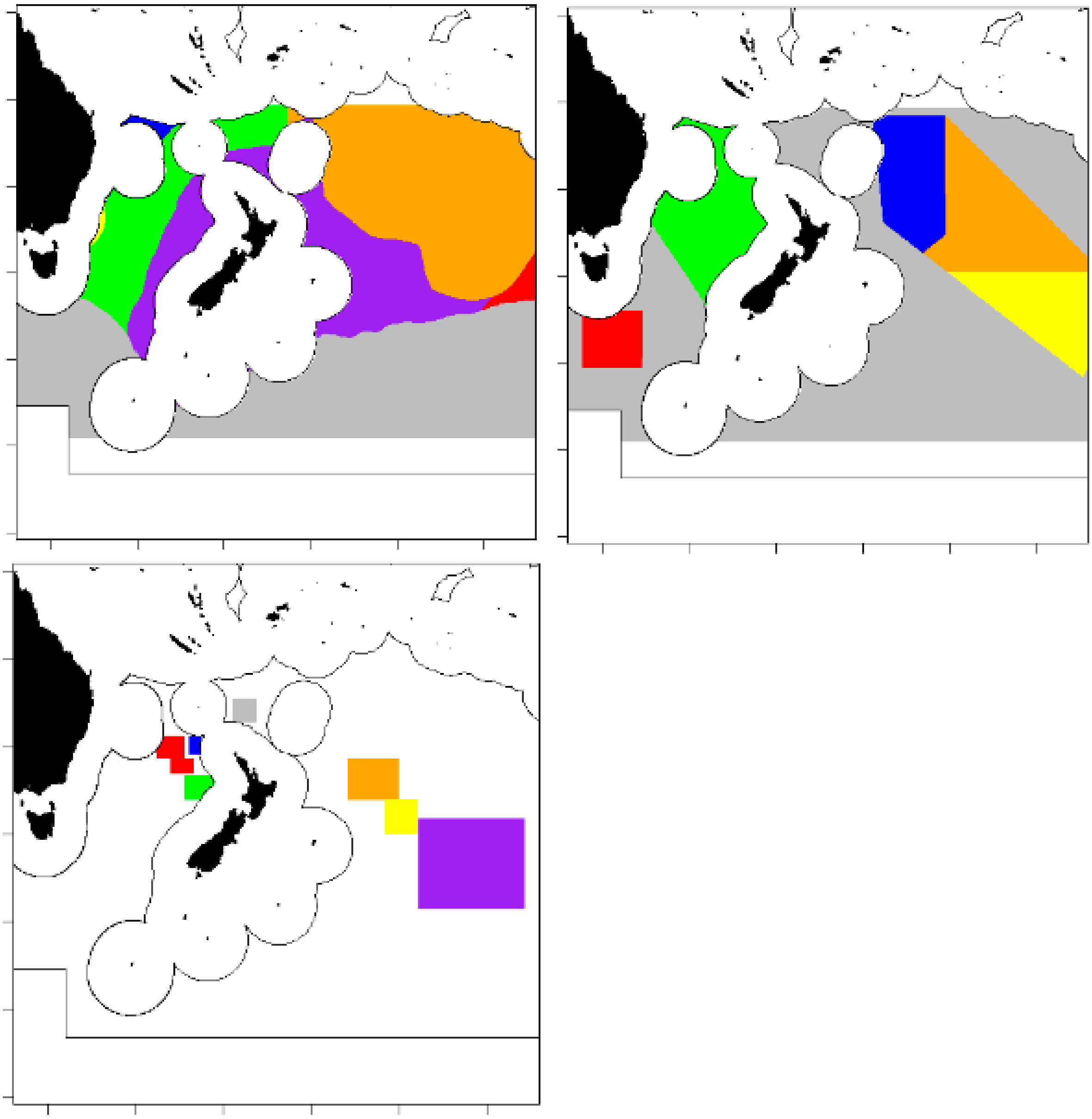


Figure 46: Bioregions from Costello et al. 2017 (upper left), broad fisheries administrative units considered in the previous assessment (upper right), and revised Fisheries Management Areas as defined by Clark et al. 2016 (lower left), represented as coloured areas.

The bottom trawl footprint dominates in all these percentages, and is estimated to have contacted 0.13% of the total seafloor in the high-seas of the Evaluated Area, but 1.9% when restricted to the depths used in the habitat suitability models (200–3000 m), and 6.6% when further restricted to fishable depths (<1400 m). The percentages are highest in the fishable depths of the LSC broad administrative units where they reach 40.4% in the Louisville Central, and 46.7% in the equivalent FMA of Clark et al. (2016) (Table 27).

In some regions, particularly those dominated by seamounts where tow lines may be narrowly defined (e.g. the LSC), there is potential for overestimation of these percentages, if the jittered positions of the original fishing locations overrepresent their real variability around the rounded values recorded.

This issue may be investigated in future by examination of more recent data with higher spatial resolution.

Table 27: Percentage of seafloor contacted within the high seas parts of the Evaluated Area and areas of the Costello et al. (2017) Bioregions and two different administrative areas, by fishing gear type. –, zero footprint for a method in an area.

	All depths			Model depths (200-3000 m)			Fishable depths (<1400 m)		
Regions	**BT**	**MW**	**BLL**	**BT**	**MW**	**BLL**	**BT**	**MW**	**BLL**
Evaluated Area	0.129	0.00000158	0.00071	1.897	0.0000232	0.01043	6.586	0.000804	0.03619
Bioregions (Costello et al 2017)									
South-East Pacific (10)	–	–	–	–	–	–	–	–	–
Tasman Sea to SW Pacific (15)	0.066	0.00001107	0.00226	0.394	0.0000669	0.01256	1.312	0.000225	0.0405
Tropical Australia & Coral Sea (16)	0.318	–	0.01622	0.357	–	0.01817	0.534	–	0.0368
Mid South Tropical Pacific (17)	0.027	0.00000009	0.00004	1.618	0.0000046	0.00253	3.507	0.000010	0.0071
South Australia (26)	–	–	–	–	–	–	–	–	–
New Zealand (28)	0.670	0.00000232	0.00184	4.324	0.0000146	0.01157	12.557	0.000043	0.0333
Southern Ocean (30)	0.009	0.00000002	0.00000	0.199	0.0000004	0.00004	1.369	0.000002	0.0002
Broad administrative units (as used in 2018)									
South Tasman Rise	0.116	0.00000020	0.00002	0.549	0.0000010	0.00010	2.820	0.000005	0.0005
Tasman Sea	1.214	0.00001703	0.00629	2.931	0.0000410	0.01438	7.327	0.000104	0.0350
Louisville (N)	0.087	0.00000032	0.00014	4.573	0.0000138	0.00810	18.349	0.000052	0.0393
Louisville (C)	0.061	0.00000007	–	9.115	0.0000033	–	40.430	0.000008	–
Louisville (S)	0.063	0.00000012	–	5.947	0.0000111	–	19.398	0.000046	–
Not assigned	0.002	0.00000004	0.00008	0.042	0.0000013	0.00232	0.726	0.000022	0.0405
ORY stock areas (FMAs) (Clark et al 2016)									
Lord Howe Rise (1)	3.855	0.00002787	0.00001	3.855	0.0000279	0.00001	5.755	0.00004	–
Lord Howe Rise (2)	0.835	0.00020733	0.00269	1.209	0.0003002	0.00390	1.707	0.00042	0.00550
NW Challenger Plateau	13.866	0.00003482	0.01813	14.363	0.0000361	0.01878	20.717	0.00005	0.02707
West Norfolk Ridge	1.389	0.00001921	0.07262	1.372	0.0000159	0.06880	2.420	0.00003	0.13358
Louisville (N)	0.338	0.00000122	0.00056	7.440	0.0000225	0.01320	22.721	0.00006	0.04874
Louisville (C)	0.675	0.00000083	–	12.476	0.0000045	–	46.727	0.00001	–
Louisville (S)	0.052	0.00000009	–	6.648	0.0000124	–	21.321	0.00005	–
Three Kings Ridge	0.140	0.00000444	0.00830	0.320	0.0000103	0.01875	2.295	0.00007	0.13211
South Tasman Rise	0.307	0.00000054	0.00005	0.705	0.0000013	0.00012	2.998	0.00001	0.00053

4.5.2 Current state of impacted taxa

Knowledge of the likely current status of impacted benthic taxa is an important input to Zonation prioritisation analyses if there is a preference to prioritise protection of locations where the fauna is likely to be in good condition. The calculation of naturalness, a spatial representation of the current status of a taxon after the effects of all historical trawling, requires at a minimum an estimate of the mortality (i.e. depletion) caused by the passing of fishing gear, and ideally also an estimate of its ability to recover. Depletion (d) and recovery rate (R) values were obtained from (or based on) values published in three studies (Welsford et al. 2013, Mormede et al. 2017, Pitcher et al. 2017) (Table 28).

Uncertainty around these values was estimated as follows: overall variability in d and R values was calculated using Median Absolute Deviations (MADs) for all available taxa in the original Pitcher et al. (2007) data, then weighted mean values of d and R for all available taxa were sampled using the uncertainty provided by the MADs, with n=24 000, to estimate the distribution of d/R ratios across all taxa. The mean of the relative MAD values for each taxon (MAD/ weighted mean) were then calculated, weighted by number of data points available for each group and these, when halved, provide a range of d/R ratios that approximately covers the inter-quartile range of the full sampling of sensitivities – so that a sensible range of values is d ±0.443/2 = ±0.2215 R ±0.507/2 = ±0.2535. This provides low and high values of d and R that can be used to produce appropriate pessimistic and optimistic estimates of naturalness.

Table 28: Trawl and longline fishing depletion (d) and recovery (R) rates for the ten taxa modelled, with sensitivities for the uncertainties in these values (low and high) as used in the calculation of naturalness. Stony corals: ERO = *Enallopsammia rostrata*, GDU = *Goniocorella dumosa*, MOC = *Madrepora oculata*, SVA = *Solenosmilia variabilis*. Other VME indicator taxa: COB = Antipatharia, COR = Stylasteridae, DEM = Demospongiae, HEX = Hexactinellida, PTU = Pennatulacea, SOC = gorgonian Alcyonacea, and Alcy = other Alcyonacea (soft corals).

	Depletion (trawl)			Depletion (longline)			Recovery		
Taxon	d	d (low)	d (high)	d	d (low)	d (high)	R	R (low)	R (high)
ERO	0.67	0.52	0.82	0.03	0.02	0.04	0.20	0.15	0.25
GDU	0.67	0.52	0.82	0.03	0.02	0.04	0.20	0.15	0.25
MOC	0.67	0.52	0.82	0.03	0.02	0.04	0.20	0.15	0.25
SVA	0.67	0.52	0.82	0.03	0.02	0.04	0.20	0.15	0.25
COB	0.50	0.39	0.61	0.27	0.21	0.33	0.33	0.25	0.41
COR	0.41	0.32	0.50	0.03	0.02	0.04	0.33	0.25	0.41
DEM	0.38	0.30	0.46	0.14	0.11	0.17	0.24	0.18	0.30
HEX	0.38	0.30	0.46	0.14	0.11	0.17	0.24	0.18	0.30
PTU	0.34	0.26	0.42	0.03	0.02	0.04	0.39	0.29	0.49
SOC	0.50	0.39	0.61	0.27	0.21	0.33	0.27	0.20	0.34
Alcy	0.35	0.27	0.43	0.03	0.02	0.04	0.24	0.18	0.30

Three different approaches to assessing taxon-specific naturalness within fished areas of SPRFMO were considered:

1. **Mormede-Sharp-Roux-Parker (MSRP)** (Mormede et al. 2017). This method calculates naturalness in a similar way to that of the footprint, adjusting the trawl or longline segment widths by the taxon-specific depletion value then adding the adjusted areas of all segments with midpoints within each grid cell, assuming random overlap between segments. This method assumes 100% mortality within the adjusted segments and does not allow for any recovery over time, so will under-estimate current naturalness.

2. **Relative benthic status (RBS)** (Pitcher et al. 2017). This method estimates the status of benthos using the formula for the equilibrium of the Schaefer (1954) population model and requires grids of total fishing effort (as Swept Area Ratios (SAR), essentially total annual footprints combined without assuming any overlap), depletion rates as in the MSRP method,

and taxon-specific recovery rates. This method accounts for future impacts as well as past impacts, so may under-estimate current naturalness in some areas.

3. **Schaeffer ("S30")**. This is a similar approach to RBS in that it takes into account both depletion and recovery, but is based directly on the Schaeffer (1954) stock production model, with status being calculated iteratively, by year. Depletion (d), recovery (R) and average annual SAR are applied iteratively for the 30 years of recorded fishing, so that future impacts are not included. Status after 30 years estimates current-day naturalness, although there may be underestimation of naturalness if fishing intensity was greater in the early part of the 30-year time period than in more recent years.

The "S30" method was selected over MSRP and RBS as it was considered to best represent current-day naturalness, taking into account both depletion and recovery. Naturalness is presented as the relative status of the taxon in each cell, with a value of zero meaning complete depletion of the taxon and a value of 1 meaning no depletion of the taxon. Estimates of naturalness for the two sponge taxa are identical as they were assumed to have the same d and R values, and the same is true for the four stony coral taxa. These taxa are used to illustrate the variability in naturalness among the ten VME indicator taxa of interest, as they represent those with the most extreme d and R values (the corals being more vulnerable and the sponges less vulnerable), and between the pessimistic and optimistic d and R sensitivities (Figure 47). In the optimistic case for sponge taxa, the Challenger Plateau region is strongly dominated by values near to 1, indicating a high level of naturalness, with just small areas of more intensely fished cells where naturalness values are closer to zero. Conversely, in the pessimistic case for stony corals, naturalness over a large region of the Challenger Plateau fishery area is 0.4 or lower, with areas of high naturalness restricted to the margins of the area where fishing intensity is lowest.

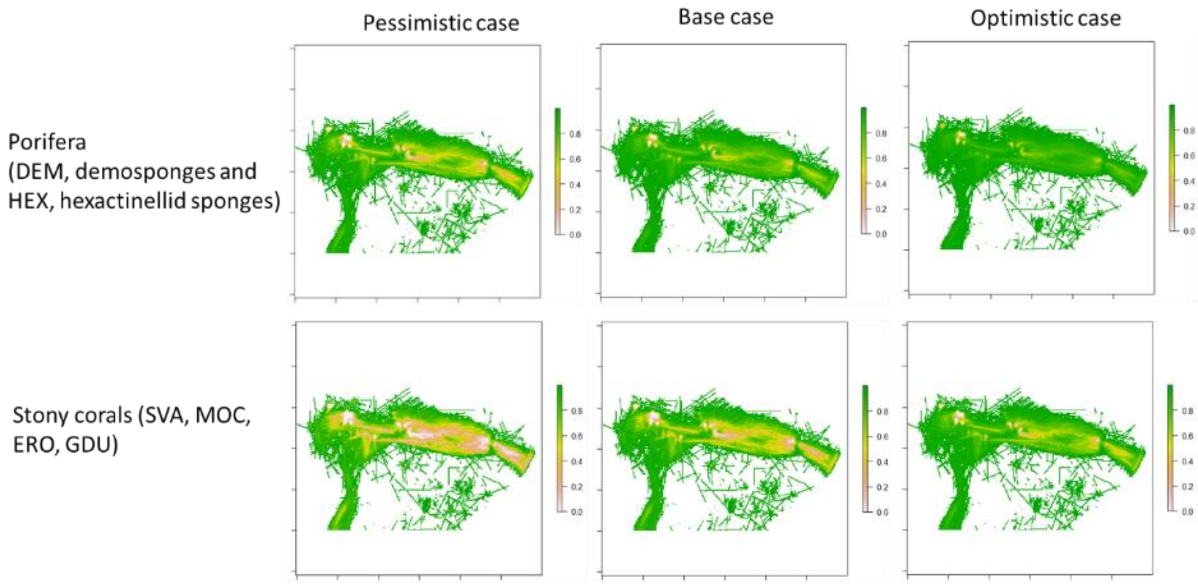


Figure 47: The representation of the current status of taxa after the effects of all historical trawling (i.e., 'naturalness estimated by "S30" for Demosponges/Hexactinellid sponges (top) and stony corals (*Madrepora oculata*/*Solenosmilia variabilis*/*Goniocorella dumosa*/*Enallopsammia rostrata*) (bottom) for the Challanger Plateau area within the Evaluated Area. Plots on the left are the result of the more pessimistic d and R values, plots in the middle column are for the base estimates of d and R, and the right-hand plots are for the most optimistic estimates of d and R (see Table 27).

4.5.1 Relative benthic status (RBS) assessment

RBS is quantitative method based on the Schaefer (1954)-type population model, as commonly used for stock assessments, with an additional term to describe the direct impacts of trawling on seabed benthos, consistent with previous dynamic-modelling approaches to seabed assessment (Ellis et al. 2014, Pitcher et al. 2015, Pitcher et al. 2016). To enable application to the typically data-limited circumstances of seabed assessment, RBS is a simpler approach, such that in habitats subject to chronic trawling, the long-term relative abundance of biota as a fraction of carrying capacity can be estimated by the equilibrium solution of the Schaefer model. Estimating RBS requires maps of fishing intensity and habitat distributions, and parameters for trawl impact and recovery rates (see Section 4.5.2). The status of trawled habitats and their RBS value depend on impact rate (depletion per trawl), recovery rate and exposure to trawling (Pitcher et al. 2017). Impact in RBS shares similarities with the Mormede et al. (2017) method, but also accounts for future trawling and recovery potential.

4.5.1.1 Methods

The status of VME taxa was estimated using the quantitative RBS method (Pitcher et al. 2017). The equation for RBS is based on the equilibrium solution of the Schaefer model, such that in habitats subject to chronic trawling, the long-term relative abundance of biota (B), as a fraction of carrying capacity (K) is estimated by:

$$B/K = 1 - F\,D/R \text{ where } F<R/D\text{, otherwise } B/K=0$$

where B/K represents "relative benthic status" (RBS) of the seabed in the range 0–1, R is the proportional recovery rate per year, which varies according to taxa, D is the depletion rate per trawl, which depends on gear-type and taxa, and F is trawling intensity as swept-area ratio (SAR: the annual total area swept by trawl gear within a given grid-cell of seabed, divided by the area of that grid-cell). The ratio D/R represents sensitivity to trawling—the time interval between trawls (years) that would cause local extinction of the biota (RBS=0)—and R/D is the corresponding critical annual trawl intensity F at which a given sensitivity will have RBS=0 (Fcrit). For RBS, SAR should be determined for grid cells of size ~1×1 km; a scale at which the distribution of most individual trawls has been shown to be random (although this may not hold for the highly targeted fishing on some features).

The assessment of absolute status for benthic biota requires information on distributions of abundance because different taxa may have different initial un-trawled abundance distributions and different exposure to trawling. Hence, absolute status will differ from relative status. To provide an absolute status assessment, the SPRFMO predicted HSI distributions (Section 4.4.2.3) were used with various adjustments for uncertainty (sections 4.4.2.3 and 4.5.2 and relationships between observed abundance and predicted HSI (section 4.8.3.1). Absolute status (*B*) was estimated by multiplying the predicted grid-cell distribution profiles (*K*) by the respective grid-cell RBS (i.e. *B*/*K*) for each taxon (i.e. *B*=*K*×*B*/*K*). The 'absolute' region-wide status was estimated by the sum of grid-cell *B* values and dividing by the sum of grid-cell *K* values, thus providing a status estimate in the range 0–1 that indicates the remaining proportion of total initial abundance in the assessed region.

As with the post-accounting estimates of the performance of spatial measures (Section 4.6.5), there are many possible permutations for the RBS. In this case, the following combinations were estimated:

1. Three fishing effort scenarios: historical; recent/current; future
2. 10 VME taxa
3. Taxa distribution adjustments:
   a) unadjusted model predictions of habitat suitability index (HSI, section 4.4.2.3);
   b) uncertainty (CV) down-weighted HSI (sections 4.4.2.3 and 4.5.2);
   c) ROC thresholded HSI (section 4.6.2) (i.e., HSI=0 below ROC threshold for suitable habitat) and CV down-weighted;
   d) 0.05 thresholded environmental extrapolated area HSI (Figure 43 in section 4.4.2.3) with ROC threshold and CV weighting;
   e) ROC thresholded HSI adjusted by continuous environmental extrapolated area;
   f) power transformed HSI^{Low} (Table 38 in section 4.8.3.1) (i.e., assuming a power relationship between HSI and abundance) with thresholded environmental layer;
   g) power transformed HSI^{High} (Table 38 in section 4.8.3.1) with thresholded environmental layer.
4. Taxa sensitivity (depletion/Recovery): low-, mean- and high- range Sensitivity (Table 28 in section 4.5.2)
5. Reporting areas: modelled region; fishery FMAs; BTMAs within FMAs.

The historical fishing effort scenario used the historical effort as annual average swept-area ratio by grid-cell for bottom trawl and for longline (see Section 4.5.1).

The recent/current fishing effort scenario adjusted the historical average to recent stanzas of effort for trawl (last 10 years, about half the historical average overall) and for long-line (last 7 years, about double) (see Figure 48) as well as confining trawl effort to within the spatial BTMAs. In practice, the change in trawl effort over time has differed between the Tasman Sea and the Louisville Seamount Chain and the last 10-year average annual SAR for the Tasman and LSC (912.1 km^2 and 35.1 km^2 respectively) was used to scale the recent/current trawl effort within BTMAs. Over the last 7 years, the average number of long-line operations has been 320 per year with a footprint of 0.026 km^2 per operation, giving an annual SAR of 8.4 km^2. Trawl effort (within BTMAs) and long-line effort were retained within previously fished cells. The South Tasman Rise is currently closed (since 2007) and received no trawl effort in the recent/current fishing effort scenario.

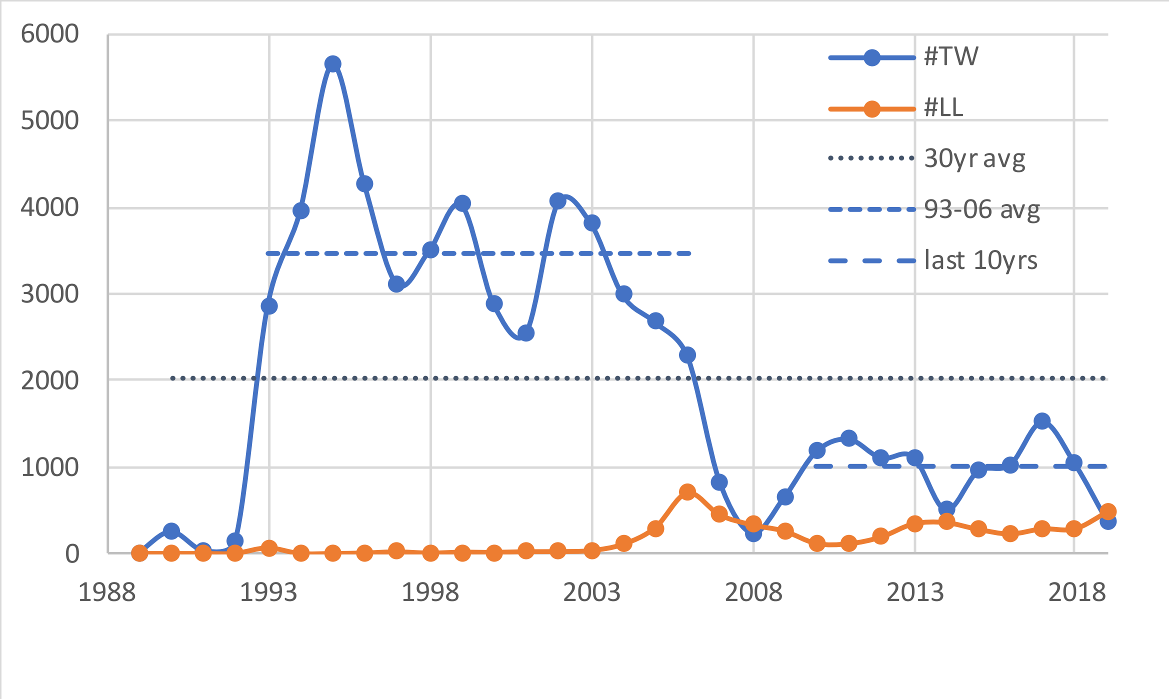


Figure 48: Annual numbers of bottom trawl (TW) and long-line (LL) operations in SPRFMO.

The future fishing effort scenario considered the limits imposed by CMMs and the mean long-term yields derived from recent orange roughy stock assessments, which are catch limits rather than effort limits. Where the recent catch history is greater than catch limits, it was assumed that effort must reduce going forward so that catch meets the limits (assuming the catch limits and catch rates in the fishery do not change). However, where the recent catch history is less than catch limits, future effort is not constrained from increasing to catch that limit. To fully understand the ongoing risks to VMEs under CMM03-2020, the future scenario should explore the limit of effort permitted under current management. The future effort adjustments are given in Table 29; the inverse of the 'under-catch' ratio is the future-effort adjustment relative to the recent/current scenario. For the future scenarios, trawl effort for the Tasman Sea, Westpac Bank and LSC were scaled separately. For the South Tasman Rise, which is currently closed but could be re-opened, the future effort was downscaled from historical effort based on the recent/historical ratio for the entire Tasman. Future trawl effort (within BTMAs) and long-line effort were retained within previously fished cells only.

It should be noted that in the reduced effort scenarios, RBS will estimate the ultimate equilibrium status. This means any previously trawled areas that are trawled with less effort will be assumed to recover to a higher status, and areas now closed will be assumed to recover completely. However, where there have been substantial historical impacts, recovery will take a very long time (up to many decades to centuries) for most taxa to recover from the historical impacts to the RBS levels indicated in such scenarios.

Table 29: Approximation of recent annual trawl catches (t) for the Tasman Sea (excluding Westpac Bank), Westpac Bank, and Louisville Seamount Chain and total regional catches for longline with current catch limits or mean long term yields estimated by recent orange roughy stock assessments. The hypothetical under-catch is indicated by recent average annual catch divided by current catch limit or mean long term yield estimated by recent stock assessments. Note that catch totals for the Tasman Sea may contain relatively small amounts of species other than orange roughy but that exclusion of these catches would not substantially change the hypothetical under-catch ratio.

Year	Tasman	Westpac	LSC	Longline
2010	879	5	584	
2011	852	5	285	
2012	681	8	288	
2013	732	3	565	257
2014	236	54	758	198
2015	732	118	462	303
2016	732	234	73	272
2017	642	129	420	280
2018	584	569	81	194
2019	257	111	139	256
Average	632.7	123.6	365.5	251.4
Catch limit or yield estimate	852	258	1140	973
Under-catch	0.743	0.479	0.321	0.258

4.5.1.2 Results

The status of fished habitats depends on their depletion (d) rate, recovery (R) rate and exposure to fishing and its intensity. Rates for d and R are taxon-specific and are given for 10 assessed taxa in Table 28. Trawl depletion rates are highest for fragile stony corals such as SVA, MOC, GDU and ERO (d=0.67, range 0.52-0.82) and lowest for sponges and glass sponges (DEM and HEX, d=0.38, range 0.30-0.46), Gorgonian alcyonacea (SOC d=0.35, range 0.27-0.43) and seapens (PTU d=0.34, range 0.26-0.42). Recovery rates vary but are lowest for stony corals such as SVA, MOC, GDU and ERO (R=0.2, range 0.15-0.25).

SPRFMO does not have agreed reference points for VME taxa and/or habitats so interpretation of RBS results can only be done qualitatively unless reference points are borrowed from elsewhere. The assessment criteria given by the Marine Stewardship Council (MSC 2014) state that, in the case of VMEs [defined as per para. 42 of the FAO Deep-Sea Guidelines], “serious or irreversible harm” is to be interpreted as reductions in habitat structure and function below 80% of the unimpacted level. The threshold defined by MSC applies to the ‘Unit of Assessment’, which is often a fish stock.

Figures 49 and 50 show RBS assessment results for VME taxa across for the SPRFMO Evaluated Area and ten orange roughy Fishery Management Areas (FMAs). Results are also provided for Bottom Trawl Management Areas (BTMAs) within each FMA (Figure 51). For each assessment, the RBS results are given for three fishing effort scenarios (future, current and historical) and seven sensitivities related to the area of suitable habitat or estimated HSI-abundance relationships. Results for *Solenosmilia variabilis* (SVA) are given for the FMA scale (Figure 50) and for the BTMAs (Figure 51) and corresponding results for the other nine taxa are given in Appendix F. The fishing effort scenarios and abundance sensitivities are described in the previous section. In the RBS plots in figures 49–51 and Appendix F, each horizontal bar is the Low–Mean–High RBS value due to the d/R sensitivity (High–Mean–Low) (see Table 28).

RBS assessment results for ten VME taxa and three fishing effort scenarios (future, current and historical) and seven abundance sensitivities for the SPRFMO Evaluated Area are shown in Figure 49. All taxa in all scenarios are above the 80% MSC threshold and within the 90-100% (0.9-1.0) RBS score range given on the X-axes. For taxa other than SVA and SOC, the ROC abundance sensitivity under the historical fishing effort scenario gives the most pessimistic RBS results. For SVA and SOC, the Pow_Hi and Pow_Lo abundance sensitivities, respectively, give the most pessimistic RBS results.

RBS assessment results for *Solenosmilia variabilis* (SVA) and three fishing effort scenarios (future, current and historical) and seven sensitivities for the area of suitable habitat or abundance for the ten orange roughy FMAs are shown in Figure 50. Results for the other nine taxa assessed at this scale are given in Appendix F. The results for SVA indicate that mean RBS scores in all FMAs and for each fishing effort and abundance sensitivity scenario are above the 80% MSC threshold. Other notable results (see Appendix F) are for COR in the North Lord Howe Rise and Lord Howe Rise FMAs, where RBS is <0.8 for a number of fishing effort and sensitivities; for the Lord Howe Rise FMA, mean RBS ranges from 0.4–0.7 for 4 out of 7 abundance sensitivities; DEM in the Northern Louisville Ridge FMA, where mean RBS is <0.8 (~0.70) for the historical fishing effort and Pow_Hi abundance sensitivity; ERO in the Northwest Challenger FMA, where low and, in some cases, mean RBS is <0.8 for a high proportion of the abundance sensitivities under the future and historical fishing effort scenarios; and SOC in the Northwest Challenger FMA, where mean RBS is <0.8 for all fishing effort scenarios under the Pow_Hi abundance sensitivity. There are a number of other isolated examples of RBS <0.8 for various taxa under certain fishing effort and sensitivity combinations. In general terms and across the range of effort and abundance sensitivities, RBS for many taxa was lowest for the Northwest Challenger and Central Louisville FMAs (COR in the two Lord Howe FMAs being a clear outlier). For most other taxa across most other FMAs and fishing effort/abundance scenarios, RBS was generally >0.9.

RBS assessment results for *Solenosmilia variabilis* (SVA) and three fishing effort scenarios (future, current and historical) and seven sensitivities for the area of suitable habitat or abundance for the BTMAs within the ten orange roughy FMAs are shown in Figure 51. Results for the other nine assessed taxa are given in Appendix F. As expected (because these are the areas open to bottom trawling), RBS scores within BTMAs in each FMA are lower than those for the entire FMAs (Figure 50). The results for SVA indicate a small number of combinations of fishing effort and other sensitivity analyses where RBS is <0.8 (see, for example the Lord Howe Rise FMA, South Tasman Rise FMA and Central Louisville Ridge FMA plots). Other notable results within BTMAs include COR within the Northern Lord Howe Rise FMA, Lord Howe Rise FMA, Northwest Challenger FMA and West Challenger FMA, where RBS for a number of effort/abundance sensitivity combinations is <0.4; DEM within the Lord Howe Rise FMA, where mean RBS is <0.6 for 5 out of 7 abundance sensitivities across all effort scenarios; ERO, GDU, HEX and MOC in the Northwest Challenger FMA, where low and in some cases mean RBS is <0.8 for a number of scenarios; and SOC in the Northwest Challenger FMA for all effort scenarios and the Pow_Hi abundance sensitivity showing mean RBS between ~0.5–~0.7. In general terms and across the range of effort and effort and abundance sensitivities, RBS for most taxa at the BTMA scale was estimated to be >0.8, with a few clear exceptions as described above.

The pattern of results as they relate to the three fishing effort scenarios is broadly consistent across the three assessments (Evaluated Area, FMAs and BTMAs within FMAs). In most cases, RBS is lowest under the historical fishing effort scenario that assumes a continuation of fishing effort based on the annual average effort for the last 30 years. An exception to this is COR in the BTMAs within the West Challenger FMA, where the future effort scenario is estimated to result in lower RBS than the historical effort scenario for all abundance sensitivities. In general, the future scenario, which assumes that bottom trawling effort could increase to catch estimated future catch limits for orange roughy, results in lower RBS than the current effort scenario, which assumes a continuation of average annual trawl effort for the past 10 years. However, this conclusion is contingent on constant distribution of fishing effort (although changes in the intensity of fishing within those area are allowed for), constant catch rates, and no changes to the proportion of fish caught using trawls with the doors fished on or off the bottom.

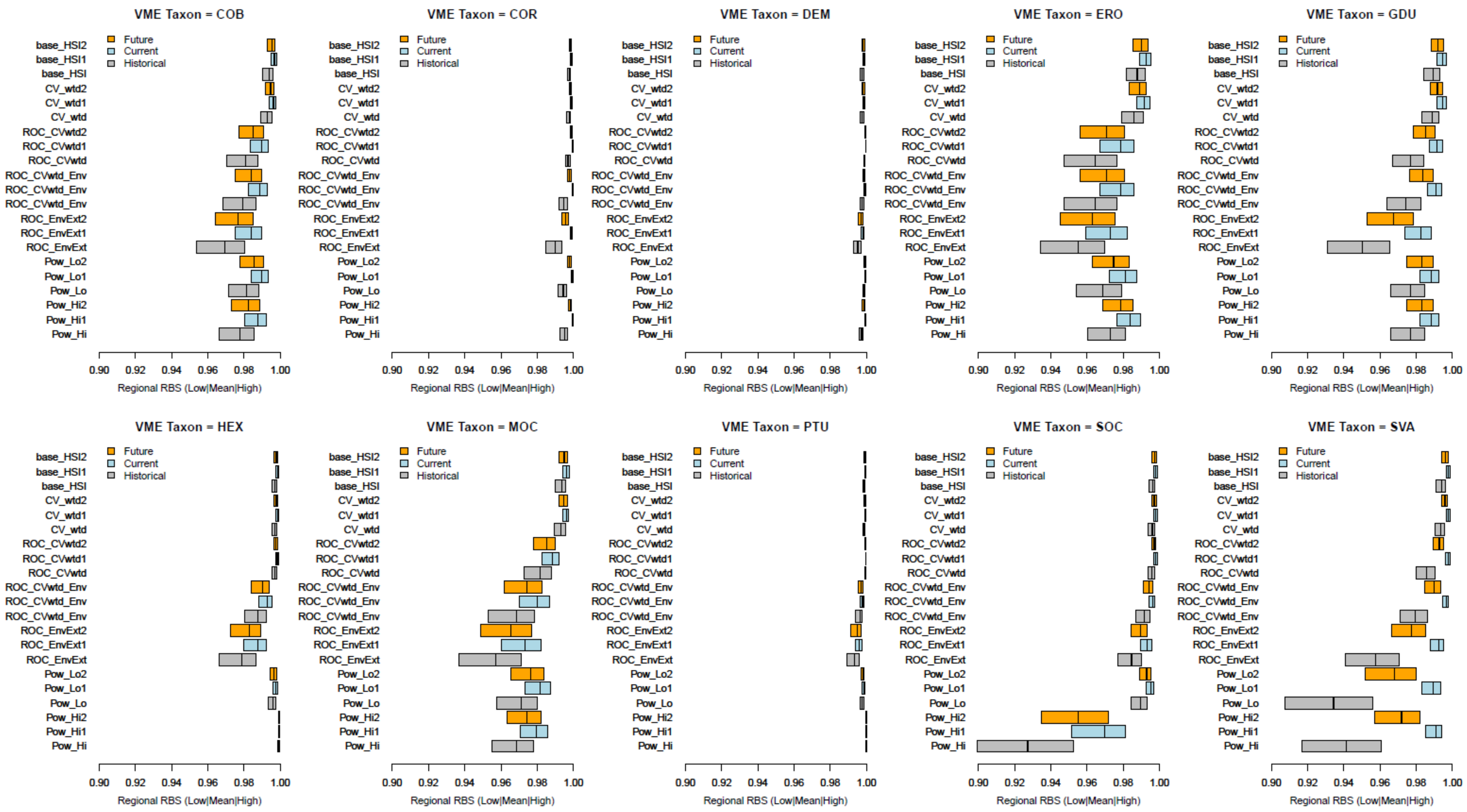


Figure 49: Low, mean and high Relative Benthic Status (RBS) assessment results for ten VME taxa and three fishing effort scenarios (future, current and historical) and seven different approaches to classifying suitable habitat (ROC methods) or abundance for the SPRFMO Evaluated Area.

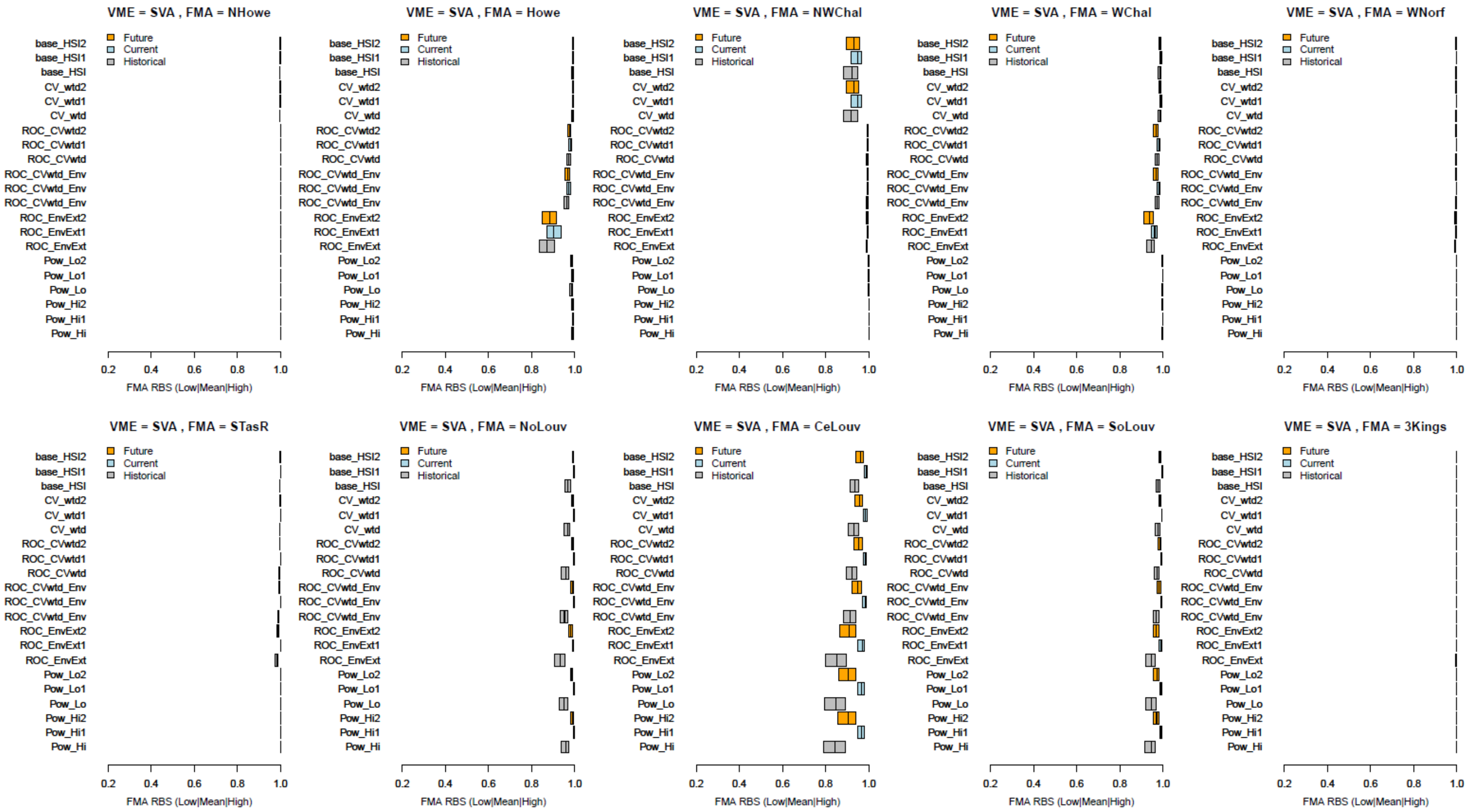


Figure 50: Low, mean and high RBS assessment results for *Solenosmilia variabilis* (SVA) for ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven different approaches to classifying suitable habitat (ROC methods) or abundance. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge.

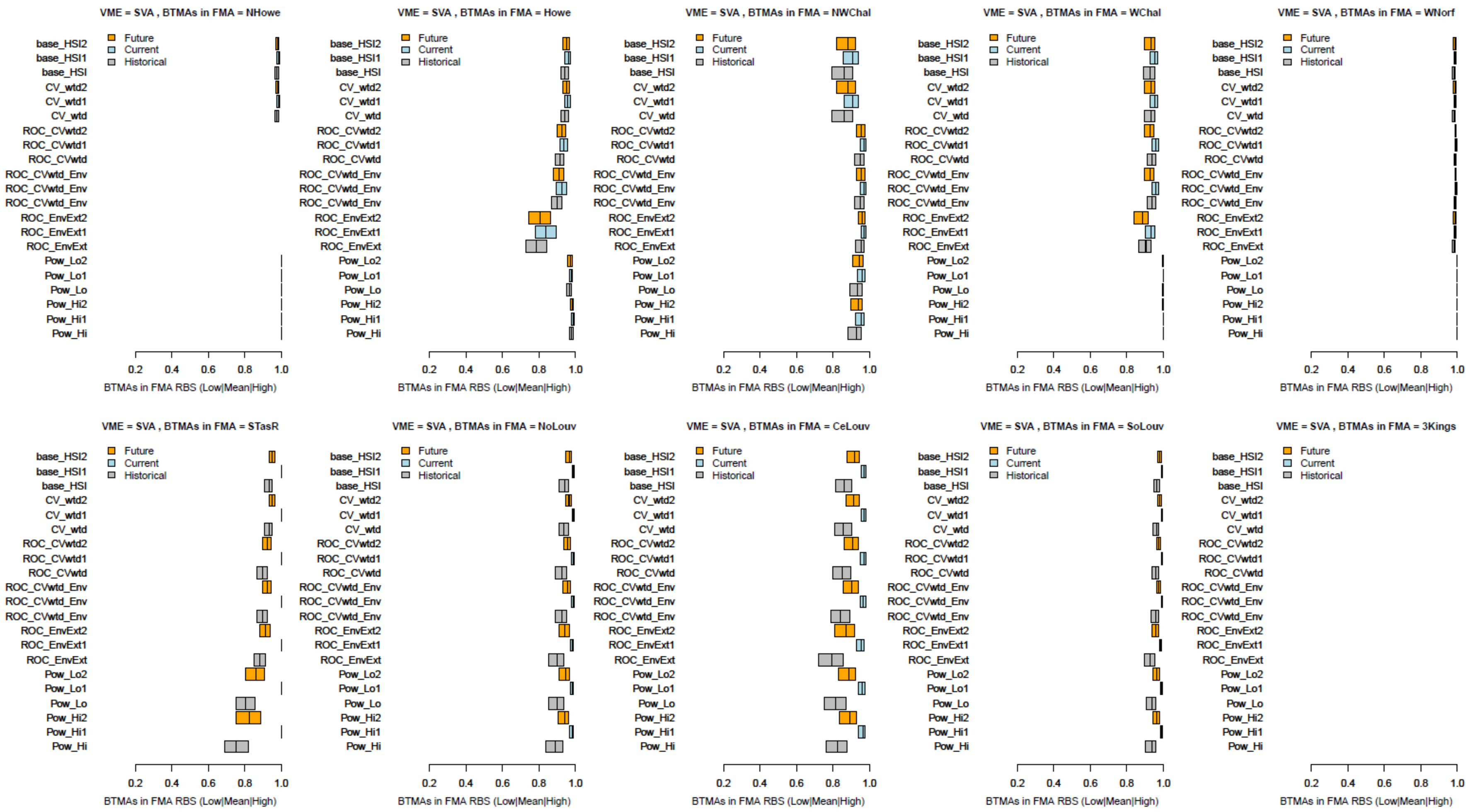


Figure 51: Low, mean and high RBS assessment results for *Solenosmilia variabilis* (SVA) for Bottom Trawl Management Areas (BTMAs) within ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge. Note that 3Kings does not have any BTMAs.

4.6 MITIGATION, MANAGEMENT AND MONITORING MEASURES

4.6.1 General approach to avoiding Significant Adverse Impacts on VMEs

Arrangements for New Zealand and Australian vessels up to 2018 are detailed elsewhere in this document, but with the introduction of CMM 03-2019 consistent measures across all Members were established. Under CMM 03-2019, spatial management areas were established to protect large proportions of the predicted distribution of VME indicator taxa while permitting access for fisheries. The measure was slightly revised in CMM 03-2020 to reduce the threshold for stony corals in the VME protocol and review the appropriateness of observer coverage levels. CMM 03-2019 was based on a spatial management approach that aims to ensure the long-term conservation and sustainable use of deep-sea fishery resources in conjunction with CMM 03a-2019 on deepwater fisheries resources, now updated to CMM 03a-2020. The measure was designed to provide an assurance that bottom fishing within the Evaluated Area would not have SAIs on VMEs, taking into account the spatial extent of the impact relative to the availability of VME indicator taxa within the Evaluated Area and at a range of finer spatial scales. The Evaluated Area contains all areas fished in the 2002–2006 criterion years for the interim measures and other nearby areas within the southwest Pacific Ocean (including the high seas areas of the South Tasman Rise which has been closed to bottom fishing for orange roughy and associated species since 2007). Within the Evaluated Area, three Management Areas exist within which different types of bottom fishing (bottom trawl, midwater trawl and bottom longlining) may be conducted. Bottom fishing is not allowed outside these Management Areas except as provided for by CMM 13-2020 for new and exploratory fisheries.

A VME encounter protocol was established as a complementary measure to spatial management within CMM03-2019. The protocol includes the temporary closure of the area if specified weights of VME indicator taxa are caught in a trawl. This protocol provides a mechanism for the rapid curtailment of bottom fishing in an area where the bycatch of VME indicator taxa is unexpectedly high relative to the predicted distributions of VME indicator taxa used to underpin spatial management measures. Following the triggering of an encounter, it is reviewed by the flag state and then by the Scientific Committee. Both the taxa to be included as VME indicators and the threshold weights for the protocol are subject to periodic review, and were modified in CMM 03-2020.

4.6.2 Design of VME encounter protocols

The UNGA Resolution 64/72 (UN General Assembly 2010) called upon States and RFMOs to establish and implement science-based "*threshold levels and indicator species*", that would define evidence of an encounter with a VME. The implementation of these measures by RFMOs was reviewed by the UNGA after four years, and UNGA Resolution 66/68 (UN General Assembly 2012) tasked the FAO with providing technical guidance on encfounter protocols, including "*encounter thresholds and move-on distances*", as well as providing further guidance on applying criteria for identifying VMEs. However, the FAO has not, as yet, provided any advice or technical guidance on what constitutes evidence of an encounter with a VME during bottom fishing operations.

In recent years, New Zealand and Australia jointly worked on potential approaches to define a VME encounter protocol which includes the temporary closure of the encounter area if threshold weights for VME indicator taxa taken as bycatch are exceeded. Once a threshold is triggered and an area closed to fishing, the information is reviewed by the flag state and then by the Scientific Committee. The Scientific Committee is required by CMM03-2020 (paragraph 33) to *review all encounters reported … and determine whether any encounters were unexpected based on the relevant VME habitat suitability models, and provide advice on management actions proposed by the* [flag state] *and any other* *management actions the Scientific Committee considers appropriate. This review should include consideration of:*

- *a) the detailed analyses provided by a Member or CNCP pursuant to paragraph 32;*
- *b) historical fishing events within 5nm of the encounter tow, in particular, any previous encounters, and all information on benthic bycatch;*
- *c) model predictions for all VME indicator taxa;*
- *d) details of the relevant fishing activity, including the bioregion; and*
- *e) any other information the Scientific Committee considers relevant.*

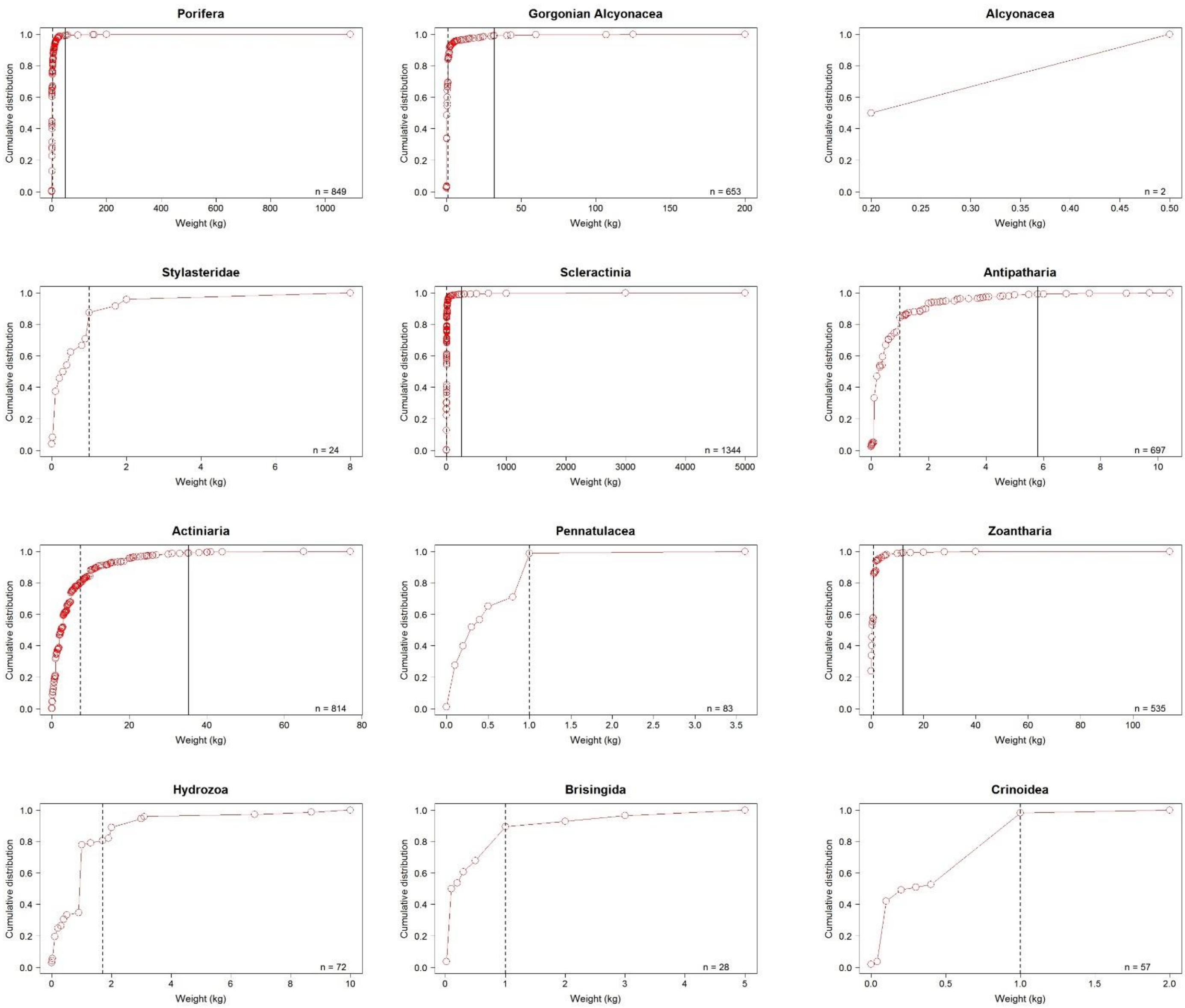
Decisions on whether the temporary closure should be lifted or confirmed are taken by the Commission, guided by paragraph 34): *Taking into account the Scientific Committee's determination of whether the encounter was unexpected based on the relevant VME habitat suitability models, and advice on management actions, at its next annual meeting, the Commission shall determine management actions for each encounter area.*

Guidance on defining appropriate thresholds was obtained from discussions a series of joint workshops between Australia and New Zealand in 2018 and at the 2018 North Pacific Fisheries Commission (NPFC)/FAO Workshop on the Protection of Vulnerable Marine Ecosystems. These discussions led to a proposal for a draft CMM for bottom fisheries within the western SPRFMO Convention Area in 2018. The methodology used to define VME thresholds are detailed in SC06-DW09.

A general principle used to define thresholds was that they should ideally be specific to area, gear type, and taxon. Among different broad approaches for determining VME indicator taxa weight thresholds, an approach setting arbitrary thresholds (but based on actual historical catch records) was ultimately selected based on data availability and time constraints. This approach used catch records from the fisheries for which a threshold is required, and set thresholds based on percentiles. Both single-taxon and multi-taxon weight thresholds were assessed, to account for the significant abundance of a single species and the possible presence of diverse fauna. The presence of several VME indicator taxa in a single tow may indicate that the fishing event has encountered an area with a diverse seabed fauna, potentially constituting evidence of a VME (Parker et al. 2009, Penney 2014).

Groomed data on bycatch of VME indicator taxa, benthic bycatch weight distributions, numbers of taxa caught per tow and cumulative weight frequency distributions were used to analyse the metrics that could be used to define VME thresholds. The data used was restricted to New Zealand bottom trawl tows (including mid-water trawls) in the Evaluated Area over the period 2008–18. Preliminary analysis of benthic bycatch records for Australian trawl fisheries in SPRFMO indicated that rates of interaction were lower than for New Zealand fisheries, but Australian data were not included in this analysis because of their lower resolution, which would degrade the usefulness of the other data. There were insufficient data for many taxa at smaller scales to enable the generation of area-specific weight thresholds. Therefore, VME indicator taxon-specific weight thresholds were generated for the entire western SPRFMO Convention Area combined. It should be noted that this approach may lead to inaccurate estimates of the potential impact of the thresholds on fishing activity if the location of fishing shifts substantially or if historic bycatch data are no longer representative of the fishery.

To help inform the systematic selection of threshold and biodiversity qualifying weights, patterns in the cumulative catch curves were examined to determine the point at which taxon-specific cumulative catch curves begin to flatten toward the asymptote, potentially indicating a naturally occurring or ecologically relevant reference point (Figure 52, Table 30). This approach was also informed by the advice of the 6th meeting of the Scientific Committee that the encounter protocol thresholds should be high and triggered by rare and large catches of VME taxa, suggesting the models used to predict the distribution of VME taxa are misleading (noting that the Commission decided in 2020 to increase the level of precaution in the measure by reducing the threshold for the stony coral *Solenosmilia variabilis* in response to identified uncertainties in the modelling supporting the measure).



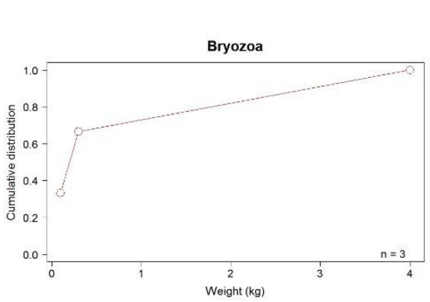


Figure 52: Cumulative distribution of non-zero bottom trawl catch weights (kg) indicating the position of the 80th (dashed line) and 98th percentiles (sold line) used to calculate biodiversity and weight thresholds in SC7-DW13 for Porifera, Gorgonacea, Stylasteridae, Scleractinia, Antipatharia, Actinaria, Pennatulacea, Zoantharia, Crinoidea and Brisingida. Note that the x-axis scale differs between panels.

Table 30: Percentiles in bycatch weight (kg) per VME indicator taxon as calculated in SC6 DW-09, and SC7-DW13, and encounter thresholds as specified in CMM 03-2019 and CMM 03-2020. * Indicates sample sizes were too small to calculate the 80th percentile from ordered values; therefore, a nominal threshold of 1 kg was selected. NA indicates taxa were not included in the analysis, and DD indicates taxa were data-deficient and the percentile could not be calculated.

	Percentiles calculated in SC6 DW-09		Percentiles calculated in SC7-DW13		Thresholds specified in CMM 03-2019		Thresholds specified in CMM 03-2020	
Taxon	**0.8**	**0.99**	**0.8**	**0.99**	**Biodiversity threshold (kg)**	**Weight threshold (kg)**	**Biodiversity threshold (kg)**	**Weight threshold (kg)**
Porifera (Sponges)	3.0	50.0	3.1	50.0	5	50	5	50
Gorgonian Alcyonacea (Tree-like forms, sea fans, sea whips, bottlebrush)	0.6	15.0	1.0	32.0	1	15	1	15
Alcyonacea (Soft corals)	1.0	60.0	1.0*	DD	1	60	1	60
Stylasteridae (Hydrocorals)	1.0	DD	1.0	DD	1	-	1	-
Scleractinia (Stony corals)	5.0	250.0	5.0	250.0	5	250	5	80
Antipatharia (Black corals)	1.0	5.5	1.0	5.8	1	5	1	5
Actiniaria (Anemones)	7.3	38.0	7.4	35.3	5	40	5	40
Pennatulacea (Sea pens)	1.0	DD	1.0	NS	1	-	1	-
Zoantharia (Hexacorals)	NA	NA	1.0	12.2	-	-	-	-
Hydrozoa (Hydroids)	NA	NA	1.7	DD	-	-	-	-
Brisingida (‘Armless’ stars)	1.0	DD	1.0	DD	1	-	1	-
Crinoidea (Sea lilies)	0.2	DD	1.0	DD	1	-	1	-
Bryozoa	NA	NA	1.0*	DD	-	-	-	-

The development of VME thresholds from historic bycatch data suffers from poorly understood catchability, limited historical identification of taxa and limited spatial extent of samples. However, it is clear that bottom trawls are inefficient at sampling fragile organisms such as corals and retain only a small proportion of the benthos impacted (Wassenberg et al. 2002, Mortensen et al. 2008, Pitcher et al. 2019). Although a small amount of a single VME indicator taxon may not provide good evidence of an encounter with a VME, the presence of an increasing number of VME indicator taxa within a tow may indicate a greater likelihood that the fishing event encountered an area with a diverse seabed fauna, potentially constituting stronger evidence of a VME (Parker 2008; Penny 2014).

SC06 therefore agreed on two different types of VME indicator taxa thresholds:

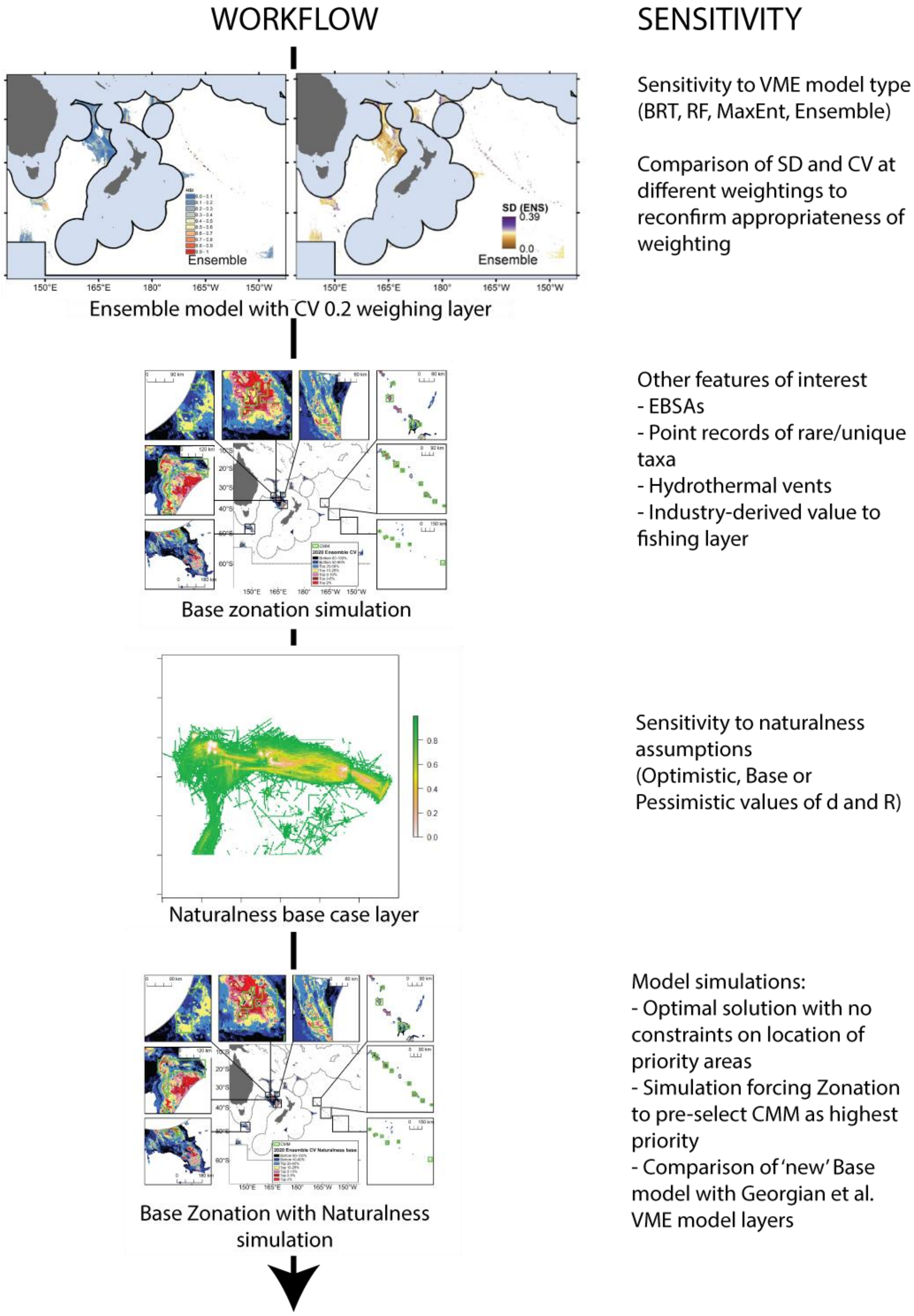
1. catch of any one of six specified VME indicator taxa over a taxon-specific threshold weight (based on the 99th percentile of the distribution of historical positive catch weights); OR
2. catch of three or more VME indicator taxa over their respective taxon-specific qualifying biodiversity weights (based on the 80th percentile of the distribution of historical positive catch weights);

To ensure thresholds were consistent with the objectives of CMM 03-2019, the Commission agreed that Scientific Committee regularly review encounter protocols and thresholds to incorporate additional data as they become available.

4.6.3 Use of spatial decision support tools

Work to underpin the development of spatial management approaches has been ongoing for several years. At the 3rd meeting of the Scientific Committee in 2015, Australia, New Zealand, and Chile agreed to work together on finalising the various components. After the 4th meeting of the Scientific Committee, a detailed update was provided to the Commission in early 2017 (see Bottom Fishing CMM Information Paper – COMM5-INF05), describing progress on the two key pieces of work required to develop candidate spatial management areas: the predictive mapping of VMEs; and the use of spatial decision-support software to inform the location and design of open or closed areas to bottom fishing that would prevent SAIs on VMEs and provide for a fishery.

Records of the location or density of VMEs or VME indicator taxa such as reef-forming corals within the SPRFMO Convention Area are sparse and inadequate to map the distribution of VMEs directly. This situation means that predictive models are required to map where VMEs are likely to occur. During 2017 and 2018, New Zealand generated models covering the Evaluated Area. All available biological, physical and chemical information from depths between 200 and 3000 metres was used to predict habitat suitability (and, hence, a proxy for the predicted distribution) of a variety of VME indicator taxa (Georgian et al. 2019).



Group	Taxa included	Code	ROC	Power_Low	Power_High	Linear
Stony corals	*Enallopsammia rostrata*	ERO	71.5	73.6	72.0	90.5
	Goniocorella dumosa	GDU	83.7	91.3	91.3	91.3
	Madrepora oculata	MOC	86.8	87.9	84.1	94.3
	Solenosmilia variabilis	SVA	89.4	60.8	63.0	93.6
Other VME indicators	Antipatharia (black corals)	COB	76.8	79.0	71.7	90.1
	Stylasteridae (hydrocorals)	COR	95.6	96.4	97.4	95.2
	Demospongiae (demosponges)	DEM	99.0	96.3	92.6	95.9
	Hexactinellida (glass sponges)	HEX	95.9	98.5	99.5	95.2
	Pennatulacea (sea pens)	PTU	96.9	99.2	99.5	96.2
	Alcyonacea (gorgonian taxa only)	SOC	92.6	92.1	63.8	94.1

Post-accounting (% of protected area):
- linear relationship
- ROC cutoff
- HSI/abundance relationship (power)

Figure 53: Workflow and inputs of the Zonation simulations, including sensitivity elements tested during the process.

The modelled distribution maps of VME indicator taxa and the reported distribution of fishing and catch can be used within spatial decision-support software to identify priority areas to close to fishing (to prevent SAIs on VMEs) and areas to be opened to fishing (to provide for a viable fishery). New Zealand has been using Zonation software (Moilanen et al. 2009) for this purpose since 2014 because it provides a flexible and powerful tool for policy makers, scientists and stakeholders to explicitly consider the costs and benefits of opening or closing particular areas to bottom fishing. A key output from Zonation is a prioritization of the landscape for conservation (Figure 54). Cells ranked highly from a conservation perspective are those that contribute most to VME representation and where impacts of fishing should be minimized, and low ranked cells are those areas that contribute least to VME representation and are more compatible with bottom fishing. These rankings were used alongside other information and knowledge of all stakeholders' objectives in the design of the spatial management areas. Although both the habitat suitability modelling and the outputs of the Zonation analysis were conducted at the scale of 1 km x 1 km squares, the spatial management areas were designed at a minimum linear scale of ~6 minutes of arc (or ~10 km). The latter is the finest scale that the Scientific Committee has previously recommended would be useful for management.

In the months leading up to the 5th meeting of the Scientific Committee (SC-05) in 2017, New Zealand and Australia convened five workshops (a meeting of the Scientific Committee's Deep Water Working Group, chaired by Chile, in May 2017 in Hobart, primarily scientific, and four in Wellington in July-August 2017 involving Australian and New Zealand stakeholders). These workshops sought to guide the development of appropriate models to predict the distribution of VME indicator taxa and agree on the objectives and key settings for the application of Zonation software. The outputs from these workshops and other research relevant to the revised CMM were considered in detail by SC-05, who appreciated that significant improvements in the protection of VMEs could probably be achieved at reduced cost to the fishing industry (in terms of access to fishing areas they valued). SC-05 agreed that the scientific approach was appropriate.

Following SC-05, and in line with its advice, New Zealand convened two further stakeholder workshops in Wellington in November 2017 to further develop the Zonation analyses and provide for the scientific analyses on the design of candidate spatial management areas. These areas were included in an information paper and a descriptive supporting paper to Commission in early 2018 (COMM6-INF09). Australian and New Zealand stakeholders, and both scientific and policy personnel from both nations were included in these meetings. As with previous stakeholder workshops, the focus of the discussions was around maps showing relative priorities for fishing and protection of VME indicator taxa, and the relative performance of different candidate spatial management areas offered by New Zealand officials as a basis for discussion. Candidate spatial management areas were designed using a combination of automated GIS procedures at a spatial scale of ~10 km and "nuancing" of the boundaries by officials to achieve better protection for cells prioritised highly for the protection of VME indicator taxa and, where feasible, better access for the fishery. Once spatial management areas had been designed, their performance, in terms of the proportion of different VME indicator taxa protected at a range of scales, was estimated. More detail on these methods was presented at the 6th meeting of the Scientific Committee (SC-06) in 2018 which agreed that the scientific approach could be used to underpin a revised bottom fishing CMM.

Following SC-06, and in line with its advice, New Zealand convened two further stakeholder workshops in Wellington in October and November 2018 to further refine the proposed spatial management areas, including exploring opportunities to improve conservation benefits within EBSA 17 (Ecologically or Biologically Significant Area for the northern LSC), while allowing for fishing. Having workshopped the boundaries with stakeholders, Zonation and intersection analyses to underpin CMM03-2019 were finalized in December 2018 in time for use by New Zealand and Australia to formulate and submit the draft CMM.

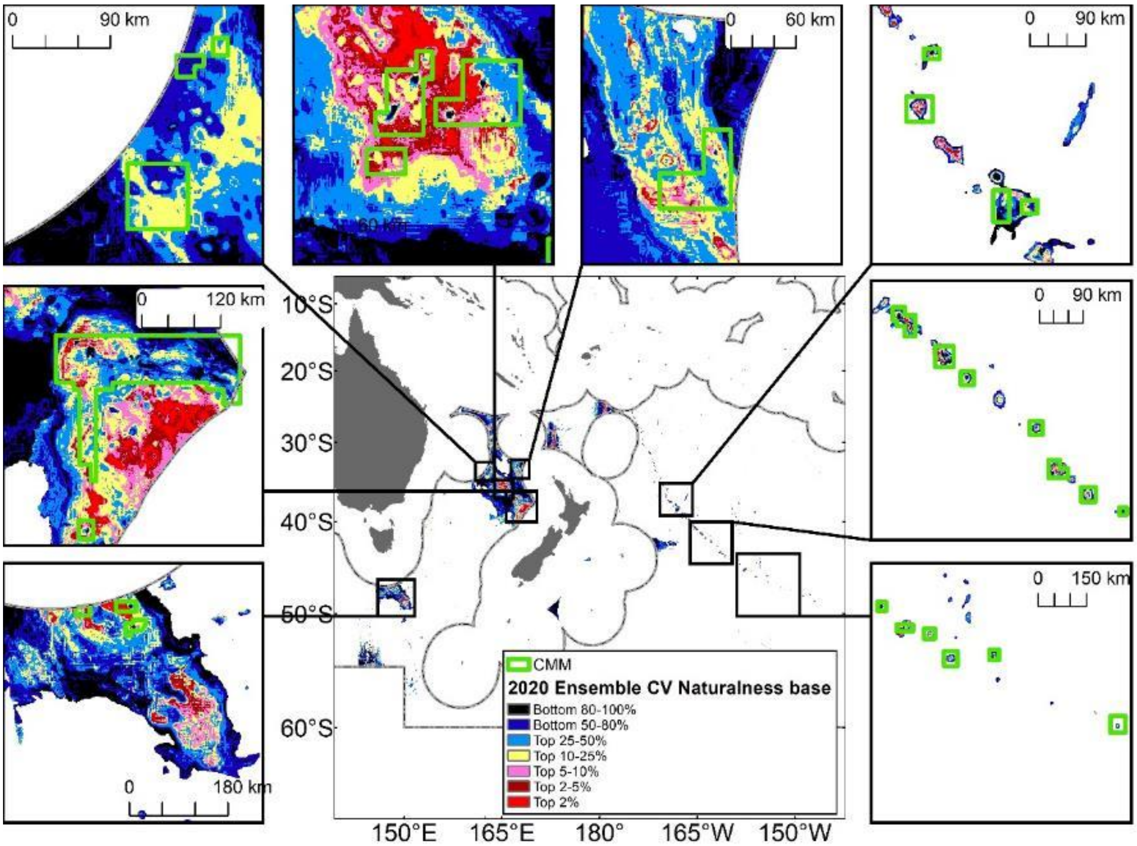


Figure 54: Output from the most recent Zonation prioritization analysis (2020) utilizing an ensemble layer for VME taxa distribution, its weighted uncertainty CV, and base case naturalness to identify those areas that make the greatest contribution to the representation of VME indicator taxa. Colours indicate relative priority for conservation. Bottom trawl management areas defined in CMM 03-2020 are shown as green polygons.

4.6.4 Other complementary measures

As well as reviewing any encounters triggered by catches of VME indicator taxa in excess of the thresholds specified in CMM03-2020, the Scientific Committee also reviews annual analyses and summaries of benthic bycatch data collected during the previous year. These data were provided by flag States (e.g., Geange et al. 2019 SC-07-DW-15). At the time of writing this assessment, the process to combine the information from these annual reviews of all data with information from encounters has not been determined or tested by the Scientific Committee. Periodically, the availability of new data to test and/or update habitat suitability models is reviewed (Rowden and Anderson 2019, SC-07-DW-12), and models are updated as required. Encounter protocols have been subject to considerable discussion (Cryer et al. 2018 SC-06-DW-09, Cryer et al. 2019a and b SC-07-DW-16-rev1, SC-07-DW-17-rev1, Pitcher et al. 2019 SC-07-DW-21-rev1) and the Commission decided in 2020 to reduce the threshold for stony corals from 250 kg to 80 kg.

4.6.5 Estimating the performance of spatial measures

The key metric of the likely performance of spatial management areas used to advise the Scientific Committee in 2018 and the Commission in 2019 was the estimated proportion of suitable habitat for each VME indicator taxa which was not exposed to fishing impacts (Cryer et al. 2018 SC-06-DW-11 and Delegation of New Zealand 2019, COMM7-Prop03.1). That assessment was done at three different spatial scales, including (from coarsest to finest): the whole of the SPRFMO Evaluated Area; five bioregions (after Costello et al. (2017) occurring within the Evaluated Area; and several distinct broad fisheries administrative units within the Evaluated Area (Tasman Sea, South Tasman Rise, Louisville Seamount Chain, split into Northern, Central and Southern areas, and "other" areas). The proportion of the distribution of each taxon exposed (or not) to fishing impacts was estimated by summing the habitat suitability indices for all 1 km^2 cells outside (or inside) the spatial management areas using no cut-offs for the habitat suitability indices. Using this approach, calculations in 2018 suggested that the proposed spatial management areas would provide substantially greater protection for stony corals and other VME indicator taxa than the management areas implemented by Australia and New Zealand under CMM03-2018 (Appendix E). Across the whole Evaluated Area, the estimated proportions of the distribution of suitable habitat for VME indicator taxa protected from any adverse effects of fishing were estimated to increase from 60–70% under CMM03-2018 to over 80% under CMM03-2019 (Appendix E). There was some regional variation in these proportions; about 90% of the predicted distribution of suitable habitat for VME indicator taxa would be protected in the Tasman Sea fishery areas and the northern parts of the LSC, compared with about 50% further south on the LSC. A sensitivity analysis was conducted by recalculating the proportions, assuming that those parts of the suitable habitat distribution of VME indicator taxa that were deeper than 1400 m were not exposed to fishing, given that over 99% of bottom-contacting trawl fishing is reported shallower than 1250 m. For the bioregional analysis conducted in 2018, the estimated proportion of VME indicator taxa not exposed to fishing was greater than 80% across all bioregions.

The approach to estimating the likely performance of spatial management areas used in 2018 assumed that, in effect, the relationship between habitat suitability indices and the abundance of each modelled taxon was linear. Initial analyses (shown in Cryer et al. 2019b, Pitcher et al. 2019) and additional detailed work conducted for this assessment show that the relationship is quite uncertain, probably variable, and is much more complex than the simple linear assumption. In particular, cells with low habitat suitability indices are unlikely to have substantive abundances of VME indicator taxa and only cells with high habitat suitability indices are likely to have very dense populations of VME indicator taxa. Clearly, this complexity has implications for the estimation of the performance of spatial management areas and estimates of the likely performance have, therefore, been recalculated for this assessment.

For this assessment, similar metrics of the estimated proportion of suitable habitat or abundance for each VME indicator taxon that falls outside the areas designated as open to trawling under CMM03-2020 were calculated. Again, the calculations were done at a range of spatial scales (Figure 55) but continued to a finer scale than in 2018. Estimates were calculated for: the whole SPRFMO Evaluated Area (Tables 31–33); bioregions as proposed by Costello (2017) (Tables 34 and 35); broad fisheries administrative units (Table 36) as in 2018; and orange roughy fisheries management areas (FMAs) after Clark et al. (2016) (Tables 37 and 38). The first three of these were used in 2018, the last and finest scale is applied for the first time in this assessment.

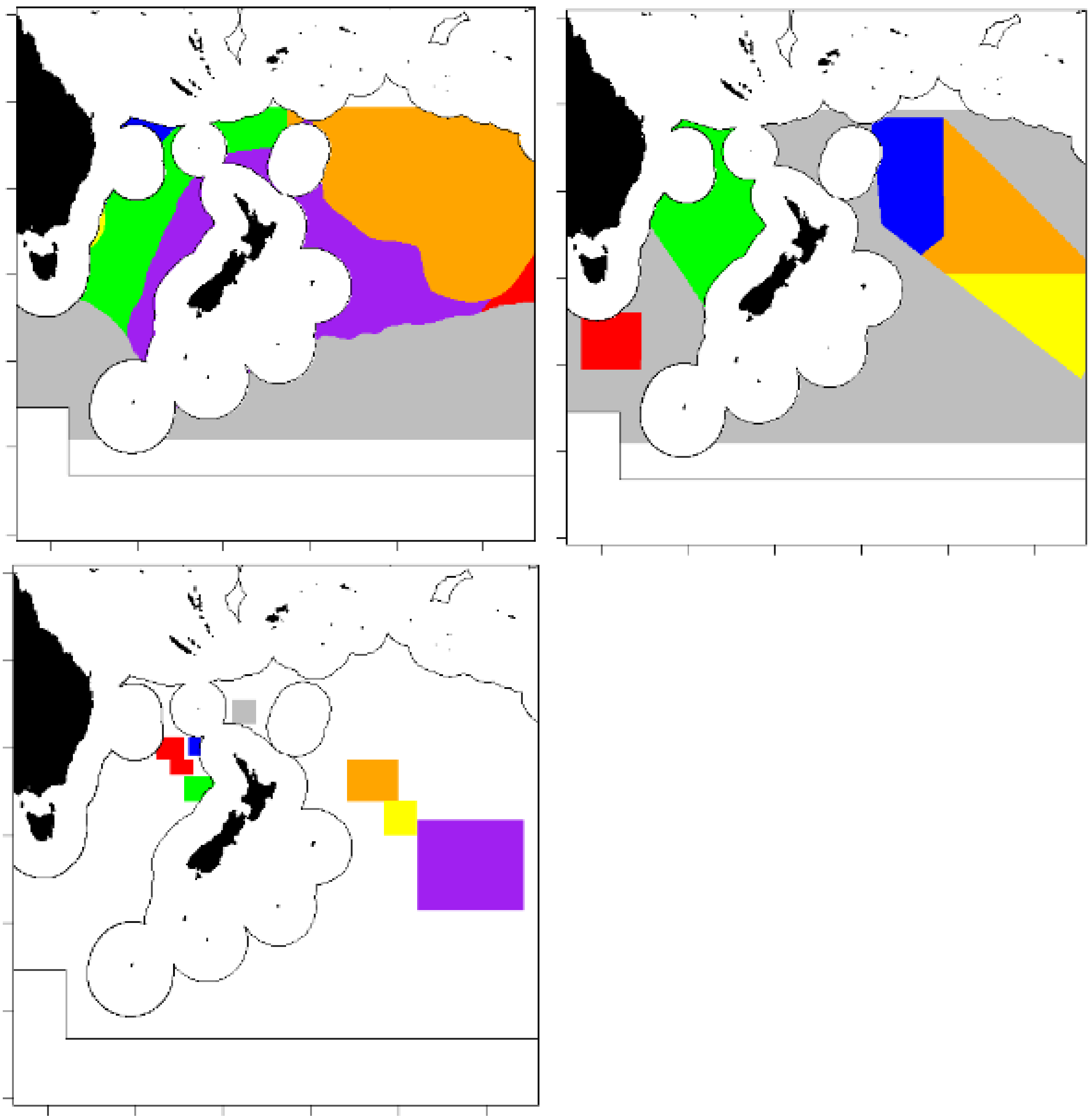


Figure 55: Spatial stratifications used to assess the likely performance of spatial management areas in force under CMM03-2020 at different scales. Top left, bioregions after Costello et al. (2017): green, bioregion 15 (Tasman Sea & SW Pacific); grey, bioregion 30 (Southern Ocean); purple, bioregion 28 (New Zealand); orange, bioregion 17 (Mid-South Tropical Pacific); blue, bioregion 16 (Tropical Australia & Coral Sea). Top right, broad fisheries administrative units as used in the 2018 assessment: red, South Tasman Rise; green, Tasman Sea; blue, North Louisville; orange, Central Louisville; yellow, South Louisville; grey, all other areas combined. Bottom left, orange roughy management areas (FMAs) after Clark et al. (2016) (noting the FMAs do not cover the whole Evaluated Area; Table 32shows the proportion of each taxon estimated to be outside the FMAs): red, North and South Lord Howe Rise; blue, West Norfolk Ridge; green, NW Challenger; grey, Three Kings Ridge; orange, North Louisville; yellow, Central Louisville; purple, South Louisville.

Estimates were made by summing habitat suitability indices as in 2018 (for comparability and for some sensitivity trials) but, recognising that this is probably not a good assumption, estimates were also calculated using two alternative approaches. First, estimates were made (using the Receiver Operating

Characteristics (ROC) curve) of the proportion of cells inside and outside the BTMA that had HSI scores above the cutoff value indicating the presence of suitable habitat in a binary classification setting[19] within each HSI model. This is generally referred to as the ROC approach in this assessment. Second, the HSI scores for each taxon were transformed to estimates of abundance using power curves estimated using information on the cover or abundance of VME indicator taxa within grid cells for which HSI predictions were available. These estimates of abundance were summed for cells inside and outside the BTMA to estimate the proportion of the overall abundance inside and outside the BTMA. This is generally referred to as the power relationship or approach in this assessment.

Table 31: Cutoff HSI values for predicted suitable habitat from the receiver operating characteristic (ROC) curves for each VME indicator taxon for which HSI models were developed and used in post-accounting. Results are given for each new model in 2020 (RF, random forest; BRT, boosted regression tree; MX, maximum entropy; ENS, ensemble model) and for the ensemble model assembled in 2018 by Georgian et al. (2019).

							ROC cutoff values
Group	**Taxon**	**Name**	**RF**	**BRT**	**MX**	**ENS**	**Georgian et al. (2019)**
Stony coral species	ERO	*Enallopsammia rostrata*	0.6519	0.6123	0.3239	0.5024	0.2269
	GDU	*Goniocorella dumosa*	0.5223	0.5155	0.2985	0.3761	0.5728
	MOC	*Madrepora oculata*	0.5657	0.5923	0.2398	0.4455	0.5538
	SVA	*Solenosmilia variabilis*	0.5981	0.5861	0.3127	0.4603	0.5550
Other VME indicator taxa	COB	Antipatharia	0.5673	0.5515	0.3797	0.5210	0.6391
	COR	Stylasteridae	0.5359	0.4885	0.4317	0.4600	0.5266
	DEM	Demospongiae	0.5031	0.4627	0.3995	0.4570	0.5055
	HEX	Hexactinellida	0.5731	0.4883	0.4597	0.4547	0.6665
	PTU	Pennatulacea	0.5498	0.5142	0.3299	0.4507	0.8605
	SOC	Alcyonacea	0.5557	0.5203	0.4867	0.5145	0.6455

Both new approaches are now considered superior to the sum of HSI approach used in 2018, but each has different characteristics, strengths and weaknesses. The ROC approach leads to an estimate of the proportion of suitable habitat for a given VME indicator taxon within or outside the BTMA. It is, arguably, the most natural way of using the predictions from the HSI models which were not designed to predict abundance but have very strong performance (estimated using fully independent data) at classifying presence and (pseudo) absence at the scale of the model grid (1 km). This approach does not distinguish between different levels of habitat suitability within quite a broad range of HSI values. The power approach leads to an estimate of the proportion of total abundance for a given VME indicator taxon within or outside the BTMA. This approach applies fitted relationships between observed abundance and predicted HSI at the sites where such detailed information is available; these typically suggests that VME taxa have substantive observed abundance only when predicted HSI is high. The power approach therefore focuses much more on habitat predicted to be highly suitable,

[19] In the ROC approach, cells were classified as either suitable habitat, or not, for a given taxon. The post accounting counts the number of cells classified as suitable habitat.

especially when the estimated power curves are very steep. Recognising the paucity of suitable data and the difficulties fitting to the available data, this is the best translation between suitable habitat and total abundance that has been possible in time for this assessment, although other approaches are possible.

SPRFMO does not have agreed reference points for VME taxa and/or habitats in the SPRFMO Convention Area so interpretation of these post-accounting results can only be done qualitatively unless reference points are borrowed from elsewhere. Scientific guidance on the protection of VMEs (coldwater corals and sponge-dominated communities) from Significant or Irreversible Harm (SIH, analogous to SAI) provided by the Department of Fisheries and Oceans Canada suggested that, "*from a practical and operational perspective, preventing SIH on Significant Benthic Areas (SBAs) requires closures to all fishing activities that encompass sufficient habitat to allow for the SBA ecosystem services to be maintained. At present, precise and quantitative definitions of the necessary amount are not possible*". Different SBA types were defined to constitute different habitats, and hence, provide different suites of ecosystem services and mixes of taxa. The authors of the DFO report recommended that, where 100% of VMEs cannot be protected due to compelling social and economic reasons, protection of 70% of the total extent of each VME in the Newfoundland and Labrador bioregion was expected to be enough to maintain ecosystem functionality (DFO 2017). DFO went on to state that, until the importance of SBAs as fish habitat, biogeochemical processing, and in benthic pelagic coupling are sufficiently advanced to provide quantitative evaluations of SIH, expert opinion based on existing analyses suggests that low risk of SIH appears associated with protection of ~70% (or more) of each bioregion's SBAs.

Table 32: Estimated percentage of each modelled VME indicator taxon within the Evaluated Area but outside the FMAs for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power-Hi and Power-Lo = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power-Lo is the mean estimated relationship minus 1 standard deviation and Power-Hi is the mean estimated relationship plus 1 standard deviation.

Group	Taxon	Name	ROC	Power-Lo	Lower-Hi	Linear
Stony coral species	ERO	*Enallopsammia rostrata*	14.54	16.01	9.67	52.59
	GDU	*Goniocorella dumosa*	17.53	55.76	55.76	54.70
	MOC	*Madrepora oculata*	41.44	51.62	45.65	62.58
	SVA	*Solenosmilia variabilis*	45.84	17.54	17.54	58.96
Other VME indicator taxa	COB	Antipatharia	24.39	31.84	18.95	52.90
	COR	Stylasteridae	45.29	53.44	52.81	61.02
	DEM	Demospongiae	54.25	69.70	74.97	65.81
	HEX	Hexactinellida	74.34	87.35	93.51	68.29
	PTU	Pennatulacea	69.46	78.11	80.29	66.78
	SOC	Gorgonian Alcyonacea	45.94	48.90	16.18	58.37

When averaged across the whole of the Evaluated Area, 80% of stony coral habitat (ROC approach) or abundance (power approach) and 91% of the habitat or abundance of other VME indicator taxa are found outside the areas open to bottom trawling (BTMA, see Table 33). Both calculations exclude the linear abundance estimation method.

As expected, variability in the estimates of the proportion of habitat or abundance outside the BTMA increases at finer geographical and taxonomic scales (Table 33 full details are given in Appendix I). Among the stony corals within the Evaluated Area, 72% of the estimated habitat of *Enallopsammia rostrata* and 73% of its estimated abundance is outside the BTMA whereas the corresponding figures for *Goniocorella dumosa* are 84% of habitat and 91% of abundance. The estimate of abundance outside the BTMA for *Solenosmilia variabilis* (62%) is much lower than the estimate of suitable habitat (89%). Among the other VME indicator taxa within the Evaluated Area, 77% of the estimated habitat of black corals and 75% of their estimated abundance is outside the BTMA whereas the corresponding figures for glass sponges are 96% of habitat and 99% of abundance. Other species fall within this range. At the finest geographical scale (orange roughy management areas, FMAs), the average proportion of habitat for stony corals (four species combined) outside the BTMA ranges from 58 to 93% among the FMAs, estimated abundance ranging from 42 to 95%. The average proportion of habitat for other VME indicator taxa (six broad taxa combined) outside the BTMA ranges from 50 to 96% among the FMAs, and the estimated abundance ranges from 44 to 96%.

The geographic strata with the lowest estimated proportions of suitable habitat or abundance of VME indicator taxa outside the BTMAs are bioregion 28 (waters close to New Zealand), the central and southern parts of the Louisville Ridge (at both the broad administrative area scale and at the finer FMA scale), and the NW Challenger Plateau.

The details of a sensitivity analysis completely excluding all predictions of suitable habitat or abundance of VME indicator taxa throughout the Evaluated Area where the environmental coverage (the level of available data to inform the habitat suitability models) was low are tabulated in Appendix J). In general, and because the fished areas have more records of benthic invertebrates than unfished areas, this clipping reduced the estimated proportion of suitable habitat or abundance outside the BTMA by several percentage points (on average). The sensitivity varied between species and areas but, in terms of suitable habitat (using the ROC approach), the average reduction for stony corals in the NW Challenger and central-southern Louisville Ridge was 2 percentage points (range 0–7 percentage points) and the average for other VME indicator taxa was 6 percentage points (range 9 percentage point increase to 25 percentage point decrease). The corresponding sensitivity estimates for abundance using the power approach in these areas were 6 percentage points for stony corals (range 2–8) and 7 percentage points for other VME indicator taxa (range 4–13).

Another sensitivity analysis assuming that habitat or colonies of VME indicator taxa occur significantly deeper than the current and historical depth distribution of fishing is tabulated in Appendix K where cells deeper than 1400 m are assumed not to be exposed to the impacts of fishing (bottom trawling essentially ceases at 1250 m depth). In the Tasman Sea, the results of the post-accounting are not very sensitive to application of a depth cutoff; generally, the increase in the proportion of habitat or abundance not exposed to fishing is only a few percentage points. In some areas, however, and especially the Central and Southern Louisville Ridge, the proportion of VME indicator taxa not exposed to fishing increased substantially in this analysis. Excluding *Enallopsammia rostrata*, which is very rare on the Louisville Ridge, the proportion of suitable habitat for stony corals not exposed to fishing impacts increased by an average of 24 percentage points and the proportion of suitable habitat for other VME indicator taxa increased by an average of 32 percentage points. The comparable sensitivity estimates for abundance were an average increase of 28 percentage points for stony corals and 30 percentage points for other VME indicator taxa. Thus, although Table 33 shows that the proportion of suitable habitat of VME indicator taxa outside the BTMAs is substantially below DFO's guideline of 70% for the Central-Southern Louisville Ridge, the average proportion of suitable habitat not exposed to the effects of fishing are much closer to the guideline.

Table 33: Estimated overall percentage of each modelled VME indicator taxon within the Evaluated Area and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation.

Group	Taxa included	Code	ROC	Power_Low	Power_High	Linear
Stony corals	*Enallopsammia rostrata*	ERO	71.5	73.6	72.0	90.5
	Goniocorella dumosa	GDU	83.7	91.3	91.3	91.3
	Madrepora oculata	MOC	86.8	87.9	84.1	94.3
	Solenosmilia variabilis	SVA	89.4	60.8	63.0	93.6
Other VME indicators	Antipatharia (black corals)	COB	76.8	79.0	71.7	90.1
	Stylasteridae (hydrocorals)	COR	95.6	96.4	97.4	95.2
	Demospongiae (demosponges)	DEM	99.0	96.3	92.6	95.9
	Hexactinellida (glass sponges)	HEX	95.9	98.5	99.5	95.2
	Pennatulacea (sea pens)	PTU	96.9	99.2	99.5	96.2
	Alcyonacea (gorgonian taxa only)	SOC	92.6	92.1	63.8	94.1

Table 34: Estimated overall percentage of stony corals (averaged across the four species) and other modelled VME indicator taxa (averaged across the six broader taxa) outside the areas open to fishing for each of three post-accounting methods at each of the scales of assessment. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power-Hi and Power-Lo = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power-Lo is the mean estimated relationship minus 1 standard deviation and Power-Hi is the mean estimated relationship plus 1 standard deviation.

		ROC		**Power-Lo**		**Power-Hi**		**Linear**
	Stony corals	Other VME taxa	Stony corals	Other VME taxa	Stony corals	Other VME taxa	Stony corals	Other VME taxa
Evaluated Area	82.9	92.8	78.4	93.6	77.6	87.4	92.4	94.5
Bioregion 15 (Tasman Sea & SW Pacific Ocean)	98.2	97.3	98.6	97.8	99.1	90.8	98.2	98.1
Bioregion 30 (Southern Ocean)	92.5	98.6	93.4	99.1	91.4	97.6	98.6	99.2
Bioregion 28 (New Zealand)	72.1	86.9	58.8	89.1	56.7	82.6	83.8	88.5
Bioregion 17 (Mid-South Tropical Pacific)	91.7	93.5	91.8	93.9	92.3	93.6	92.5	93.2
Bioregion 16 (Tropical Australia & Coral Sea)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Tasman Sea	79.8	90.6	83.0	91.4	83.3	79.8	89.3	91.9
North Louisville	83.2	87.5	85.1	86.5	82.0	88.9	87.1	87.1
Central Louisville	71.1	60.1	61.5	56.4	54.8	54.6	69.4	68.9
South Louisville	63.0	53.4	49.1	54.2	45.4	40.9	53.0	53.5
South Tasman Rise	93.8	97.3	92.8	98.2	90.8	96.6	97.4	98.1
Lord Howe Rise South FMA	75.9	88.3	75.3	84.9	74.2	70.0	82.5	85.8
Lord Howe Rise North FMA	75.4	92.6	94.5	92.6	96.0	79.6	91.9	92.1
NW Challenger FMA	63.0	68.6	64.6	67.9	67.1	63.1	64.4	68.4
West Norfolk Ridge FMA	57.8	91.7	76.2	91.8	74.6	83.9	83.8	89.2
Louisville Ridge North FMA	68.6	79.2	75.6	75.2	72.7	75.1	78.3	79.0
Louisville Ridge Central FMA	59.1	49.8	48.8	47.4	39.1	50.6	57.1	57.4
Louisville Ridge South FMA	60.9	54.3	45.6	51.8	42.5	40.4	47.4	48.2
South Tasman Rise FMA	92.7	96.4	92.2	97.3	90.6	95.5	96.6	97.5

4.7 HIGH LEVEL ASSESSMENT ACROSS ALL ASSETS/OBJECTIVES

- Key target fish stocks (tiers 1 and 2 in the stock assessment framework):
  - risk is low for orange roughy given the availability of quantitative stock assessment modelling and precautionary area-specific catch limits.
  - risk is low for other target species of trawl fisheries but may be higher for some of the target species of bottom line fisheries (i.e., bluenose/blue-eye trevalla and *Polyprion* spp.). Catch for these species is limited only by aggregate limits for all species combined (excluding orange roughy) and changes in targeting behaviour may lead to higher risks. Collection of more data is recommended to reduce uncertainties.
- Other fish stocks (tier 3 in the stock assessment framework)
  - Risk is generally low to medium for fish stocks other than those in tiers 1 and 2 of the stock assessment framework but continued monitoring and periodic reassessment is recommended for all stocks and more intense data collection is recommended for some species at higher risk.
- Marine mammals, seabirds, reptiles, and other species of concern
  - Captures of marine mammals are very rare and risk is probably very low.
  - Captures of seabirds are rare, and most captured birds are released alive (but with unknown prognosis). However, these fisheries overlap with a large number of seabird species that are known to be vulnerable to fishing impacts and no quantitative estimates of captures or risk to these populations have been made. Risk is probably low but continued monitoring of captures and the implementation and effectiveness of mitigation methods is recommended.
  - Captures of reptiles are very rare and risk is probably very low.
  - Captures of other species of concern are infrequent and those species that have been reported by fishers or observers are assessed to be at low risk by the chondrichthyan risk assessment presented here.
- Benthic habitats and VMEs
  - New habitat suitability index (HSI) models have been made for ten VME indicator taxa at a 1 km scale throughout the Evaluated Area. These models have very high skill for classifying presence or informed pseudo-absence of relevant VME indicator taxa.
  - Using the model predictions of HSI for the ten taxa, estimates of the proportion of the estimated distribution of suitable habitat and abundance for each taxon outside the spatial management areas have been calculated.
  - These calculations have been done at four spatial scales from the whole Evaluated Area through marine bioregions, broad fisheries administrative units, and orange roughy stock areas and using a variety of model structures and assumptions to assess sensitivity in the estimates.
  - At the broadest scale, about 80% of suitable habitat or abundance of stony corals and about 90% of suitable habitat or abundance of other VME indicator taxa are outside the BTMAs. At finer geographical and taxonomic scales, and using different assessment approaches, the proportions outside the BTMAs vary quite widely, and estimates for the NW Challenger Plateau average <70%.
  - Estimates of the proportions of VME indicator taxa outside the BTMAs are lowest for the Central-South Louisville Ridge where an average of 60% of suitable habitat and 45% of abundance of the key species of stony coral are outside the BTMA, together with 52% of suitable habitat and 48% of the abundance of other VME indicator taxa.

A sensitivity analysis assuming VME indicator taxa significantly deeper than bottom trawl fisheries are not exposed to fishing disturbance increases these values by 20-30 percentage points in these areas. However, there is limited information as to the abundance of a number of taxa below these depths.

- An assessment of Relative Benthic Status (RBS) has been undertaken with the results indicating that RBS for most taxa across the two scales assessed (Evaluated Area and FMAs) is >0.8 for most fishing effort and abundance sensitivity scenarios, with a number of clear exceptions at the FMA scale and within BTMAs.
- The RBS results indicate that status under the current and future fishing effort scenarios will be higher than status under the historical fishing effort scenario, and that status under the current fishing effort scenario will be higher than under the hypothetical future fishing effort scenario.
- A range of additional analyses have been undertaken to assess uncertainty in the habitat suitability index (HSI) modelling, including potential model over-prediction, as well as analyses of the relationships between HSI and abundance of VME taxa on the seafloor and the catchability of VME taxa in trawl gears. These analyses should be considered when interpreting results provided in the VME impact assessment and making inferences about the performance of CMM03-2020 (bottom fishing).

4.8 UNCERTAINTIES, NEXT STEPS AND RESEARCH REQUIREMENTS

The following non-exhaustive list includes information gaps and needs identified during the development of this bottom fishery impact assessment.

4.8.1 Key fish stocks

- Stock structure for key target stocks (ORY, ALF, BWA, HAU, etc.)
- Key biological information (growth, longevity, productivity) and indices of biomass and/or fishing mortality for key target stocks
- Stock information and first assessment for exploratory fisheries (in progress)
- SPRFMO-specific management targets and limits for key target and other stocks
- Limitations in the risk assessment for bycaught species

4.8.2 Marine mammals, seabirds, reptiles, other species of concern

- Frequency of interactions of each species with each fishery, including cryptic mortality
- Identification of seabirds, marine mammals and rare deepwater sharks and rays by fishers and observers
- At-sea distribution, including seasonality, of species potentially at-risk from SPRFMO bottom fisheries
- Population size and productivity estimates for species with wide distributional ranges/poorly known biology (might prevent more detailed risk assessments)

4.8.3 Benthic habitats and VMEs

4.8.3.1 Relationships between predicted probability of presence and observed abundances of VME indicator taxa

If assessment of the performance of the spatial management approach in CMM03-2020 is required in terms of abundance of VME indicator taxa, a key requirement is to understand the relationships between predicted habitat suitability and observed abundances of VME indicator taxa on the seafloor. Results from these analyses can be used to explore and improve the post-accounting summation of the amount of VME taxa abundance assumed to be protected by CMM03-2020 (Section 4.6.5) — as well as the RBS assessment of the status of VME indicator taxa (Section 4.5.3). A series of additional analyses have been undertaken to-date, building on those presented in Pitcher et al. (2019) (SC07-DW21-rev1), using predictions of HSI distribution from both the Georgian et al. (2019) models and the updated (2020) models.

Previous analyses described in SC07-DW21-rev1, based on observed abundance of *Solenosmilia* corals in parts of Australia's southeast marine region that overlapped the Georgian et al. (2019) predictions, showed that the observed *Solenosmilia variabilis* cover of the seabed was non-zero or substantive only at the highest predicted habitat suitability indices. Subsequent explorations of these relationships for additional VME indicator taxa and for additional survey datasets have identified similar results for most survey-taxa combinations but, in some cases, the relationship between predicted habitat suitability and observed abundance was different or lacking. The more recent analyses have included other Australian research survey data plus NORFANZ survey data for the broader Tasman sea region, as well as New Zealand research survey data for features of the Louisville Seamount Chain, and from surveys on the Challenger Plateau and Chatham Rise. Surveys have included both towed-video transects and benthic sampling. Wherever possible surveys were aggregated by sampling method (e.g. video, sled) and response metric (e.g. %cover, counts, biomass) to provide the most spatially extensive comparison in each case.

Figures 56 and 57 show example plots for observed abundance against predicted HSI for three VME taxa sampled, using towed-video, by Australian and New Zealand research surveys. These examples illustrate the most frequently observed patterns: 1) a prevalence of zero observations extending well into high and very high predicted HSI, with 2) non-zero observations occurring predominantly at high and very high predicted HSI, with substantive non-zero abundances occurring almost exclusively at the highest predicted HSI in these data sets. The full suite of results for all taxa by survey-type combinations are shown in Appendix G. While many cases showed similar raw patterns of observed versus predicted (Appendix G), there were also cases of no clear pattern, and at least one case of an apparent negative pattern. These plots of raw observations suggest that while there may be a relationship between observed abundance and predicted HSI, the relationship is not simple or linear.

Various alternative fits to the observed-versus-predicted data were attempted. A constraint was that fitted parameters had to be readily synthesized across survey-type/response-metric combinations. Given the frequent pattern of typically steeply increasing observed abundance relationships at high predicted HSI, a power relationship was considered appropriate—and when fitted to the observations as a profile (observed abundance/total observed abundance) also met the requirement to be readily synthesized. Initially, a 'super smoother' running means was computed (in log space, weighted by prediction variance $1/SD^2$) to indicate the mean trend in observed abundance against predicted HSI. The 'best' power of the super-smooth profile in natural scale was estimated by searching for the best least squares fit (Rsqd) and for the nearest 1:1 relationship (slope=1) between power transformed HSI and the super-smooth profile. For each power, the goodness of fit (R^2) to the observed abundance profile was tested (raw $\text{profile}^{1/\text{root}} \sim \text{HSI}^{\text{power}}$ where the product of root and power = 'best' power). A direct linear relationship between observed abundance and predicted HSI would be indicated by a 'best' power of 1. In most cases, powers >1 were selected – and where power=1 was retained, it generally had a poor fit to the data. In the majority of cases, the estimated 'best' power closely follows the super-smooth mean profile. Finally, the estimated 'best' powers across each survey-type/response-metric combination, for each taxon, were summarized using weighted means, where the weights were goodness of fit to the observed abundance profile. Overall uncertainty was estimated as the weighted means of the lower and upper Standard Error (SE) of each fit—subject to the overall uncertainty not being less-than or greater than any fitted best estimate. The final range of overall power estimates for comparisons of observed abundance against predicted HSI for each VME taxon is shown in Table 39.

The absence of simple linear relationships between observed abundance and predicted HSI has major implications for performance assessment of the spatial arrangements under CMM 03-2020. In particular, directly summing predicted HSI will lead to over-optimistic estimates of the proportion of VME taxa that are outside of areas where trawling is permitted. This arises because low to medium values of predicted HSI for most taxa will likely correspond to zero or insignificant actual VME taxa abundance. Other post-accounting summations (such as based on the power-relationship adjusted HSI), substantially change the estimated amount of certain VME taxa outside of trawling areas, and may provide more plausible estimates of the proportions of VME taxa assumed to be protected by CMM 03-2020 than the simple linear assumption used in 2018, but also have substantive uncertainty. Assessments of protection should ideally be done at spatial scale extents relevant to VME populations (as is done for Orange Roughy stock assessments that use assumed stock boundaries on the Louisville Seamount Chain and in the Tasman Sea). Such scales are not well understood, and further research is needed to establish the scale and extents of VME populations, such as genetic and larval connectivity work.

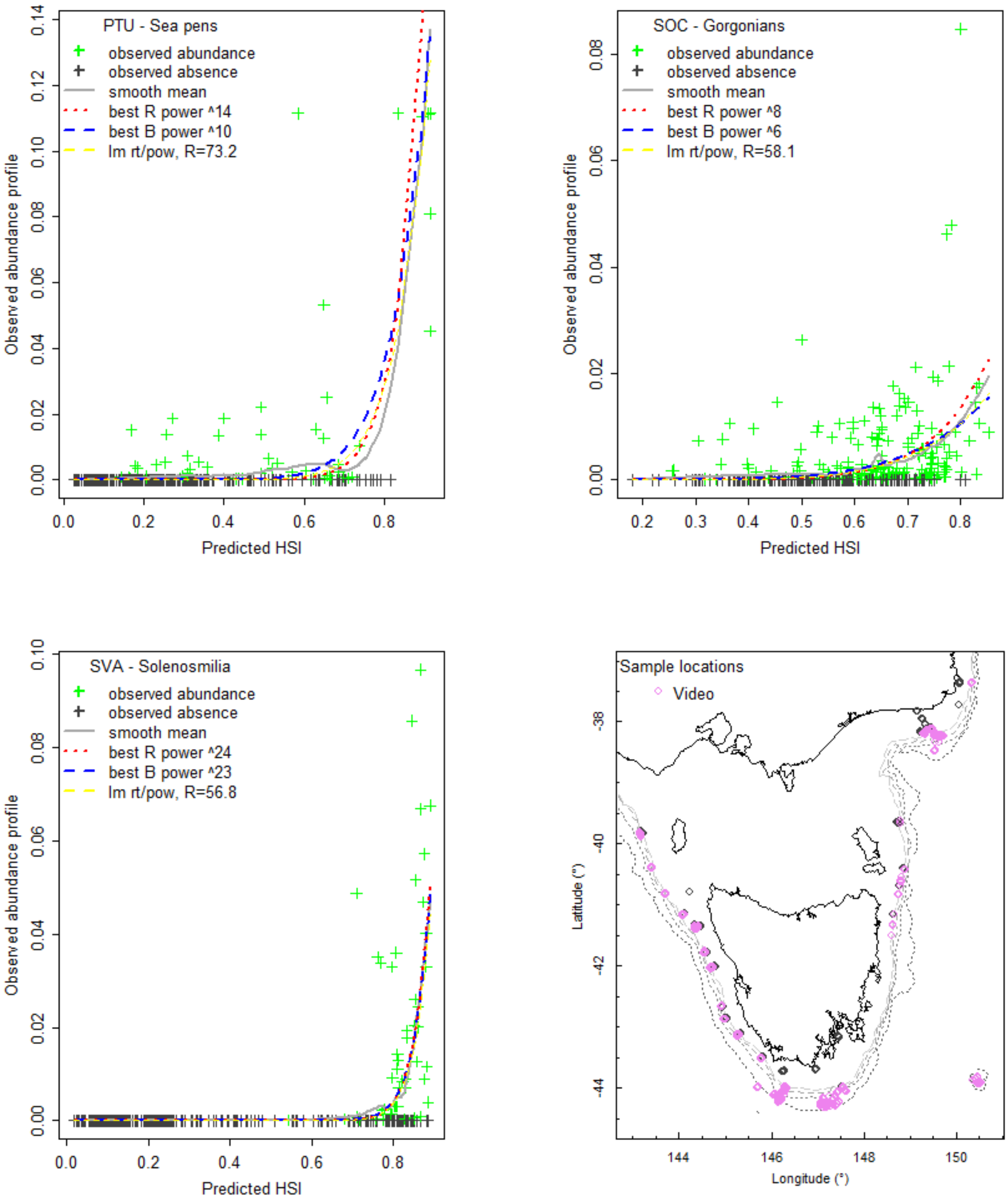


Figure 56: Comparisons of observed abundance against updated 2020 predictions of HSI for three VME taxa in Australia's southeast marine region overlapping the SPRFMO 2020 prediction grid. Curves indicate alternative fits to the data: smooth running mean; best power of HSI based on Rsqd (best R); best power of HSI based on slope (best B); Rsqd of fit (R=%) to root-transformed observations against power-transformed HSI (having same overall paper as best-power). Map shows video transect locations for surveys in the region (Althaus et al. 2009; Pitcher et al. 2015).

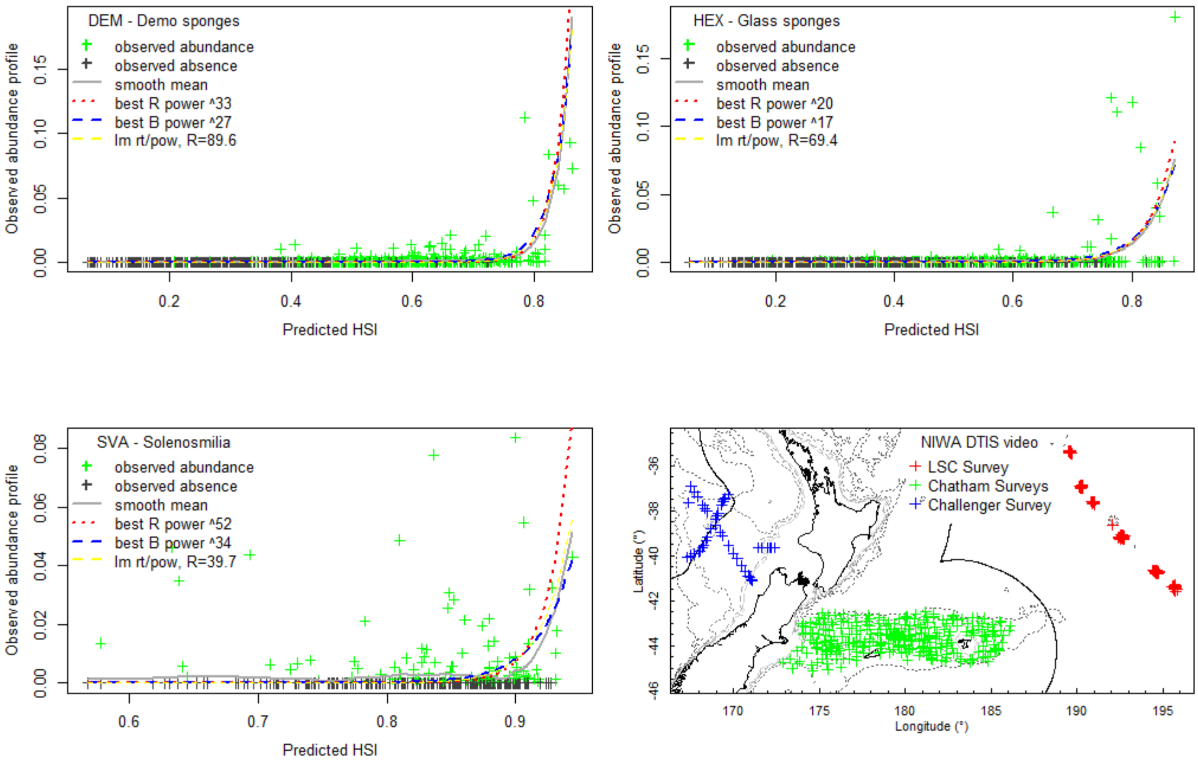


Figure 57: Comparisons of observed abundance against predicted HSI for three VME taxa on New Zealand's Challenger Plateau and Chatham Rise, and on the Louisville Seamount Chain, which overlap the SPRFMO 2020 prediction grid. Curves indicate alternative fits to the data: smooth running mean; best power of HSI based on Rsqd (best R); best power of HSI based on slope (best B); Rsqd of fit (R=%) to root-transformed observations against power-transformed HSI (having same overall paper as best-power). Map shows video transect locations for surveys in the region (Bowden et al 2011; Clark et al 2014)

Table 35: Final range of overall power estimates for comparisons of observed abundance against predicted HSI.

	Range of Power		
Taxon	Low	Mean	High
COB	3.3	4.1	5.7
COR	7.0	9.1	12.7
DEM	26.0	33.3	49.3
ERO	5.6	7.8	10.0
GDU	1.0	1.0	1.0
HEX	9.1	13.3	18.0
MOC	5.3	6.4	7.5
PTU	11.7	22.3	52.7
SOC	3.8	7.4	26.7
SVA	29.0	33.2	44.0

4.8.3.2 Potential over-prediction of the SPRFMO HSI modelling

Outputs from the previous section, regarding relationships between predicted habitat suitability and observed abundances of VME indicator taxa, also provide insight into potential over-prediction of habitat suitability for VME taxa by the SPRFMO 1km HSI modelling. Similar to SC07-DW21-rev1 (Pitcher et al. 2019), this involves comparing the SPRFMO predictions with existing observations data, particularly where there is zero observed abundance at increasingly high predicted HSI values.

Figures 56 and 57 in the previous section show example plots for observed abundance against predicted HSI for three VME taxa sampled by towed-video in Australian and New Zealand research surveys. Similar plots for the full suite of results for the 37 taxa by survey-type combinations are shown in Appendix G. A consistently observed pattern in these plots is the prevalence of observed zero abundances extending well into high and very high predicted HSI, and frequently non-zero observations occur predominantly at high and very high predicted HSI, with substantive non-zero abundances occurring mostly at high predicted HSI. The previous section addresses the implications of this non-linearity for performance assessment of CMM 03-2020 based on predicted abundance, including that direct summing of predicted HSI leads to over-optimistic estimates of the proportion of VME taxa protected, because low to medium values of predicted HSI for most taxa likely correspond to zero or insubstantial actual VME taxa abundance. While this non-linearity is a form of over-prediction, in this section, the focus is on the observed zero abundances with increasing predicted HSI values.

This focus is illustrated with residuals plots for the fitted relationships between observed abundance and predicted HSI in Appendix H. These plots show the observed data on the natural scale, with the fitted relationships, as well as the standardised residuals of the observations in the transformed space for two fitted relationships. These plots correspond with those in Appendix G. Given the observed patterns, few if any of the fitted relationships could be expected to exhibit the ideal bivariate normal residuals plot and, for some taxa in some datasets, there is no relationship and thus no model can be expected; where there is a model, the residuals are somewhat symmetrical above and below, but some are large, emphasising the magnitude of the potential over-prediction issue addressed in this section. Observed abundances and absences are indicated in these plots, which emphasise the key issue with these relationships (also evident in the residuals) of the high prevalence of zero observations as predicted HSI increases, even at high HSI. The fitted relationships fall between the zero and positive abundances, as is to be expected. In the residuals plots, there is frequently an obvious split between the observed absences and positive abundances.

There are two key potential explanations for these patterns: 1) the grain-size of the sampling that provides the observations is 1000-3000m² whereas the HSI predictions are for larger 1×1km grid cells, which leads to 'false-zero' observations; 2) 'missing predictors' in the underlying HSI modelling and predictions, which leads to high predicted HSI on seabed types where VME taxa do not occur. Both of these issues affect these data; the important question is their relative magnitude. A simulation of the sampling process (using gamma distributions with scale and shape informed by real data for *Solenosmilia* sampling in 2×12.5m segments of 1-3 km long video transects from one NIWA survey on the LSC to characterise a range of transect means and sample variances) suggest that 'false-zeroes' only occur when the expected grid-cell mean abundance is very low (lowest 9% of the expected range). However, observed zeroes frequently occur across the full range of predicted HSI, suggesting that the issue of the prevalence of observed zeroes is much more substantive than can be explained by sampling grain-size alone. Nine of the ten VME indicator taxa do not live on sediments but require hard and/or rocky substratum, yet this predictor is not available to the HSI modelling or predictions in

SPRFMO (although percent mud and percent gravel were included in the models, as was variability in bathymetry, as sourced these predictors were very broad scale and provide only indirect proxies for hard substratum at scales larger than required for taxa that require hard/rock substratum). Adding such an unknown factor that causes zeroes observations when >zero is expected was added to the gamma simulation and generated patterns with a clear split between the zero and >zero observations analogous to those shown in Appendix H. During the development of this BFIA, opinions differed on the meaning of such splits in residuals. CSIRO and Australian government scientists were of the view that the pattern is strongly suggestive of one or more missing predictors in the models and that the high prevalence of zero observations as predicted HSI increases is primarily due to such missing predictors, such as hard/rocky substrate, in the underlying HSI modelling. NIWA, New Zealand government, and contracting New Zealand scientists were of the view that the pattern could also arise from sampling scale issues and that more work was required to tease out the possibilities.

By way of comparison, previous modelling and distribution prediction of *Solenosmilia* in southeastern Australia (Pitcher et al. 2015) was affected by the sampling grain-size issue to the same extent as in SPRFMO — and also by missing predictors, but much less pronounced than in SPRFMO due to inclusion of small scale topographic shape predictors and mud, sand and gravel layers informed by a much higher density of sediment samples. In this modelling, observed zeroes occurred only when the predicted grid-cell mean abundance was in the lowest 0–1.4% of the predicted range of abundance.

A mapped illustration of the missing predictors issue is provided by the southern Tasmanian example where *Solenosmilia* is restricted to rocky upper flanks of seamounts and a few rocky pinnacles on the adjacent slope in the appropriate depth range. However, the 2020 SPRFMO predictions were for high HSI all along the slope in the depth band and between seamounts, whereas most of this area is sedimentary substratum where *Solenosmilia* and similar VME taxa cannot occur. These many sedimentary grid cells had medium-to-high HSI whereas all the corresponding observations were zero. The consequence of this missing predictors issue is that HSI in this area is over-predicted, leading to much larger predicted area of corals compared with the possible area of coral.

Further work is required to understand why there is a disparity between the observed over-prediction demonstrated in this section, the uncertain and variable relationships between observed abundance and predicted HSI in the previous section, and the very good binary performance results of the presence models described in section 4.4.2.3 (Table 24b).

The missing predictors issue cannot be resolved in the short term because it requires substantial amounts of new information.

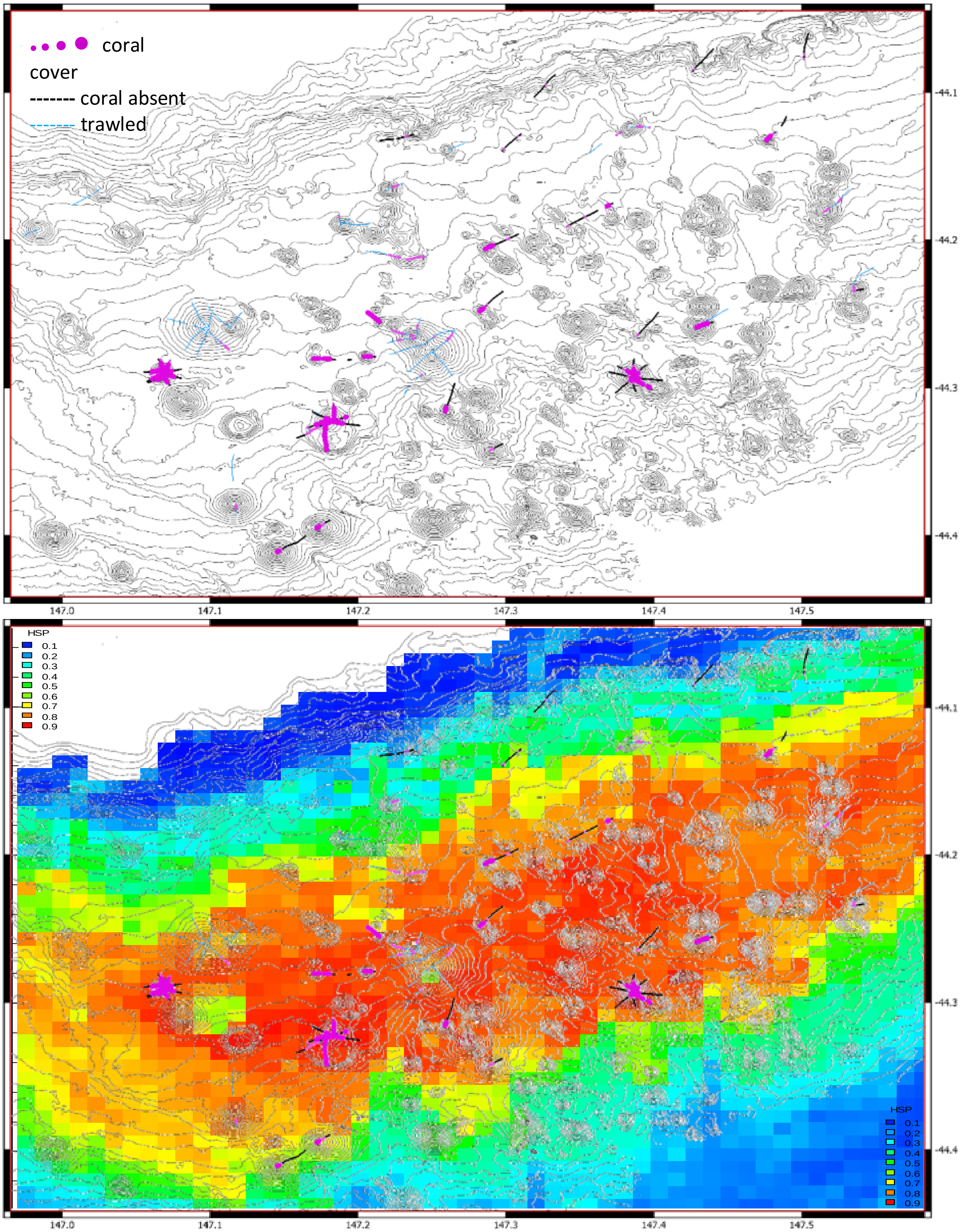


Figure 58: (Top) Map of the southern Tasmanian seamounts showing cover of *Solenosmilia* corals observed in video transects (Williams et al 2020). *Solenosmilia* is restricted to rocky upper flanks of seamounts and a few rocky pinnacles on the adjacent slope in the appropriate depth range — between seamounts and pinnacles, the seabed is sedimentary substratum where *Solenosmilia* does not occur. (Bottom) Map with underlay of the 2020 SPRFMO predictions, showing high predicted HSI all along the slope in the depth band, and many sedimentary grid cells with medium-to-high HSI and corresponding observations of zero corals.

4.8.3.3 Estimating the catchability of VME indicator taxa

A key requirement for understanding the potential effectiveness of the VME encounter thresholds included in the 'move-on' provisions of CMM03-2020 is to understand the relationship between the amount of VME taxa bycatch caught in fish-trawl nets and the actual amount of VME biota present on the seabed that may be impacted by the passage of trawl gear. A series of additional analyses have been undertaken to-date, building on those presented in Pitcher et al. (2019) (SC07-DW21-rev1), using additional datasets and for additional VME taxa. Results from these analyses can be used to contribute to review of the move-on thresholds as well as the proposed encounter-review procedure.

Previous analyses described in SC07-DW21-rev1 (Pitcher et al. 2019) and in SC07-DW14 (Geange et al. 2019), showed that fish-trawls typically catch (into the net) only very small proportions of VME taxa abundance on the seabed, and demonstrated that the VME indicator taxa thresholds outlined in CMM 03-2019 were very likely to correspond to very high covers and biomasses of VME taxa on the seabed.

Similar to SC07-DW21-rev1 (Pitcher et al. 2019), the analyses here involve comparing catch-rates of co-located sampling of VME taxa by different sampling gears—including by fish-trawls, where available—and where possible, comparing these catch-rates with observed abundances of VME taxa on the seabed.

Additional analyses of Australian data, where surveys had purposely paired two or more sampling gears at the same location, have progressed including gear-scale matching of Tasmanian Seamounts sampling, NORFANZ survey data, SEF Ecosystem surveys and NOO gear trials (Table 36 Figure 60). Typically, fish trawls catch ~30-40× less sessile benthos biota than sleds or beam trawls, noting that sleds do not sample all benthos present. These results are consistent with those presented in SC07-DW21-rev1, and reinforce existing evidence that fish trawls retain only a very small fraction of benthos that they contact on the seabed. Further data for additional NZ surveys are available and remain to be examined in collaboration with NIWA.

Table 36: mean catch rates (g/100m²) of co-located sampling of VME taxa by different sampling gears. FTW=fish trawl; BTW=research beam-trawl; SLD-epibenthic sled. Ratio indicates the relative catch-rates of the two gear types in each comparison.

		NORFANZ Survey				NORFANZ Survey				NOO SE gear trials surveys				Overall Weighted Average			
Taxon		N	avFTW	avBTW	Ratio	N	avFTW	avSLD	Ratio	N	avFTW	avSLD	Ratio	N	avFTW	avSL/BT	Ratio
ACT	Anemones	9	0.004	0.265	0.013	14	0.021	0.577	0.036	15	0.080	11.498	0.007	38	0.040	4.814	0.008
BRAC	Brachiopods					2	0.022	0.000		6	0.007	20.225	0.000	8	0.010	15.169	0.001
BRYO	Bryozoans	4	0.003	0.291	0.012	8	0.003	0.837	0.004	6	0.316	0.889	0.356	19	0.102	0.835	0.122
GOR	Gorgonians	10	0.017	1.126	0.015	16	0.161	3.216	0.050	8	0.524	2.138	0.245	35	0.198	2.297	0.086
HYZ	Hydrozoa	4	0.003	0.110	0.025	6	0.017	0.368	0.046	13	0.017	6.087	0.003	24	0.014	3.410	0.004
POR	Sponges	9	0.191	5.419	0.035	16	0.241	8.133	0.030	15	12.310	489.005	0.025	41	4.640	187.563	0.025
PTU	Seapens	6	0.001	0.128	0.009	8	0.004	0.416	0.010	8	0.060	1.198	0.050	22	0.024	0.622	0.038
SOC	Soft corals	4	0.004	0.029	0.139	9	0.007	0.297	0.025					14	0.006	0.388	0.015
STOC	Corals solitary	4	0.005	0.151	0.031	8	0.007	0.634	0.010	1	0.000	0.197	0.000	13	0.005	0.452	0.012
STOCRB	Stony corals	7	0.006	0.215	0.028	7	0.006	0.348	0.018	9	0.213	2.968	0.072	24	0.083	1.290	0.065
STY	Stylasterids	4	0.003	0.097	0.027	6	0.031	0.264	0.118					10	0.020	0.197	0.100
ZOANT	Zoantharians	3	0.001	0.054	0.026	5	0.003	0.201	0.016					8	0.003	0.146	0.018
TOTAL			0.238	7.884	0.030		0.524	15.290	0.034		13.526	534.205	0.025		5.145	217.182	0.024

For the southeast Australian surveys, gear-scale matching where benthic-sleds had been purposely towed over video-transects (Williams et al. 2015, Williams et al. 2020) provided catch-rate and observed seabed cover data for bryozoans (BRY), gorgonians (GOR), sponges (POR) and stony corals

(STO, primarily *S. variabilis*) (see Figure 59). Inferred fish trawl catch rates are indicated (blue lines) based on the overall catchabilities highlighted in Table 40 above. These results are consistent with those presented in SC07-DW21-rev1 from 0.01° grid-scale matching of video and sled for *S. variabilis*. For bryozoans, at 50% bottom cover, sled catches may typically range between ~6-75 g/100m² and inferred trawl catches ~0-6 g/100m². For gorgonians, at 50% bottom cover, sled catches may typically range between ~6-54 g/100m² and inferred trawl catches ~0-3 g/100m². For sponges, at 50% bottom cover, sled catches may typically range between ~9-1552g/100m² and inferred trawl catches ~0-46g/100m². For stony corals, at 50% bottom cover, sled catches may typically range between ~755-3480g/100m² and inferred trawl catches ~41-192 g/100m².

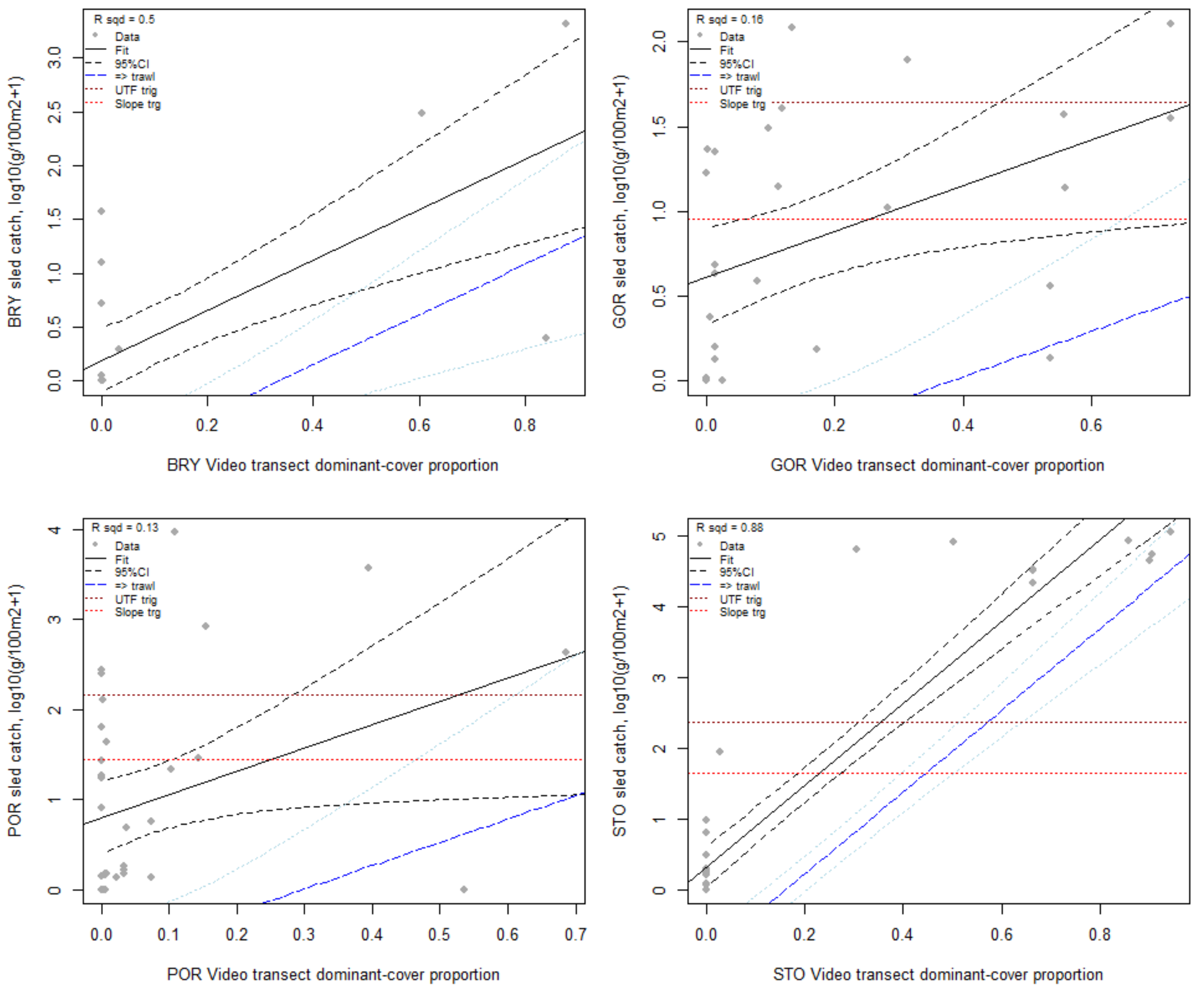


Figure 59: Relationship between biomass ($\log_{10}$(g/100m²+1)) of four VME taxa (BRY: bryozoans, GOR: gorgonians, POR: sponges, STO: reef building stony corals primarily *S. variabilis*) sampled by heavy epi-benthos sled against %cover of the same taxa observed in co-located video transects at the same stations in the southeast Australian surveys. Catch range for fish trawls is inferred from maximum estimated catchabilities of fish-trawls relative to dredges/sleds for the same taxa (highlighted in Table 39).

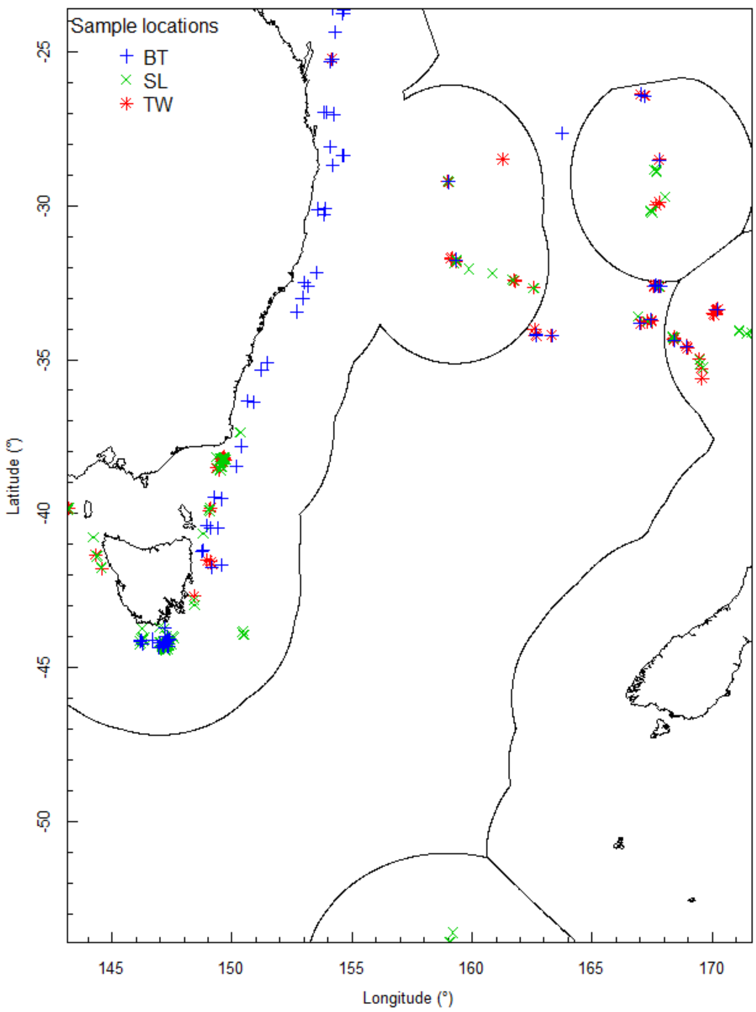


Figure 60: Map of survey stations from datasets contributing to co-located gears comparisons; only paired samples were used for the catch-rate comparisons shown in Table 40, where either beam-trawls (BT) or benthic sleds (SL) were towed directly over fish-trawl (TW) tows. Such gear-pair samples were well distributed around the Tasman Sea, primarily from the NORFANZ Survey but also from gear catch-rate comparisons in SE Australia.

Current trigger thresholds are 15 kg for gorgonians, 50 kg for sponges and 80kg for stony corals; no threshold has been set for bryozoans. The average net swept area (Mormede et al. 2017) of "slope" trawls is 18.81 Ha and for "UTF" trawls is 3.49 Ha. Thus, for "slope" trawls, the threshold catches correspond to 7.97 g/100m^2 for gorgonians, 26.58 g/100m^2 for sponges and 42.53 g/100m^2 for stony corals. These in turn correspond to >100% cover (65% to >100%) for gorgonians, ~85% cover (47% to >100%) for sponges, and ~45% cover (40% to 50%) for stony corals (light red dotted lines). And, for "UTF" trawls, the threshold catches correspond to 42.97 g/100m^2 for gorgonians, 143.27 g/100m^2 for sponges and 229.23 g/100m^2 for stony corals. These in turn correspond to >100% cover (94% to >100%) for gorgonians, >100% cover (61% to >100%) for sponges, and ~57% cover (51% to 65%) for stony corals (dark red dotted lines). Hence, the current trigger thresholds correspond to high covers of VME taxa types on the seabed, which are likely to be considered indicative of VME habitats, given recent evidence (Rowden et al. 2020) that ~30% cover represents significant concentration of VME taxa supporting high diversity of associated taxa that the authors suggest could be used to distinguish deep-sea structurally complex VMEs. Further, the total contact area of "slope" trawls is ~7.6× larger than the net swept area, and of "UTF" trawls is 5.7× larger, indicating greater potential for impact.

The relative catch rates shown in Table 39 show the difference between sampling gears, but do not indicate the absolute catchability of these gears in relation to how much of these taxa is present on the seabed. It is known that sleds and beam trawls do not collect all benthos present. Some additional catchability comparisons were possible between sleds and beam trawls against tow-video transects with high-resolution still images where the response variable was density (counts of individuals per m²), using additional southeast Australian VME taxa survey data. This density comparison (Figure 61) suggests that research beam trawls catch only ~1.1% of what is seen on the seabed and sleds catch only ~1.7%. Combined with other evidence showing that fish trawls catch ~10× to ~100× less than sleds, this means the estimated impact on the seabed is likely to be greater than indicated previously, for any given VME bycatch taxa caught in a fish trawl.

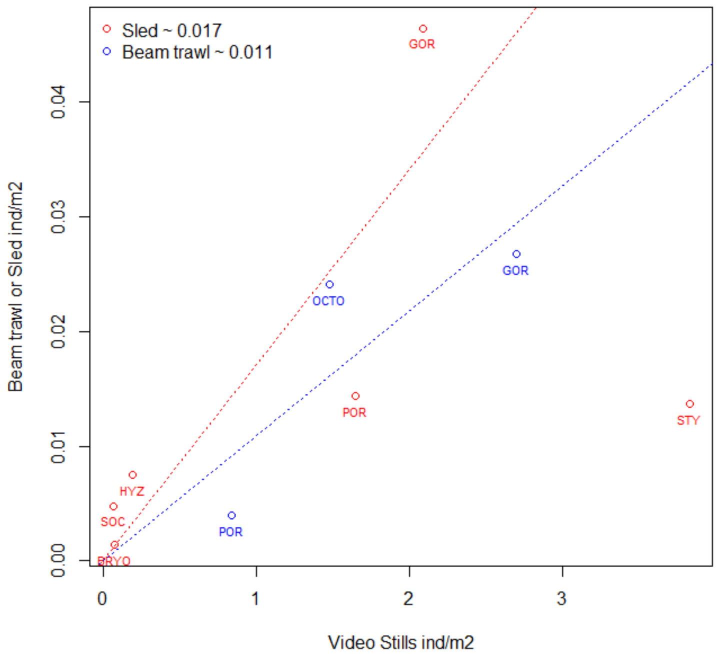


Figure 61: Relationship between density of VME taxa (see codes in Table 39) sampled by sleds and beam trawls compared with density observed on the seabed. Note that counts of individuals are not possible for brittle taxa, which break up when sampled by benthic gears.

4.8.3.4 Other uncertainties

- Distribution (and abundance) of VME indicator taxa and other VME taxa uncertainties in modelled distributions, as well as in model projections in low environmental predictor resolution areas.
- There is a particular need for more abundance/biomass data for VME indicator taxa so abundance-based models can be developed. It might also be worth compiling all abundance/biomass data for VME indicator taxa to see if they would support abundance/biomass-based models for specific regions.

- Continue to examine the relationship between HSI indices and abundance of VME indicator taxa to understand difference between presence and abundance models, and the non-linear relationships between HSI and abundance.
- Quantify the uncertainties around the environmental variables used for modelling the habitat suitability of for VME indicator taxa, and consider how to feed that uncertainty into the predictive models.
- For the naturalness estimates, include uncertainties in the footprint estimate (might be relevant at small spatial scales) and in the depletion/recovery parameters for VME indicator taxa (i.e., include more site-, method- and taxon-specific estimates of d and R parameters for estimating naturalness and conducting RBS assessments).
- Investigate automated methods for making polygons to define a range of different features within the seascape to facilitate post-accounting at a range of spatial scales or subsets of features.
- Continue to investigate the effects of sensitivity in model assumptions/parameters

2. Management measures
    - Propagation and accounting of uncertainties in prioritization tools (post-accounting)
    - SPRFMO-specific management targets and limits, including spatial scale
    - Operational definitions of SAI (refers again to spatial scale), ideally with FAO as part of an across-RFMO initiative.

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Appendix A - List of key species codes, scientific names and common names used

FAO Code	NZ Code	Scientific Name	Common Name
ALF	BYX	*Beryx splendens, B. decadactylus*	Alfonsino & Long-finned beryx
BOE	BOE	*Allocyttus niger*	Black oreo
BWA	BNS	*Hyperoglyphe antarctica*	Bluenose/blue-eye trevalla
CJM	JMM	*Trachurus murphyi*	Chilean jack mackerel
DGS	SPD	*Squalus spp.*	Spiny dogfish, northern spiny dogfish
EDR	SBO	*Pseudopentaceros richardsoni*	Southern boarfish
EGD		*Epigonus denticulatus*	Pencil (or bigeye) cardinalfish
EPI	CDL	*Epigonus telescopus*	Deepsea cardinalfish
GIS	N/A	*Dosidichus gigas*	Jumbo flying squid
GRN	HOK	*Macruronus novaezelandiae*	Hoki, blue grenadier
HAU	HPB	*Polyprion oxygeneios, P. americanus*	Wreckfish (Hapuku & Bass)
MOW	KTA	*Nemadactylus* spp.	King tarakihi
ONV	SOR	*Neocyttus rhomboidalis*	Spiky oreo
ORY	ORH	*Hoplostethus atlanticus*	Orange roughy
RIB	RIB	*Mora moro*	Ribaldo
ROK	SPE	*Helicolenus* spp.	Sea perch
RTX	RAT	*Macrouridae (Family)*	Rattails
RXX	SKI	*Rexea spp.*	Gemfish, southern kingfish
SCK	BSH	*Dalatias licha*	Seal shark
SEM	WAR	*Seriollela brama*	Common warehou
SEP	SWA	*Seriollela punctata*	Silver warehou
SNK	BAR	*Thyrsites atun*	Barracouta
SSO	SSO	*Pseudocyttus maculatus*	Smooth oreo
TAK	TAR	*Nemadactylus macropterus*	Tarakihi/jackass morwong
TOA	TOT	*Dissostichus mawsoni*	Antarctic toothfish
TOP	PTO	*Dissostichus eleginoides*	Patagonian toothfish
YTC	KIN	*Seriola lalandi*	Kingfish

Appendix B - List of Teleost and Chondrichthyan Species Included in the SPRFMO Ecological Risk Assessments

Species name	Common name	Teleost/Chondrichthyan	FAO Code (3-alpha)
Abalistes stellaris	Starry Triggerfish	Teleost	AJS
Alepocephalus australis	Smallscale Slickhead	Teleost	AVS
Allocyttus niger	Black Oreodory	Teleost	BOE
Allocyttus verrucosus	Warty Oreodory	Teleost	ALL
Allomycterus pilatus	Australian Burrfish	Teleost	AYT
Alopias superciliosus	Bigeye Thresher	Chondrichthyan	BTH
Alopias vulpinus	Thresher Shark	Chondrichthyan	ALV
Amblyraja hyperborea	Amblyraja hyperborea	Chondrichthyan	#N/A
Anoplogaster cornuta	Fangtooth	Teleost	AGW
Antimora rostrata	Violet Cod	Teleost	ANT
Aphareus rutilans	Rusty Jobfish	Teleost	ARQ
Aprion virescens	Green Jobfish	Teleost	AVR
Apristurus albisoma	Apristurus albisoma	Chondrichthyan	#N/A
Apristurus ampliceps	Apristurus ampliceps	Chondrichthyan	#N/A
Apristurus australis	Apristurus sp G	Chondrichthyan	#N/A
Apristurus exsanguis	Apristurus exsanguis	Chondrichthyan	#N/A
Apristurus garricki	Apristurus garricki	Chondrichthyan	#N/A
Apristurus longicephalus	Smoothbelly Catshark	Chondrichthyan	CSF
Apristurus melanoasper	Apristurus melanoasper	Chondrichthyan	#N/A
Apristurus pinguis	Apristurus pinguis	Chondrichthyan	#N/A
Apristurus platyrhynchus	Borneo catshark	Chondrichthyan	APZ
Apristurus sinensis	Apristurus sp A	Chondrichthyan	ASI
Argentina elongata	Argentina elongata	Teleost	ARE
Bassanago hirsutus	Deepsea Conger	Teleost	CBH
Bathyraja eatonii	[a skate]	Chondrichthyan	BEA
Bathyraja richardsoni	Richardson's ray	Chondrichthyan	BYQ
Bathyraja shuntovi	Bathyraja shuntovi	Chondrichthyan	BYU
Bathytoshia brevicaudata	Short-tail stingray	Chondrichthyan	#N/A
Bathytoshia lata	Brown stingray / Black Stingray	Chondrichthyan	#N/A
Benthodesmus elongatus	Slender Frostfish	Teleost	BDL
Beryx decadactylus	Imperador	Teleost	BXD
Beryx splendens	Alfonsino	Teleost	BYS
Bodianus perditio	Goldspot Pigfish	Teleost	BDT
Brama brama	Ray's Bream	Teleost	POA
Brochiraja asperula	Brochiraja asperula	Chondrichthyan	#N/A
Brochiraja heuresa	Brochiraja heuresa	Chondrichthyan	#N/A
Brochiraja leviveneta	Brochiraja leviveneta	Chondrichthyan	#N/A
Brochiraja spinifera	Brochiraja spinifera	Chondrichthyan	#N/A
Brochiraja vitticauda	Brochiraja vitticauda	Chondrichthyan	#N/A
Caprodon longimanus	Longfin Perch	Teleost	RNL
Carangoides orthogrammus	Island trevally	Teleost	NGT
Caranx lugubris	Black Trevally	Teleost	NXU
Caranx sexfasciatus	Bigeye Trevally	Teleost	CXS
Carcharhinus altimus	Bignose Shark	Chondrichthyan	CCA
Carcharhinus galapagensis	Galapagos Shark	Chondrichthyan	CCG
Carcharodon carcharias	White Shark	Chondrichthyan	WSH
Centriscops humerosus	Banded Bellowsfish	Teleost	CUQ
Centroberyx affinis	Redfish	Teleost	CXF
Centroberyx gerrardi	Bight Redfish	Teleost	CXZ

Species name	Common name	Teleost/Chondrichthyan	FAO Code (3-alpha)
Centrolophus niger	Rudderfish	Teleost	CEO
Centrophorus granulosus	Gulper Shark	Chondrichthyan	GUP
Centrophorus harrissoni	Harrisson's Dogfish	Chondrichthyan	CEU
Centrophorus moluccensis	Endeavour Dogfish	Chondrichthyan	CEM
Centrophorus squamosus	Leafscale Gulper Shark	Chondrichthyan	GUQ
Centroscyllium kamoharai	Centroscyllium kamoharai	Chondrichthyan	CYK
Centroscymnus coelolepis	Portuguese Dogfish	Chondrichthyan	CYO
Centroscymnus owstonii	Owston's Dogfish	Chondrichthyan	#N/A
Centroselachus crepidater	Golden Dogfish	Chondrichthyan	#N/A
Cephalopholis cyanostigma	Bluespotted Rockcod	Teleost	CFY
Cephalopholis sonnerati	Tomato Rockcod	Teleost	EFT
Cephaloscyllium signourum	Flagtail swellshark	Chondrichthyan	#N/A
Cetorhinus maximus	Basking Shark	Chondrichthyan	BSK
Chauliodus sloani	Sloane's Viperfish	Teleost	CDN
Chelidonichthys kumu	Red Gurnard	Teleost	KUG
Chimaera carophila	Chimaera carophila	Chondrichthyan	#N/A
Chimaera fulva	Southern Chimaera	Chondrichthyan	#N/A
Chimaera lignaria	Giant Chimaera	Chondrichthyan	#N/A
Chimaera macrospina	Longspine Chimaera	Chondrichthyan	#N/A
Chimaera panthera	Chimaera panthera	Chondrichthyan	#N/A
Chlamydoselachus anguineus	Frill Shark	Chondrichthyan	HXC
Cirrhigaleus australis	Cirrhigaleus australis	Chondrichthyan	#N/A
Cnidoglanis macrocephalus	Estuary Cobbler	Teleost	CNM
Coelorinchus fasciatus	Banded Whiptail	Teleost	CQF
Coelorinchus kaiyomaru	Kaiyomaru Whiptail	Teleost	MCK
Coelorinchus oliverianus	Hawknose grenadier	Teleost	CKV
Cyttus australis	Silver Dory	Teleost	ZCU
Cyttus novaezealandiae	New Zealand Dory	Teleost	ZCN
Cyttus traversi	King Dory	Teleost	ZCT
Dalatias licha	Black shark	Chondrichthyan	SCK
Deania calceus	Brier Shark	Chondrichthyan	#N/A
Deania quadrispinosa	Longsnout Dogfish	Chondrichthyan	SDQ
Derichthys serpentinus	Deepwater Neck Eel	Teleost	ADD
Diagramma pictum	Painted Sweetlip	Teleost	DGP
Diastobranchus capensis	Basketwork Eel	Teleost	SDC
Dipturus acrobelus	Deepwater Skate	Chondrichthyan	#N/A
Dipturus innominatus	Dipturus innominatus	Chondrichthyan	DPQ
Diretmichthys parini	Black Spinyfin	Teleost	SFN
Diretmus argenteus	Silver spinyfin	Teleost	DUU
Dissostichus eleginoides	Patagonian toothfish	Teleost	TOP
Dissostichus mawsoni	[an icefish]	Teleost	TOA
Echinorhinus brucus	Bramble Shark	Chondrichthyan	SHB
Echinorhinus cookei	Prickly Shark	Chondrichthyan	ECK
Elagatis bipinnulata	Rainbow Runner	Teleost	RRU
Emmelichthys nitidus	Redbait	Teleost	EMM
Epigonus robustus	Robust Deepsea Cardinalfish	Teleost	EGR
Epigonus telescopus	Black Deepsea Cardinalfish	Teleost	EPI
Epinephelus coioides	Orange-spotted Grouper	Teleost	ENI
Epinephelus cyanopodus	Purple Rockcod	Teleost	EPY
Epinephelus ergastularius	Banded Rockcod	Teleost	#N/A
Epinephelus fasciatus	Blacktip Rockcod	Teleost	EEA
Epinephelus fuscoguttatus	Flowery Rockcod	Teleost	EWF

Species name	Common name	Teleost/Chondrichthyan	FAO Code (3-alpha)
Epinephelus maculatus	Highfin Grouper	Teleost	EEC
Epinephelus morrhua	Comet Grouper	Teleost	EEP
Epinephelus quoyanus	Longfin Rockcod	Teleost	EFQ
Epinephelus retouti	Red-tipped grouper	Teleost	EWR
Epinephelus septemfasciatus	Convict Grouper	Teleost	EIF
Etelis carbunculus	Ruby Snapper	Teleost	ETA
Etelis coruscans	Flame Snapper	Teleost	ETC
Etmopterus bigelowi	Smooth Lanternshark	Chondrichthyan	ETB
Etmopterus granulosus	Etmopterus granulosus	Chondrichthyan	ETM
Etmopterus litvinovi	Etmopterus litvinovi	Chondrichthyan	#N/A
Etmopterus lucifer	Blackbelly Lanternshark	Chondrichthyan	ETF
Etmopterus molleri	Moller's Lanternshark	Chondrichthyan	ETL
Etmopterus pusillus	Slender Lanternshark	Chondrichthyan	ETP
Etmopterus pycnolepis	Etmopterus pycnolepis	Chondrichthyan	#N/A
Etmopterus unicolor	Bristled Lanternshark	Chondrichthyan	ETJ
Etmopterus viator	Etmopterus viator	Chondrichthyan	EZT
Euprotomicroides zantedeschia	Euprotomicroides zantedeschia	Chondrichthyan	EUZ
Euprotomicrus bispinatus	Pygmy Shark	Chondrichthyan	EUP
Galeocerdo cuvier	Tiger Shark	Chondrichthyan	TIG
Galeorhinus galeus	School Shark	Chondrichthyan	GAG
Gempylus serpens	Snake Mackerel	Teleost	GES
Genypterus blacodes	Pink Ling	Teleost	CUS
Gnathanodon speciosus	Golden Trevally	Teleost	GLT
Gollum attenuatus	Gollum attenuatus	Chondrichthyan	CPG
Grammicolepis brachiusculus	Thorny Tinselfish	Teleost	GMG
Gymnocranius euanus	Paddletail Seabream	Teleost	GMQ
Gymnocranius grandoculis	Robinson's Seabream	Teleost	GMW
Halargyreus johnsonii	Slender Cod	Teleost	MHJ
Harriotta haeckeli	Harriotta haeckeli	Chondrichthyan	HCH
Harriotta raleighana	Bigspine Spookfish	Chondrichthyan	HCR
Helicolenus percoides	Reef Ocean Perch	Teleost	HFR
Heptranchias perlo	Sharpnose Sevengill Shark	Chondrichthyan	HXT
Hexanchus griseus	Bluntnose Sixgill Shark	Chondrichthyan	SBL
Hexanchus nakamurai	Bigeye Sixgill Shark	Chondrichthyan	HXN
Hoplostethus atlanticus	Orange Roughy	Teleost	ORY
Hoplostethus intermedius	Blacktip Sawbelly	Teleost	#N/A
Hydrolagus bemisi	Hydrolagus bemisi	Chondrichthyan	#N/A
Hydrolagus cf affinis	Smalleyed rabbitfish	Chondrichthyan	#N/A
Hydrolagus homonycteris	Black whitefin	Chondrichthyan	#N/A
Hydrolagus lemures	Blackfin Ghostshark	Chondrichthyan	CYS
Hydrolagus novaezealandiae	Hydrolagus novaezealandiae	Chondrichthyan	CYV
Hydrolagus trolli	Hydrolagus trolli	Chondrichthyan	#N/A
Hyperoglyphe antarctica	Blue-Eye Trevalla	Teleost	BWA
Isistius brasiliensis	Smalltooth Cookiecutter Shark	Chondrichthyan	ISB
Isurus oxyrinchus	Shortfin Mako	Chondrichthyan	SMA
Isurus paucus	Longfin Mako	Chondrichthyan	LMA
Kathetostoma giganteum	Giant stargazer	Teleost	STZ
Lagocephalus lagocephalus	Oceanic puffer;Ocean Puffer	Teleost	LGH
Lamna nasus	Porbeagle	Chondrichthyan	POR
Lampadena speculigera	Mirror lanternfish	Teleost	LDS
Lampris guttatus	Spotted moonfish;Opah	Teleost	LAG
Latridopsis ciliaris	Blue Moki	Teleost	BMO

Species name	Common name	Teleost/Chondrichthyan	FAO Code (3-alpha)
Latridopsis forsteri	Bastard Trumpeter	Teleost	WLF
Latris lineata	Striped Trumpeter	Teleost	LRL
Lepidion microcephalus	Smallhead Cod	Teleost	LMF
Lepidocybium flavobrunneum	Escolar	Teleost	LEC
Lepidoperca pulchella	Eastern Orange Perch	Teleost	LDP
Lepidopus caudatus	Southern Frostfish;Frostfish	Teleost	SFS
Lepidorhynchus denticulatus	Toothed Whiptail	Teleost	LDE
Lethrinus lentjan	Red Spot Emperor	Teleost	LTS
Lethrinus miniatus	Redthroat Emperor	Teleost	LHI
Lethrinus olivaceus	Longnose Emperor	Teleost	LHO
Lethrinus rubrioperculatus	Spotcheek Emperor	Teleost	LHB
Luposicya lupus	Wolfsnout goby	Teleost	UUU
Lutjanus adetii	Hussar	Teleost	LDW
Lutjanus argentimaculatus	Mangrove Jack	Teleost	RES
Lutjanus bohar	Red Bass	Teleost	LJB
Lutjanus fulvus	Blacktail Snapper	Teleost	LJV
Lutjanus lutjanus	Bigeye Snapper	Teleost	LJL
Lutjanus malabaricus	Saddletail Snapper	Teleost	MAL
Macrourus carinatus	Ridgescale Whiptail	Teleost	MCC
Macrourus whitsoni	[a whiptail]	Teleost	WGR
Macruronus novaezelandiae	Blue Grenadier	Teleost	GRN
Melanostomias valdiviae	Valdivia black dragon fish	Teleost	MNV
Merluccius australis	Southern Hake	Teleost	HKN
Mitsukurina owstoni	Goblin Shark	Chondrichthyan	LMO
Mola mola	Ocean Sunfish	Teleost	MOX
Mora moro	Ribaldo	Teleost	RIB
Nemadactylus douglasii	Grey Morwong	Teleost	CDD
Nemadactylus macropterus	Jackass Morwong	Teleost	TAK
Neocyttus rhomboidalis	Spikey Oreodory	Teleost	ONV
Notoraja alisae	Notoraja alisae	Chondrichthyan	#N/A
Notoraja azurea	Blue Skate	Chondrichthyan	#N/A
Notoraja sapphira	Notoraja sapphira	Chondrichthyan	#N/A
Odontaspis ferox	Smalltooth Sandtiger	Chondrichthyan	LOO
Odontaspis noronhai	Odontaspis noronhai	Chondrichthyan	ODH
Ophisurus serpens	Serpent Eel	Teleost	OOS
Optivus elongatus	Slender roughy	Teleost	OVE
Oreosoma atlanticum	Oxeye Oreodory	Teleost	OOT
Ostichthys kaianus	Kai soldierfish	Teleost	HWK
Ostracion cubicus	Yellow Boxfish	Teleost	OTJ
Oxynotus bruniensis	Prickly Dogfish	Chondrichthyan	OXB
Paratrachichthys trailli	Sandpaper fish, Common roughy	Teleost	TPT
Paristiopterus labiosus	Giant Boarfish	Teleost	SWH
Parmaturus macmillani	Parmaturus macmillani	Chondrichthyan	PAE
Pentaceropsis recurvirostris	Longsnout Boarfish	Teleost	ENV
Pentaceros decacanthus	Bigspine Boarfish	Teleost	EMV
Persparsia kopua	Spangled Tubeshoulder	Teleost	PPK
Phosichthys argenteus	Silver Lightfish	Teleost	HOE
Plagiogeneion rubiginosum	Cosmopolitan Rubyfish	Teleost	RYG
Platycephalus richardsoni	Tiger Flathead	Teleost	PHI
Plectropomus leopardus	Common Coral Trout	Teleost	EMO
Plesiobatis daviesi	Giant Stingaree	Chondrichthyan	RPD
Pleuroscopus pseudodorsalis	Scaled Stargazer	Teleost	UPD

Species name	Common name	Teleost/Chondrichthyan	FAO Code (3-alpha)
Polyprion americanus	Bass Groper	Teleost	WRF
Polyprion oxygeneios	Hapuku	Teleost	WHA
Prionace glauca	Blue Shark	Chondrichthyan	BSH
Pristipomoides argyrogrammicus	Ornate jobfish	Teleost	LRY
Pristipomoides auricilla	Goldflag jobfish	Teleost	LWA
Pristipomoides filamentosus	Rosy Snapper	Teleost	PFM
Pristipomoides flavipinnis	Goldeneye Snapper	Teleost	LWF
Pristipomoides multidens	Goldbanded Jobfish	Teleost	LRI
Pristipomoides sieboldii	Lavender Snapper	Teleost	LRB
Pristipomoides zonatus	Oblique-banded Snapper	Teleost	LWZ
Pseudobalistes flavimarginatus	Yellowmargin Triggerfish	Teleost	UBV
Pseudocaranx georgianus	Silver Trevally	Teleost	#N/A
Pseudocarcharias kamoharai	Crocodile Shark	Chondrichthyan	PSK
Pseudocyttus maculatus	Smooth Oreodory	Teleost	SSO
Pseudopentaceros richardsoni	Pelagic Armourhead	Teleost	EDR
Pseudophycis bachus	Red Cod	Teleost	NEC
Pseudophycis breviuscula	Bastard Red Cod	Teleost	PBV
Pseudotriakis microdon	False Catshark	Chondrichthyan	PTM
Pterygotrigla picta	Spotted gurnard	Teleost	JGU
Pterygotrigla polyommata	Latchet	Teleost	BEG
Rajella challengeri	Challenger skate	Chondrichthyan	#N/A
Regalecus glesne	Oarfish ("king of herrings")	Teleost	REL
Rexea solandri	Gemfish	Teleost	GEM
Rhinochimaera pacifica	Pacific Spookfish	Chondrichthyan	RCP
Rhombosolea plebeia	Sand flounder	Teleost	RMP
Ruvettus pretiosus	Oilfish	Teleost	OIL
Schedophilus velaini	Violet warehou	Teleost	SEY
Scomber australasicus	Blue Mackerel	Teleost	MAA
Scymnodalatias albicauda	Scymnodalatias albicauda	Chondrichthyan	YSA
Scymnodalatias oligodon	Sparsetooth dogfish	Chondrichthyan	#N/A
Scymnodalatias sherwoodi	Sherwood dogfish	Chondrichthyan	YSS
Scymnodon ringens	Scymnodon ringens	Chondrichthyan	SYR
Seriola dumerilli	Amberjack	Teleost	#N/A
Seriola hippos	Samsonfish	Teleost	RLH
Seriola lalandi	Yellowtail Kingfish	Teleost	YTC
Seriola rivoliana	Highfin Amberjack	Teleost	YTL
Seriolella brama	Blue Warehou	Teleost	SEM
Seriolella caerulea	White Warehou	Teleost	SEU
Seriolella punctata	Silver Warehou	Teleost	SEP
Somniosus antarcticus	Southern Sleeper Shark	Chondrichthyan	RZZ
Somniosus longus	Somniosus longus	Chondrichthyan	#N/A
Sphoeroides pachygaster	Balloonfish	Teleost	TSP
Sphyraena jello	Pickhandle barracuda	Teleost	BAC
Squaliolus aliae	Smalleye Pygmy Shark	Chondrichthyan	QUA
Squalus acanthias	Whitespotted Spurdog	Chondrichthyan	DGS
Squalus albifrons	Eastern Highfin Spurdog	Chondrichthyan	#N/A
Squalus cholorculus	Greeneye Spurdog	Chondrichthyan	#N/A
Squalus fernandezianus	Squalus fernandezianus	Chondrichthyan	#N/A
Squalus griffini	Northern Spiny Dogfish	Chondrichthyan	#N/A
Squalus megalops	Piked Spurdog;Spikey Dogfish	Chondrichthyan	DOP
Squalus montalbani	Philippine Spurdog	Chondrichthyan	#N/A
Taeniurops meyeni	Blotched Fantail Ray	Chondrichthyan	#N/A

Species name	Common name	Teleost/Chondrichthyan	FAO Code (3-alpha)
Tetragonurus cuvieri	Smalleye Squaretail	Teleost	TGV
Tetronarce nobiliana	Electric ray	Chondrichthyan	#N/A
Tetronarce tremens	Tetronarce tremens	Chondrichthyan	#N/A
Thyrsites atun	Barracouta	Teleost	SNK
Triodon macropterus	Threetooth Puffer	Teleost	TDU
Tubbia tasmanica	Tasmanian Rudderfish	Teleost	TUT
Typhlonarke aysoni	Typhlonarke aysoni	Chondrichthyan	NTY
Variola albimarginata	White-edge Coronation Trout	Teleost	VRA
Variola louti	Yellowedge Coronation Trout	Teleost	VRL
Wattsia mossambica	Mozambique Seabream	Teleost	WTM
Zameus squamulosus	Velvet Dogfish	Chondrichthyan	#N/A
Zanclistius elevatus	Blackspot Boarfish	Teleost	ZAL
Zearaja nasuta	New Zealand rough skate	Chondrichthyan	ZRN
Zenopsis nebulosa	Mirror Dory	Teleost	#N/A
Zeus faber	John Dory	Teleost	JOD

Appendix C - Interactions of bottom fisheries with seabirds, marine mammals, reptiles and other species of concern

Reported interactions (SPRFMO database) of bottom fisheries with marine mammals, seabirds, reptiles and other species of concern and revised classifications following detailed review of records by Australia or New Zealand

Flag	Method	Date	Area	Targe	Captur	Scientific name	Common name (no. discarded or kg	Revised classification
AU (F)	Line	Apr-2015	Gascoyne	MZZ	PRX	Procellariidae	Petrels and shearwaters nei (1)	No change
AU (F)	Line	Oct-2016	Gascoyne	MZZ	PFC	*Puffinus carneipes*	Flesh-footed shearwater (1)	No change
AU (F)	Line	Jun-2016	Capel Bank	MZZ	TUG	*Chelonia mydas*	Green turtle (2 kg retained)	No change
AU (F)	Line	Jul-2016	Capel Bank	MZZ	EZZ	Elapidae	Sea snakes nei (1)	No change
NZ (F)	Trawl	May-2010	Challenger	ORY	BSK	*Cetorhinus maximus*	Basking shark (60 kg retained)	Deleted, seal shark
NZ (F)	Trawl	Nov-2010	Challenger	ORY	BSK	*Cetorhinus maximus*	Basking shark (180 kg retained)	Deleted, seal shark
NZ (F)	Line	Oct-2015	Challenger	BWA	POR	*Lamna nasus*	Porbeagle (20 kg retained)	No change
AU (F)	Line	Jun-2016	Capel Bank	MZZ	WSH	*Carcharodon carcharias*	Great white shark (1)	No change
AU (F)	Line	Jun-2016	Capel Bank	MZZ	WSH	*Carcharodon carcharias*	Great white shark (1)	No change
AU (F)	Line	Aug-2016	Capel Bank	MZZ	WSH	*Carcharodon carcharias*	Great white shark (1)	No change
AU (F)	Line	Aug-2017	Capel Bank	MZZ	WSH	*Carcharodon carcharias*	Great white shark (1)	No change
AU (F)	Line	Jul-2018	Capel Bank	MZZ	OCS	*Carcharhinus longimanus*	Oceanic whitetip shark (5 kg retained)	Deleted, white-tip reef shark
AU (F)	Line	Jul-2018	Capel Bank	MZZ	OCS	*Carcharhinus longimanus*	Oceanic whitetip shark (5 kg retained)	Deleted, white-tip reef shark
AU (F)	Line	Aug-2018	Capel Bank	MZZ	OCS	*Carcharhinus longimanus*	Oceanic whitetip shark (7 kg retained)	Deleted, white-tip reef shark
AU (F)	Line	Aug-2018	Capel Bank	MZZ	OCS	*Carcharhinus longimanus*	Oceanic whitetip shark (9 kg retained)	Deleted, white-tip reef shark
AU (F)	Trawl	Sep-2019	Challenger	MZZ	BSK	*Cetorhinus maximus*	Basking shark (1)	No change
AU (O)	Line	Mar-2008	Capel Bank	LHI	PFC	*Puffinus carneipes*	Flesh-footed shearwater (2)	No change
NZ (O)	Line	Oct-2014	Three Kings	BWA	PWA	*Pterodroma leucoptera*	Gould's Petrel (1)	No change
NZ (O)	Trawl	Dec-2015	Lord Howe	EPI	PDM	*Pterodroma macroptera*	Great-winged petrel (2)	No change
NZ (O)	Trawl	Mar-2016	Challenger	ORY	WFS	*Pelagodroma marina*	White-faced storm petrel (1)	No change
NZ (O)	Trawl	Jul-2017	Louisville	ORY	PRX	Procellariidae	Petrels and shearwaters nei (1)	No change
NZ (O)	Trawl	Nov-2017	Lord Howe	ALF	PDM	*Pterodroma macroptera*	Great-winged petrel (1)	No change
NZ (O)	Trawl	Oct-2018	Lord Howe	ALF	PDM	*Pterodroma macroptera*	Great-winged petrel (1)	No change
NZ (O)	Line	Nov-2018	West Norfolk	HAU	PRK	*Procellaria parkinsoni*	Parkinson's petrel (1)	White-chinned petrel
NZ (O)	Line	Nov-2018	West Norfolk	HAU	ALZ	Diomedeidae	Albatrosses nei (1)	Unidentified "black-browed"
NZ (O)	Line	Nov-2018	West Norfolk	HAU	PRK	*Procellaria parkinsoni*	Parkinson's petrel (1)	No change
NZ (O)	Trawl	Dec-2015	Challenger	ORY	MYS	Mysticeti	Baleen whales nei	Deleted, decomposing

O = reported by observer, F = reported by fisher

Appendix D - Seabird taxa that overlap with SPRFMO bottom fisheries

D.1: Taxa with known high vulnerability to bycatch

English Common Name	Scientific Name	IUCN Status	Min. Population	Documented Bycatch
Antipodean Albatross	*Diomedea antipodensis*	Endangered (EN)	44,508	Yes
Southern Royal Albatross	*Diomedea epomophora*	Vulnerable (VU)	27,200	Yes
Wandering Albatross	*Diomedea exulans*	Vulnerable (VU)	unknown	Yes
Northern Royal Albatross	*Diomedea sanfordi*	Endangered (EN)	25,000	Yes
Buller's Albatross	*Thalassarche bulleri*	Near Threatened (NT)	61,000	Yes
Indian Yellow-nosed Albatross	*Thalassarche carteri*	Endangered (EN)	160,000	Yes
Shy Albatross	*Thalassarche cauta*	Near Threatened (NT)	60,000	Yes
White-capped Albatross	*Thalassarche steadi*	Near Threatened (NT)	*559,000	Yes
Grey-headed Albatross	*Thalassarche chrysostoma*	Endangered (EN)	250,000	Yes
Campbell Albatross	*Thalassarche impavida*	Vulnerable (VU)	49,200	Yes
Black-browed Albatross	*Thalassarche melanophris*	Near Threatened (NT)	2,100,000	Yes
Salvin's Albatross	*Thalassarche salvini*	Vulnerable (VU)	90,000	Yes
Sooty Albatross	*Phoebetria fusca*	Endangered (EN)	26,400	Yes
Light-mantled Albatross	*Phoebetria palpebrata*	Near Threatened (NT)	87,000	Yes
White-chinned Petrel	*Procellaria aequinoctialis*	Vulnerable (VU)	3,000,000	Yes
Grey Petrel	*Procellaria cinerea*	Near Threatened (NT)	160,000	Yes
Black Petrel	*Procellaria parkinsoni*	Vulnerable (VU)	*10,000	Yes
Westland Petrel	*Procellaria westlandica*	Vulnerable (VU)	16,000	Yes
Southern Giant Petrel	*Macronectes giganteus*	Least Concern(LC)	150,000	Yes
Northern Giant Petrel	*Macronectes halli*	Least Concern(LC)	17,000	Yes
Buller's Shearwater	*Ardenna bulleri*	Vulnerable (VU)	1,500,000	Yes
Flesh-footed Shearwater	*Ardenna carneipes*	Least Concern(LC)	650,000	Yes
Sooty Shearwater	*Ardenna grisea*	Near Threatened (NT)	20,000,000	Yes
Wedge-tailed Shearwater	*Ardenna pacifica*	Least Concern(LC)	5,200,000	Yes
Short-tailed Shearwater	*Ardenna tenuirostris*	Least Concern(LC)	23,000,000	Yes
Cape Petrel	*Daption capense*	Least Concern(LC)	2,000,000	Yes

* lower limit of 95% credible interval from Richard et al. (2020) NZAEBR #237.

D.2: Taxa with medium vulnerability to bycatch or vulnerable to light attraction / deck strikes

English Common Name	***Scientific Name***	**IUCN Status**	**Min. Population**	**Documented Bycatch**
Fiordland Penguin	*Eudyptes pachyrhynchus*	Vulnerable (VU)	5,000	Yes
White-bellied Storm Petrel	*Fregetta grallaria*	Least Concern(LC)	300,000	Undocumented
New Zealand Storm Petrel	*Fregetta maoriana*	Critically Endangered (CR)	1	Undocumented
Black-bellied Storm Petrel	*Fregetta tropica*	Least Concern(LC)	unknown	Yes
Grey-backed Storm Petrel	*Garrodia nereis*	Least Concern(LC)	200,000	Yes
Australasian Gannet	*Morus serrator*	Least Concern(LC)	105,328	Yes
Wilson's Storm Petrel	*Oceanites oceanicus*	Least Concern(LC)	12,000,000	Yes
Slender-billed Prion	*Pachyptila belcheri*	Least Concern(LC)	7,000,000	Undocumented
Fulmar Prion	*Pachyptila crassirostris*	Least Concern(LC)	150,000	Yes
Antarctic Prion	*Pachyptila desolata*	Least Concern(LC)	50,000,000	Yes
Salvin's Prion	*Pachyptila salvini*	Least Concern(LC)	unknown	Yes
Fairy Prion	*Pachyptila turtur*	Least Concern(LC)	5,000,000	Yes
Broad-billed Prion	*Pachyptila vittata*	Least Concern(LC)	15,000,000	Yes
White-faced Storm Petrel	*Pelagodroma marina*	Least Concern(LC)	4,000,000	Yes
Common Diving Petrel	*Pelecanoides urinatrix*	Least Concern(LC)	16,000,000	Yes
Cook's Petrel	*Pterodroma cookii*	Vulnerable (VU)	670,000	Undocumented
Mottled Petrel	*Pterodroma inexpectata*	Near Threatened (NT)	60,000	Yes
White-headed Petrel	*Pterodroma lessonii*	Least Concern(LC)	600,000	Yes
Gould's Petrel	*Pterodroma leucoptera*	Vulnerable (VU)	3,000	Undocumented
Great-winged Petrel	*Pterodroma macroptera*	Least Concern(LC)	1,500,000	Yes
Grey-faced Petrel	*Pterodroma gouldi*	Least Concern(LC)	*839,000	Yes
Soft-plumaged Petrel	*Pterodroma mollis*	Least Concern(LC)	5,000,000	Undocumented
Providence Petrel	*Pterodroma solandri*	Vulnerable (VU)	100,000	Yes
Little Shearwater	*Puffinus assimilis*	Least Concern(LC)	300,000	Undocumented
Fluttering Shearwater	*Puffinus gavia*	Least Concern(LC)	100,000	Yes
Hutton's Shearwater	*Puffinus huttoni*	Endangered (EN)	300,000	Yes

* lower limit of 95% credible interval from Richard et al. (2020) NZAEBR #237.

D.3: Taxa with lower vulnerability to bycatch

English Common Name	***Scientific Name***	**IUCN Status**	**Min. Population**	**Documented Bycatch**
Kerguelen Petrel	*Aphrodroma brevirostris*	Least Concern(LC)	1,000,000	Yes
Silver Gull	*Chroicocephalus novaehollandiae*	Least Concern(LC)	1,000,000	Yes
Little Penguin	*Eudyptula minor*	Least Concern(LC)	1,000,000	Yes
Southern Fulmar	*Fulmarus glacialoides*	Least Concern(LC)	2,000,000	Yes
Gull-billed Tern	*Gelochelidon nilotica*	Least Concern(LC)	150,000	Undocumented
Blue Petrel	*Halobaena caerulea*	Least Concern(LC)	3,000,000	Undocumented
Caspian Tern	*Hydroprogne caspia*	Least Concern(LC)	240,000	Yes
Kelp Gull	*Larus dominicanus*	Least Concern(LC)	3,300,000	Yes
Pacific Gull	*Larus pacificus*	Least Concern(LC)	unknown	Undocumented
Little Pied Cormorant	*Microcarbo melanoleucos*	Least Concern(LC)	10,000	Yes
Australian Pelican	*Pelecanus conspicillatus*	Least Concern(LC)	unknown	Yes
Great Cormorant	*Phalacrocorax carbo*	Least Concern(LC)	1,400,000	Yes
Black-faced Cormorant	*Phalacrocorax fuscescens*	Least Concern(LC)	20,000	Yes
Australian Pied Cormorant	*Phalacrocorax varius*	Least Concern(LC)	unknown	Yes
Grey Noddy	*Procelsterna albivitta*	Least Concern(LC)	unknown	Undocumented
Brown Skua	*Stercorarius antarcticus*	Least Concern(LC)	10,000	Yes
Parasitic Jaeger	*Stercorarius parasiticus*	Least Concern(LC)	500,000	Yes
Pomarine Skua	*Stercorarius pomarinus*	Least Concern(LC)	250,000	Yes
White-fronted Tern	*Sterna striata*	Least Concern(LC)	24,000	Yes
Little Tern	*Sternula albifrons*	Least Concern(LC)	190,000	Undocumented
Fairy Tern	*Sternula nereis*	Vulnerable (VU)	2,500	Yes
Greater Crested Tern	*Thalasseus bergii*	Least Concern(LC)	150,000	Yes

Appendix E - Historical estimates of the proportion of VME indicator taxa protected by the spatial management measures in CMM03-2019

All estimates in the following tables were generated by assuming a linear relationship between habitat suitability scores from the ensemble model of habitat suitability for each of ten VME indicator taxa. Habitat suitability scores were summed for all cells falling outside the areas open to bottom fishing. Recent information, including analyses presented in this assessment, shows that this is not the best assumption.

Table A5.1 (Table 1 from COMM7-Prop03.1): 2018 estimates of overall performance of the Spatial Management Areas implemented in CMM03-2019 ("proposed management areas") compared with those implemented by Australia and New Zealand under CMM03-2018 ("existing management areas"). The percentage (averaged across all taxa and areas) of the total distribution of stony corals and other VME indicator taxa protected from bottom fishing is given. The proportion of each relevant Ecological or Biologically Significant Area, EBSA, hydrothermal vent fauna, and rare records of individual (non-VME) taxa are also shown, together with an estimate of the index of lost value for the fishing industry (percentage of access to valuable fishing lost)

Attribute	Existing Management Areas	Proposed Management Areas
Stony coral	62.0	82.2
Other VME indicator taxa	67.6	84.2
EBSA5	84.7	100.0
EBSA6	100.0	100.0
EBSA7	100.0	100.0
EBSA15	90.8	98.1
EBSA17	48.6	76.9
EBSA20	100.0	100.0
EBSA21	99.7	99.7
Point records of rare taxa	48.0	68.0
Hydrothermal vents	100.0	100.0
Percent of Evaluated Area open to fishing	11.1	5.5
Index of lost value for the fishing industry	8.7	6.6

Table A5.2 (Table 2 from COMM7-Prop03.1): 2018 estimates of the performance of the spatial management areas in terms of the estimated percentage of the total distribution of stony corals and other VME indicator taxa protected from bottom fishing. Overall means are averaged across all taxa and areas. Ecological or Biologically Significant Area 17 (EBSA17) is the only EBSA significantly overlapped by the areas that were opened to fishing. The performance for hydrothermal vent fauna and for rare records of individual (non-VME) taxa are also shown, together with an estimate of the index of lost value for the fishing industry (percentage of access to valuable fishing space lost) in each area.

Attribute	Overall	S. Tasman Rise	Tasman Sea	L'ville North	L'ville Central	L'ville South	Other areas
Stony coral	82	95	86	83	62	47	100
Other VME indicator taxa	84	95	87	86	69	51	100
EBSA17	77	n/a	n/a	77	n/a	n/a	n/a
Rare species (point records)	68	57	77	92	14	n/a	100
Hydrothermal vents	100	n/a	n/a	n/a	n/a	n/a	100
Lost value for industry (%)	7	0	2	3	43	2	6

Table A5.3 (Table 3 from COMM7-Prop03.1): 2018 estimates of the performance of the spatial management areas in terms of the percentage of the predicted distribution of each VME taxon protected from bottom fishing. Overall means averaged across all taxa and areas, subsequent rows show estimated performance in each relevant Global Marine Biological Realm and in fisheries management areas. Nominal protection is the percentage of the predicted distribution of VME indicator habitat that occurs outside the areas open to bottom trawling, whereas effective protection is the percentage of the predicted distribution of VME indicator habitat that occurs outside areas proposed open to bottom trawling plus those parts of areas open to fishing that are deeper than 1400 m. The overall maximum possible protection is less than 100% because the estimated impact of historical fishing was accounted for in the models

Region	Stony corals (4)		Other VME taxa (6)		All VME taxa (10)	
Overall max possible	93		94		94	
	nominal	effective	nominal	effective	nominal	effective
Overall	82	85	84	88	84	87
Marine Biological Realms (bioregions):						
Realm 15	97	97	95	95	96	96
Realm 16	100	100	100	100	100	100
Realm 17	89	93	90	96	90	95
Realm 28	81	85	82	86	82	85
Realm 30	96	96	97	97	96	97
Fishery areas:						
S Tasman Rise	95	95	95	95	95	95
Tasman Sea	86	87	87	87	86	87
Louisville North	83	89	86	93	85	91
Louisville Central	62	80	69	89	66	85
Louisville South	47	71	51	81	49	77
Other fishing areas	100	100	100	100	100	100

Appendix F – RBS results

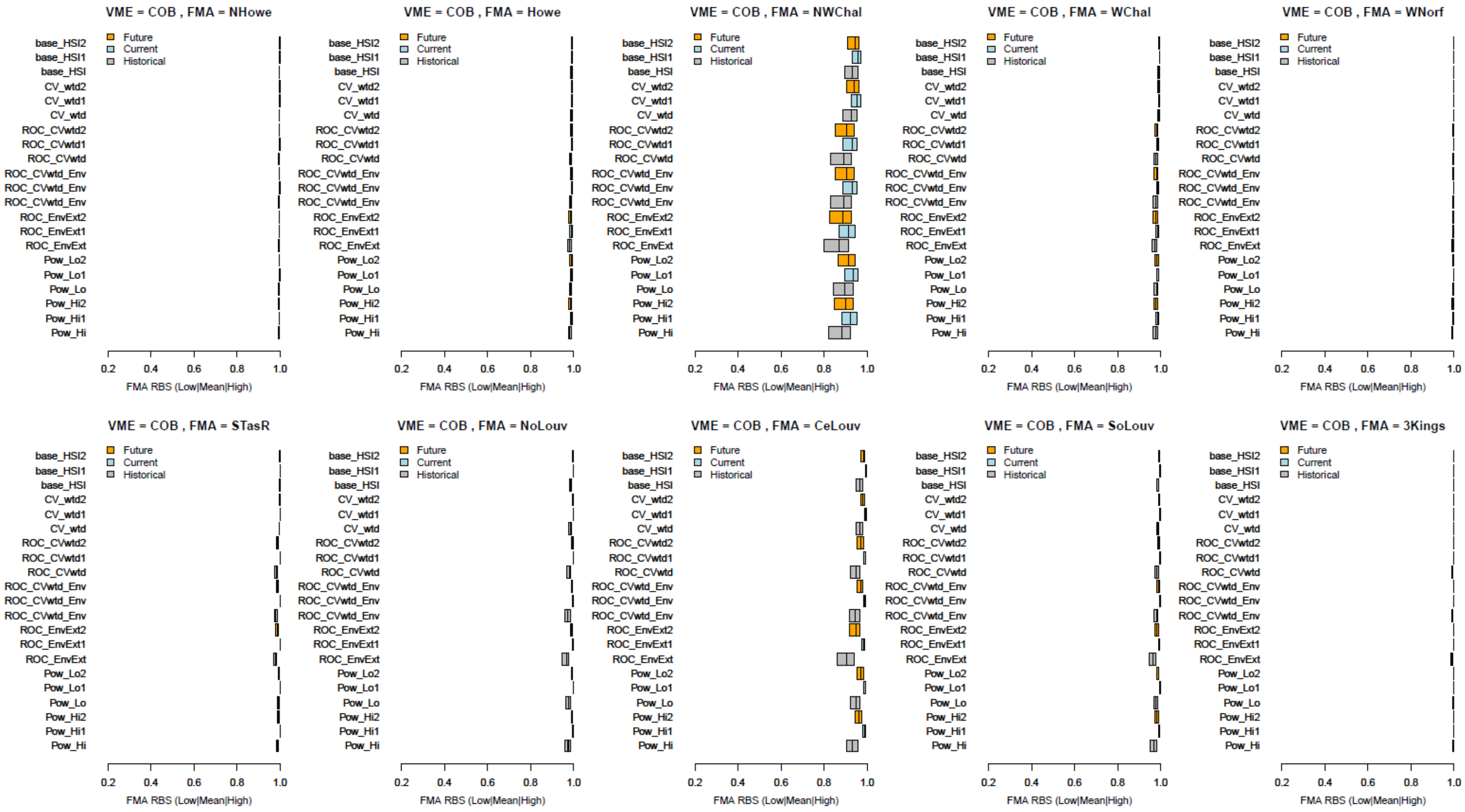

Figure A6.1: Low, mean and high RBS assessment results for Antipatharia (COB) for ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge.

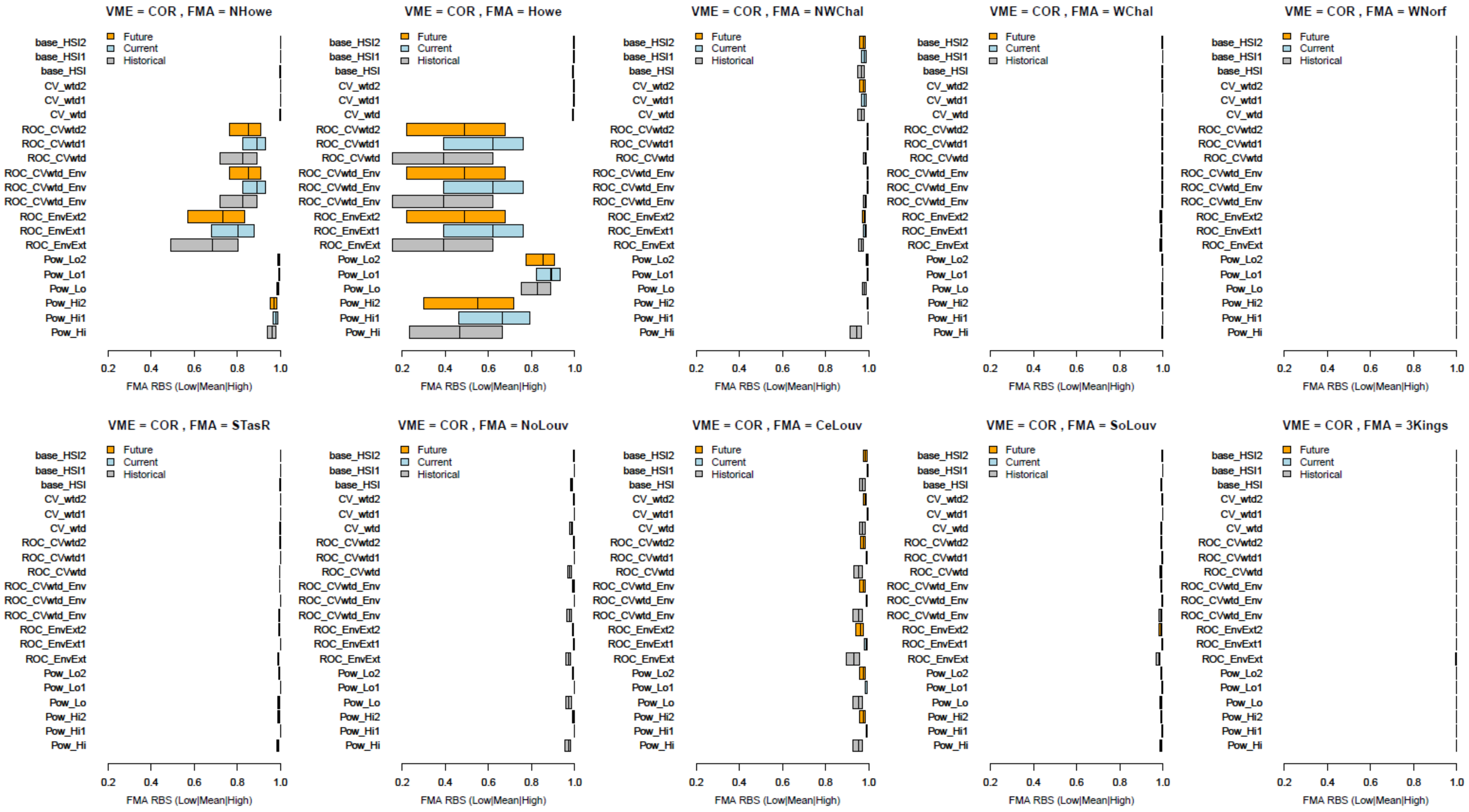

Figure A6.2: Low, mean and high RBS assessment results for Stylasteridae (COR) for ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge.

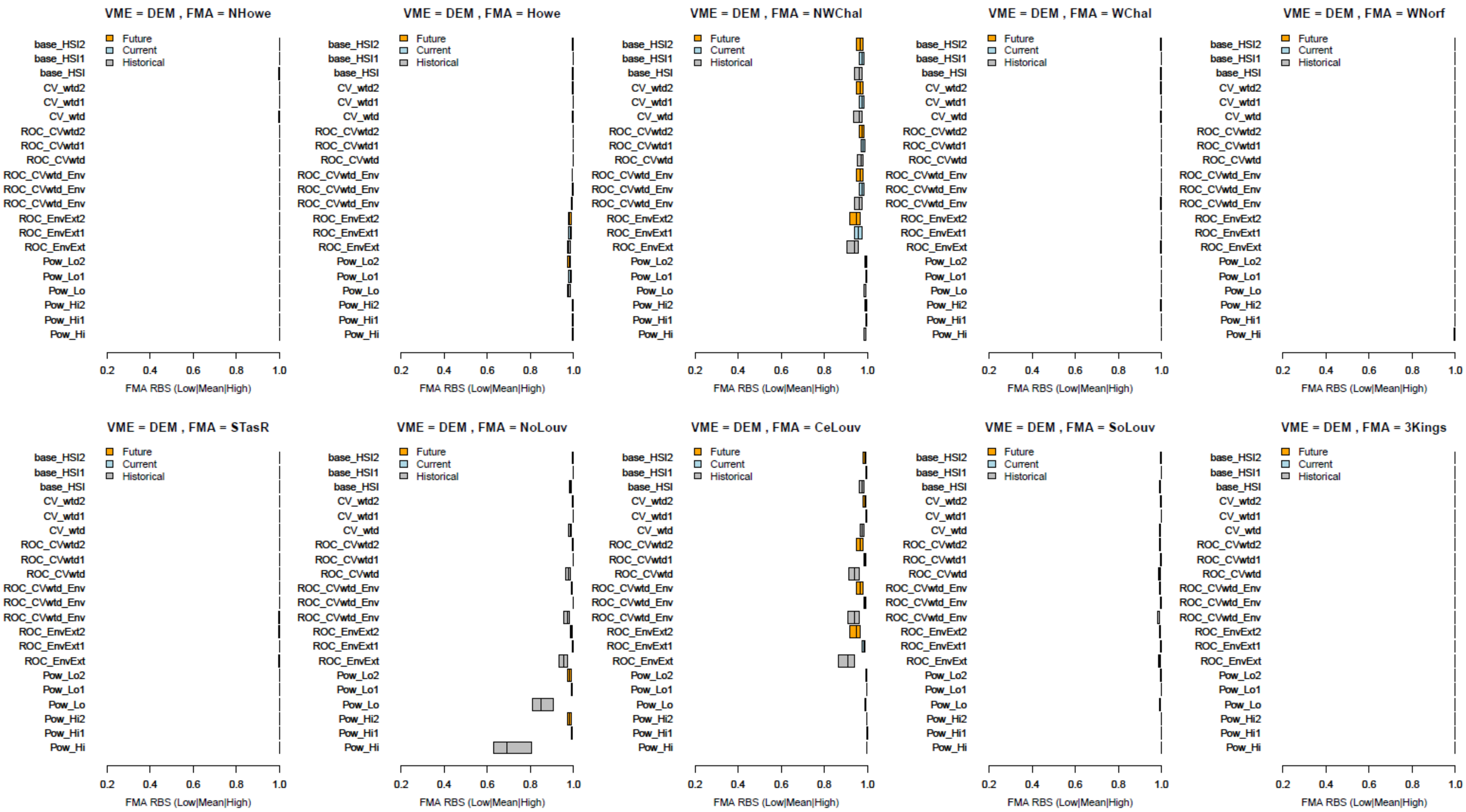

Figure A6.3: Low, mean and high RBS assessment results for Demospongiae (DEM) for ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge.

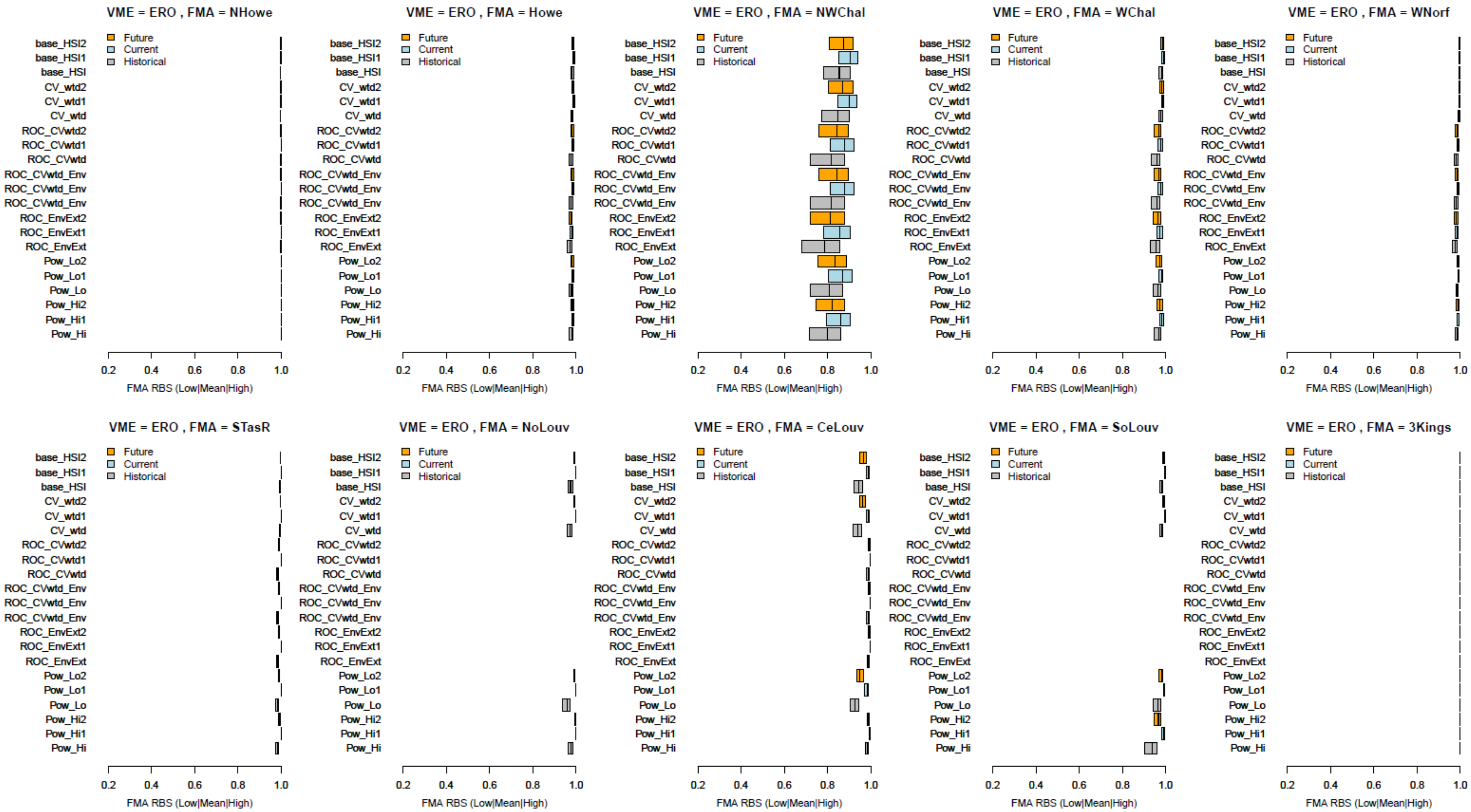

Figure A6.4: Low, mean and high RBS assessment results for *Enallopsammia rostrata* (ERO) for ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge.

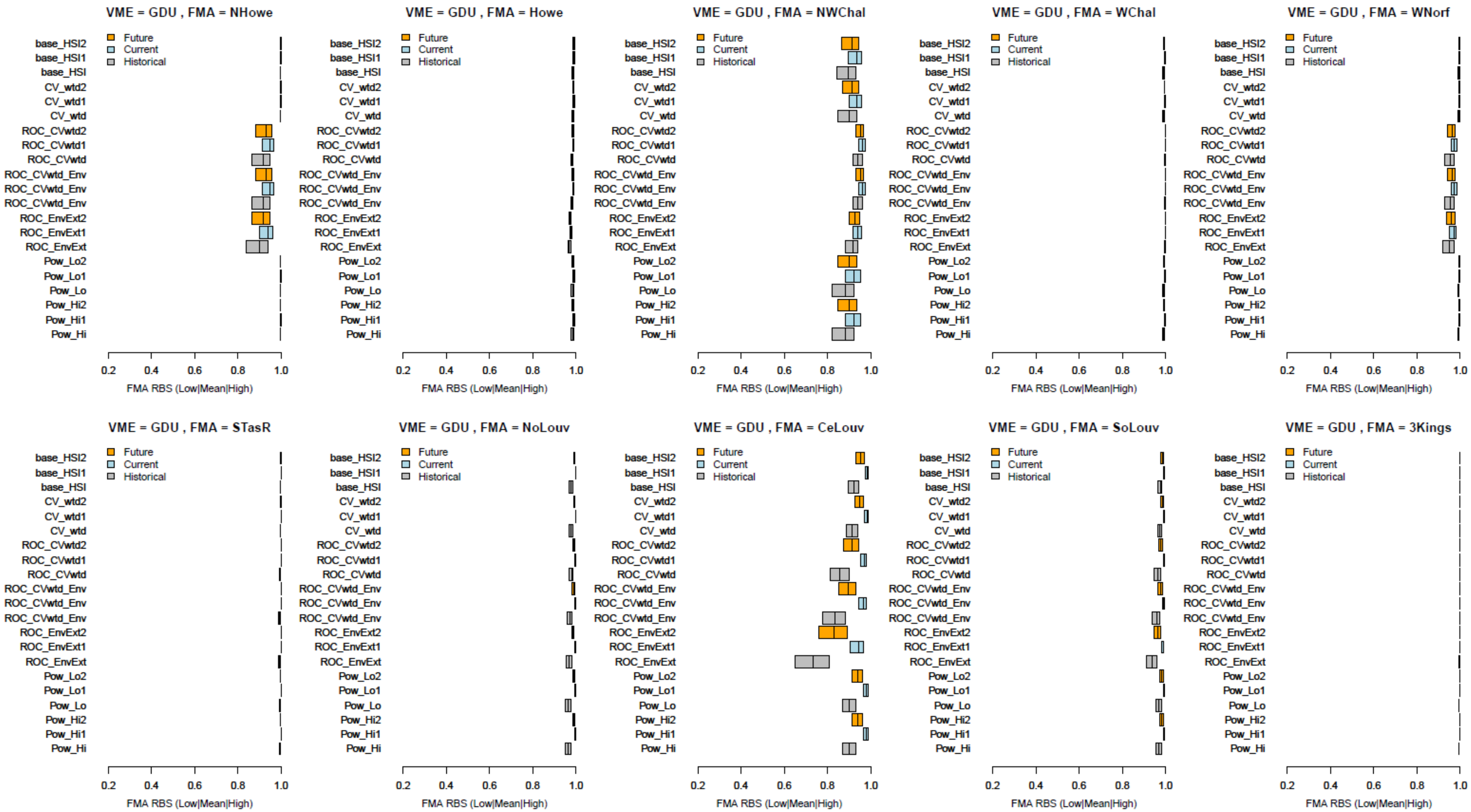

Figure A6.5: Low, mean and high RBS assessment results for *Goniocorella dumosa* (GDU) for ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge.

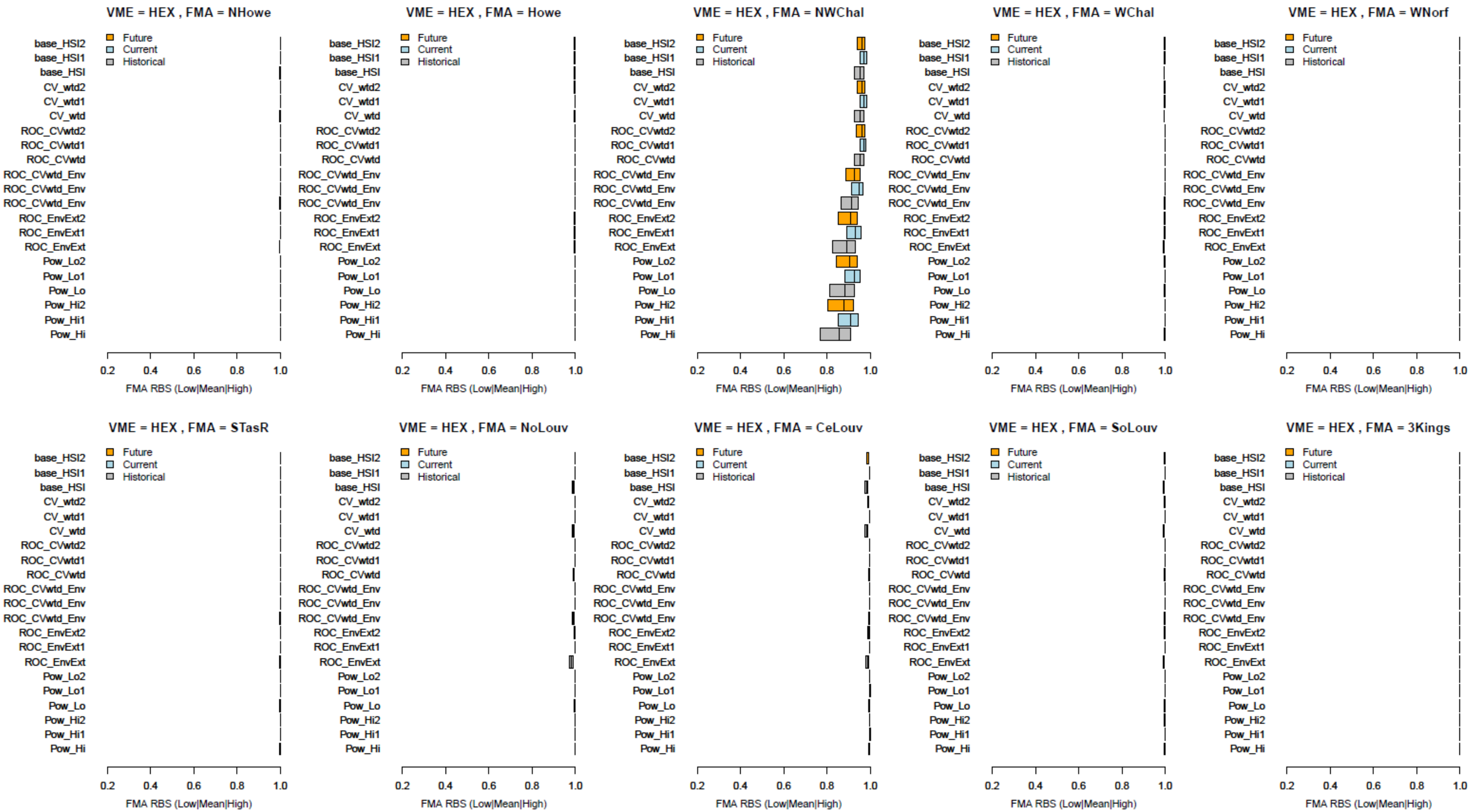

Figure A6.6: Low, mean and high RBS assessment results for Hexactinellida (HEX) for ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge.

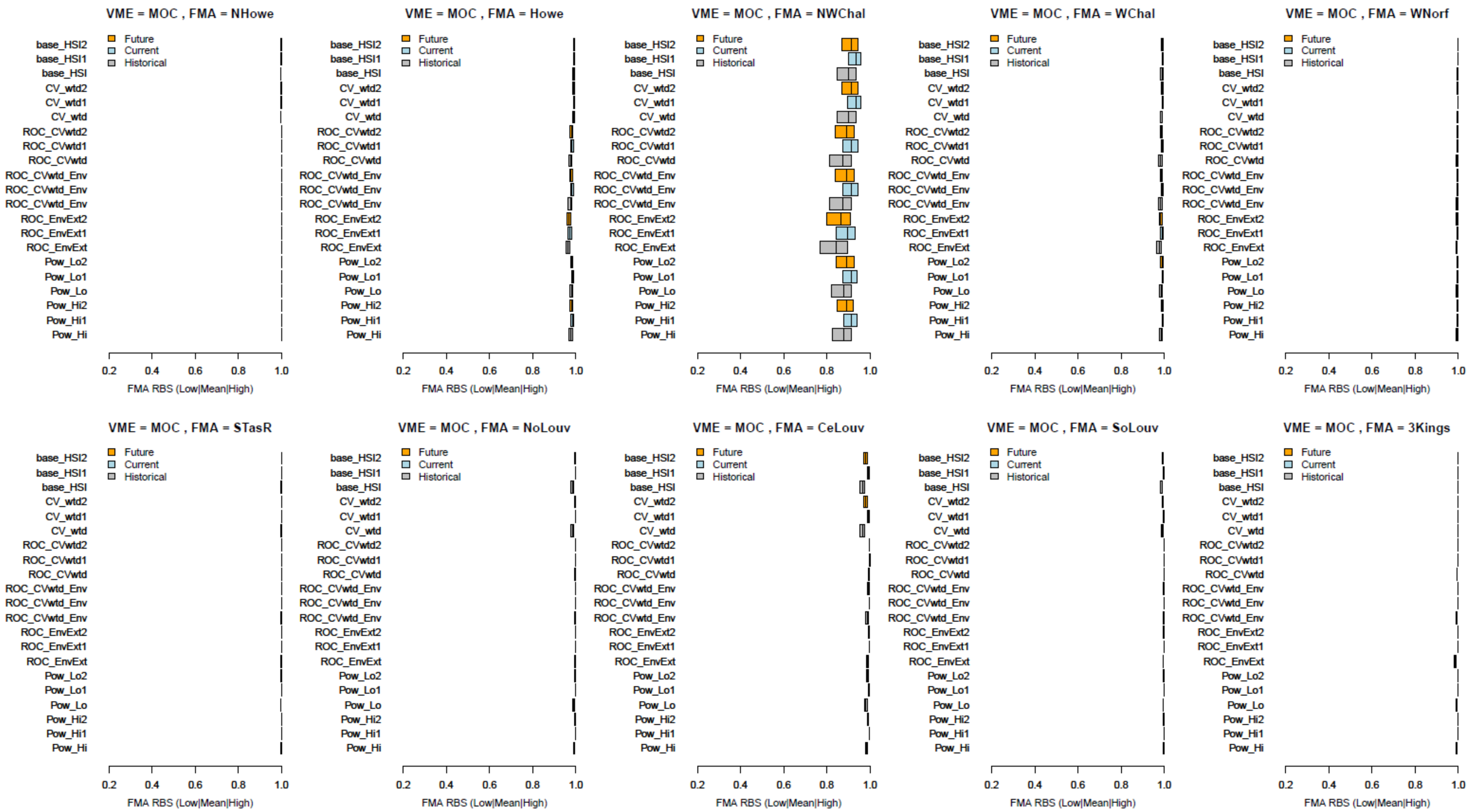

Figure A6.7: Low, mean and high RBS assessment results for *Madrepora oculata* (MOC) for ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge.

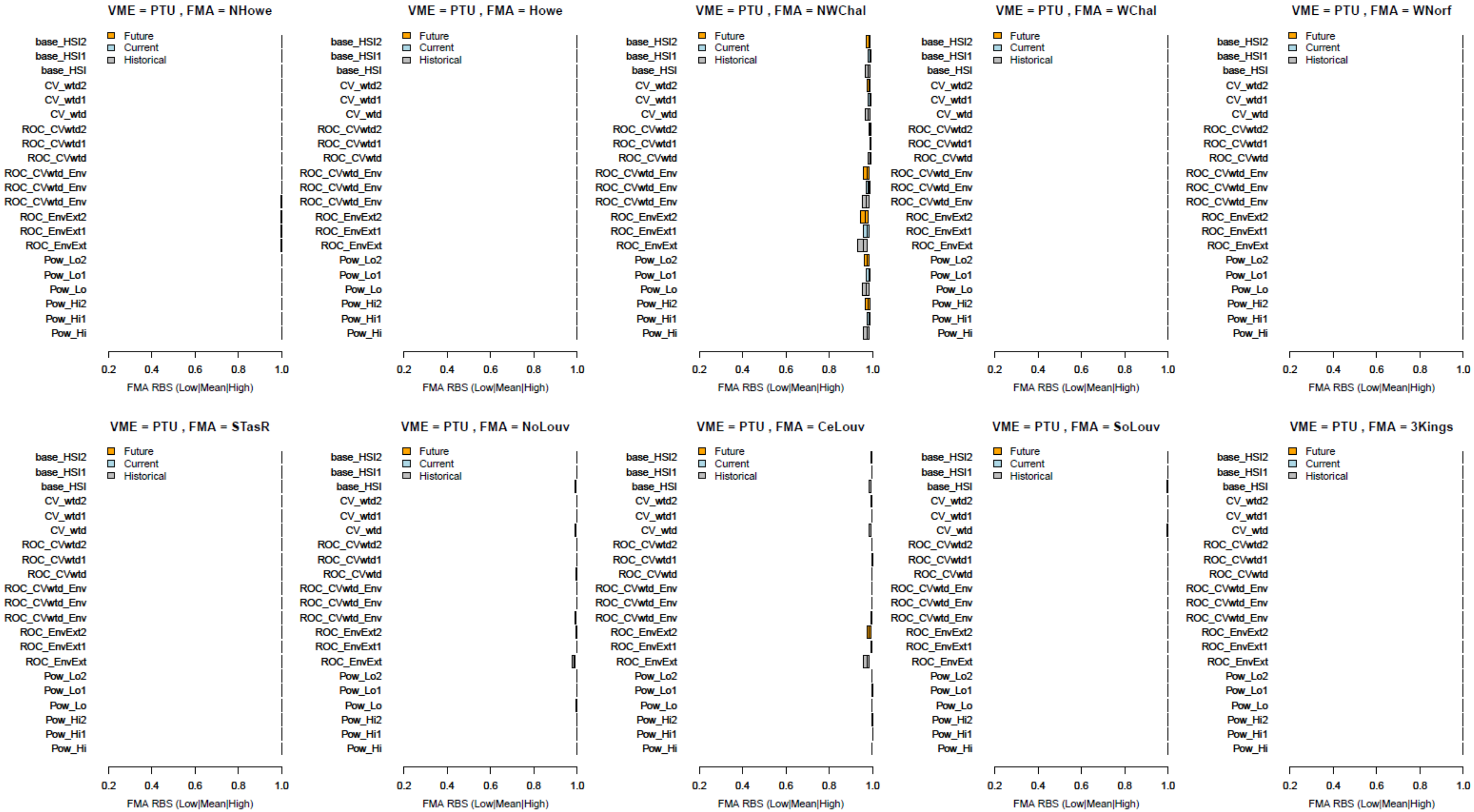

Figure A6.8: Low, mean and high RBS assessment results for Pennatulacea (PTU) for ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge.

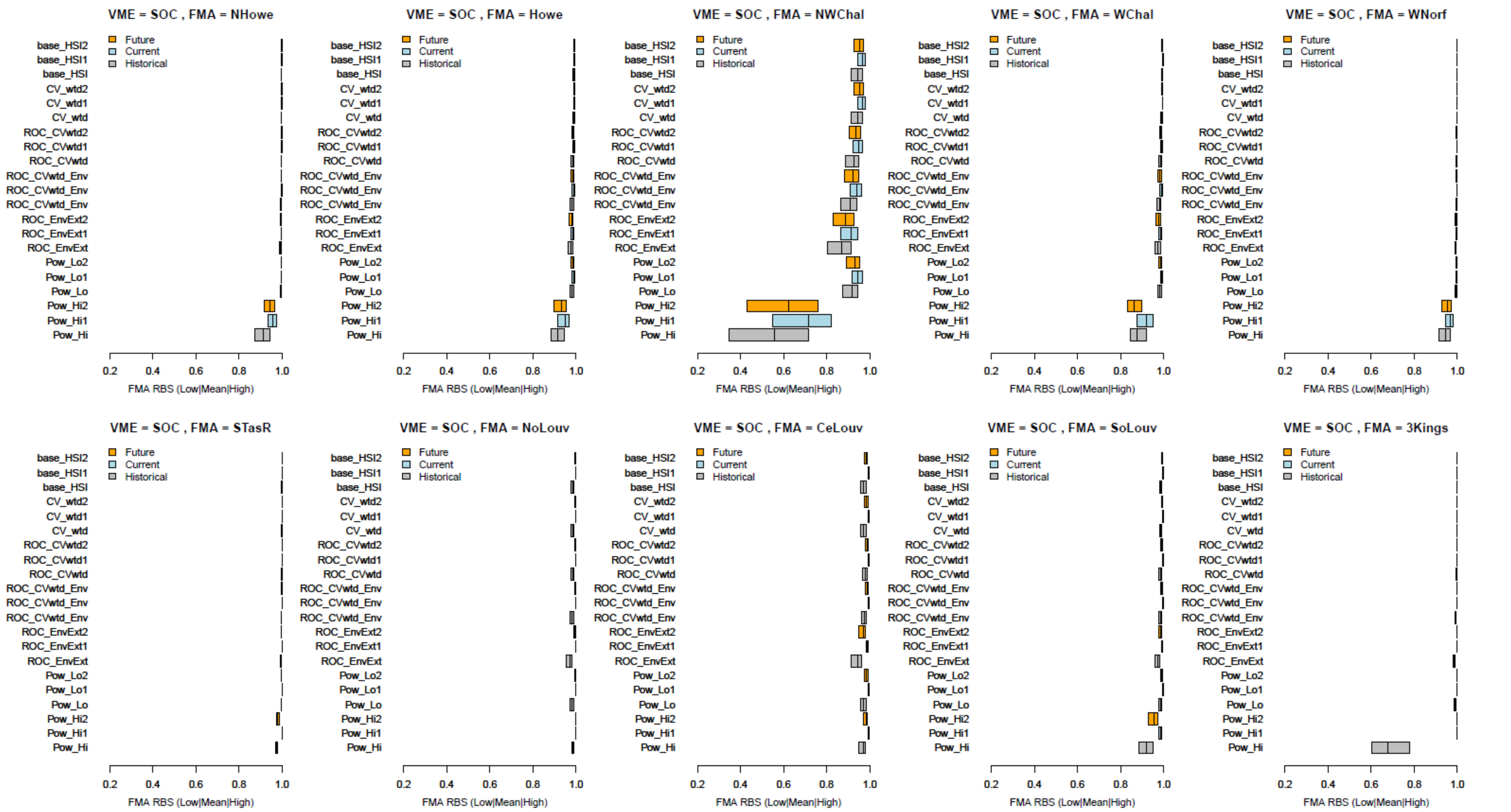

Figure A6.9: Low, mean and high RBS assessment results for Alcyonacea (SOC) for ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge.

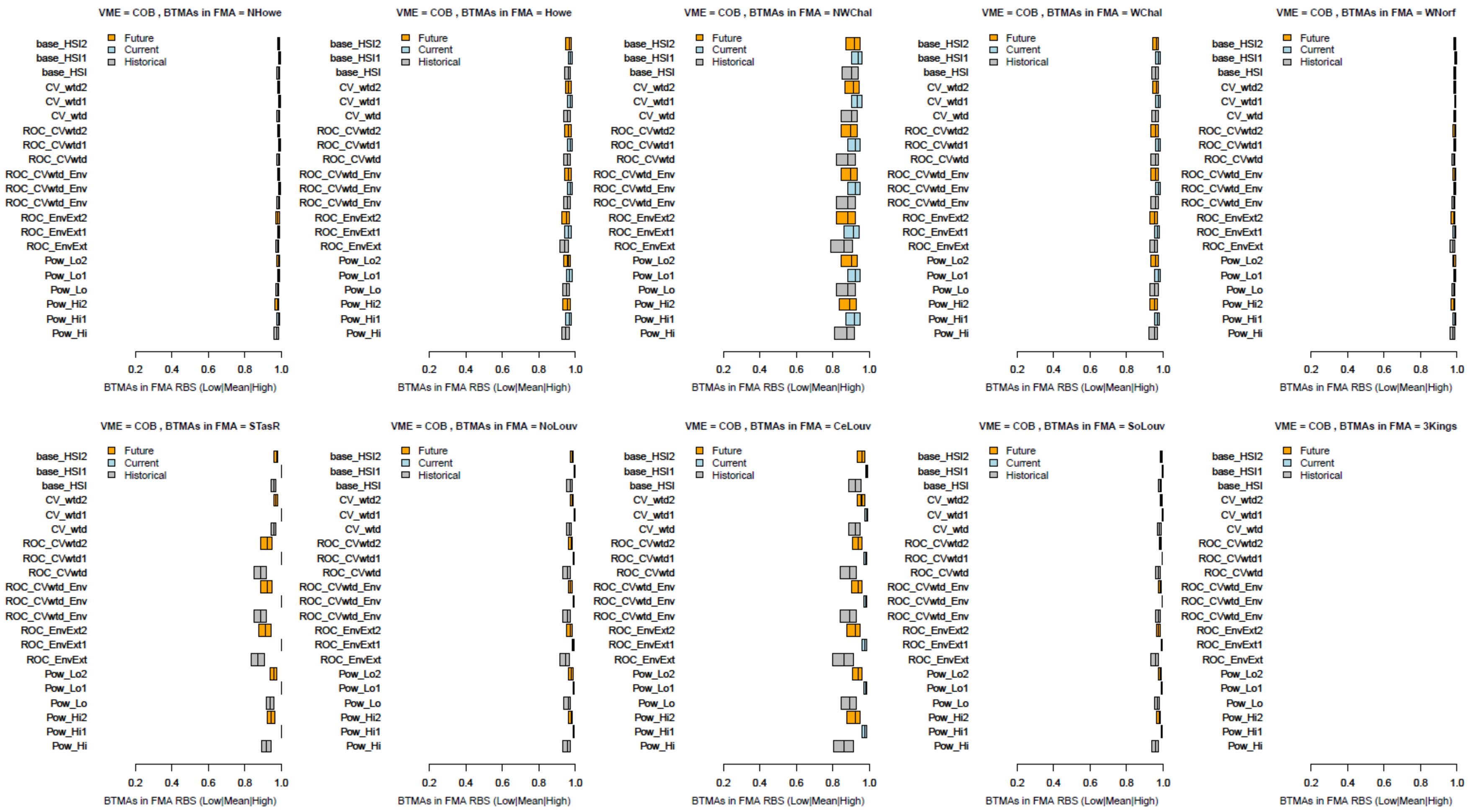

Figure A.6.10: Low, mean and high RBS assessment results for Antipatharia (COB) for Bottom Trawl Management Areas (BTMAs) within ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge. Note that 3Kings does not have any BTMAs.

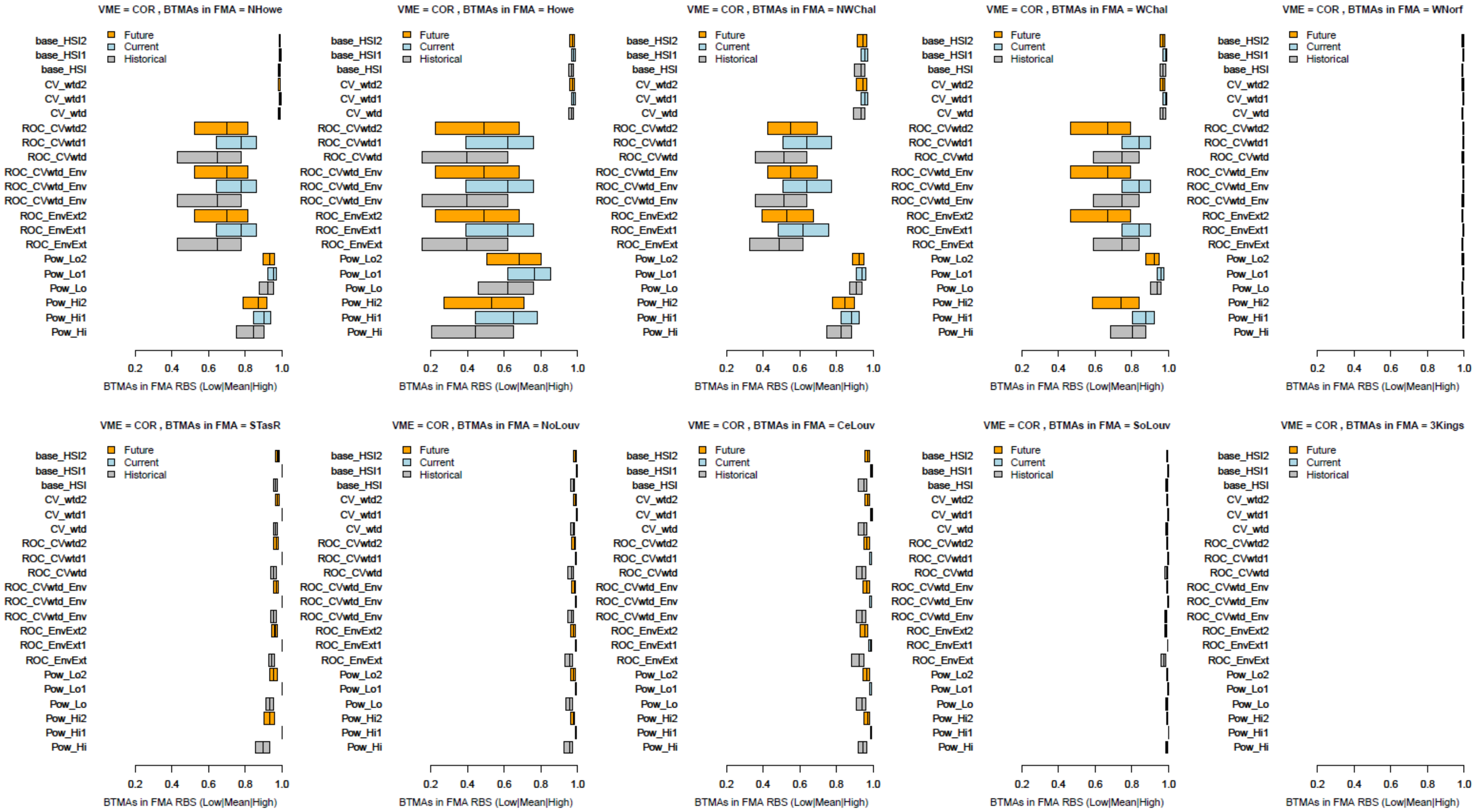

Figure A6.11: Low, mean and high RBS assessment results for Stylasteridae (COR) for Bottom Trawl Management Areas (BTMAs) within ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge. Note that 3Kings does not have any BTMAs.

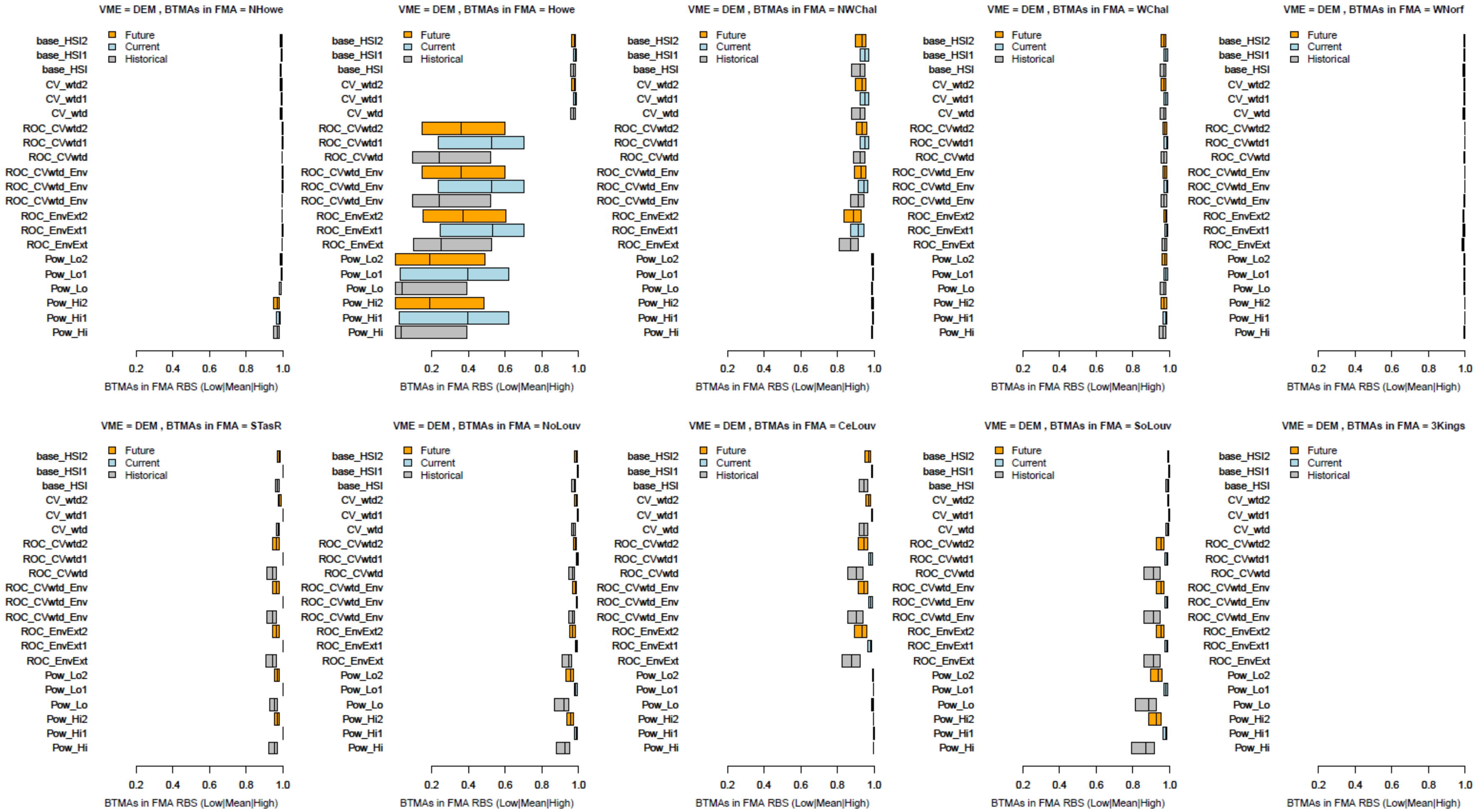

Figure A6.12: Low, mean and high RBS assessment results for Demospongiae (DEM) for Bottom Trawl Management Areas (BTMAs) within ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge. Note that 3Kings does not have any BTMAs.

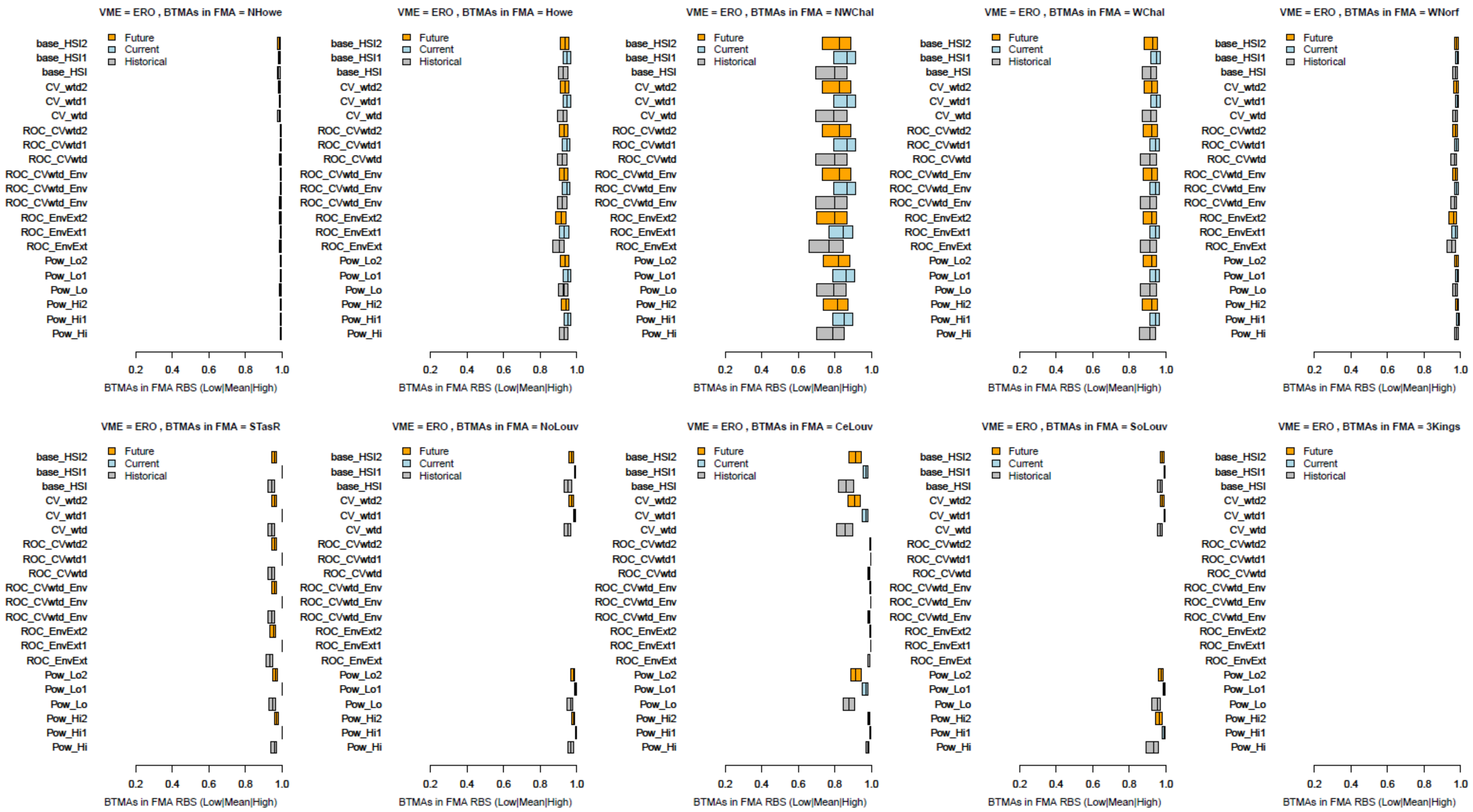

Figure A6.13: Low, mean and high RBS assessment results for *Enallopsammia rostrata* (ERO) for Bottom Trawl Management Areas (BTMAs) within ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge. Note that 3Kings does not have any BTMAs.

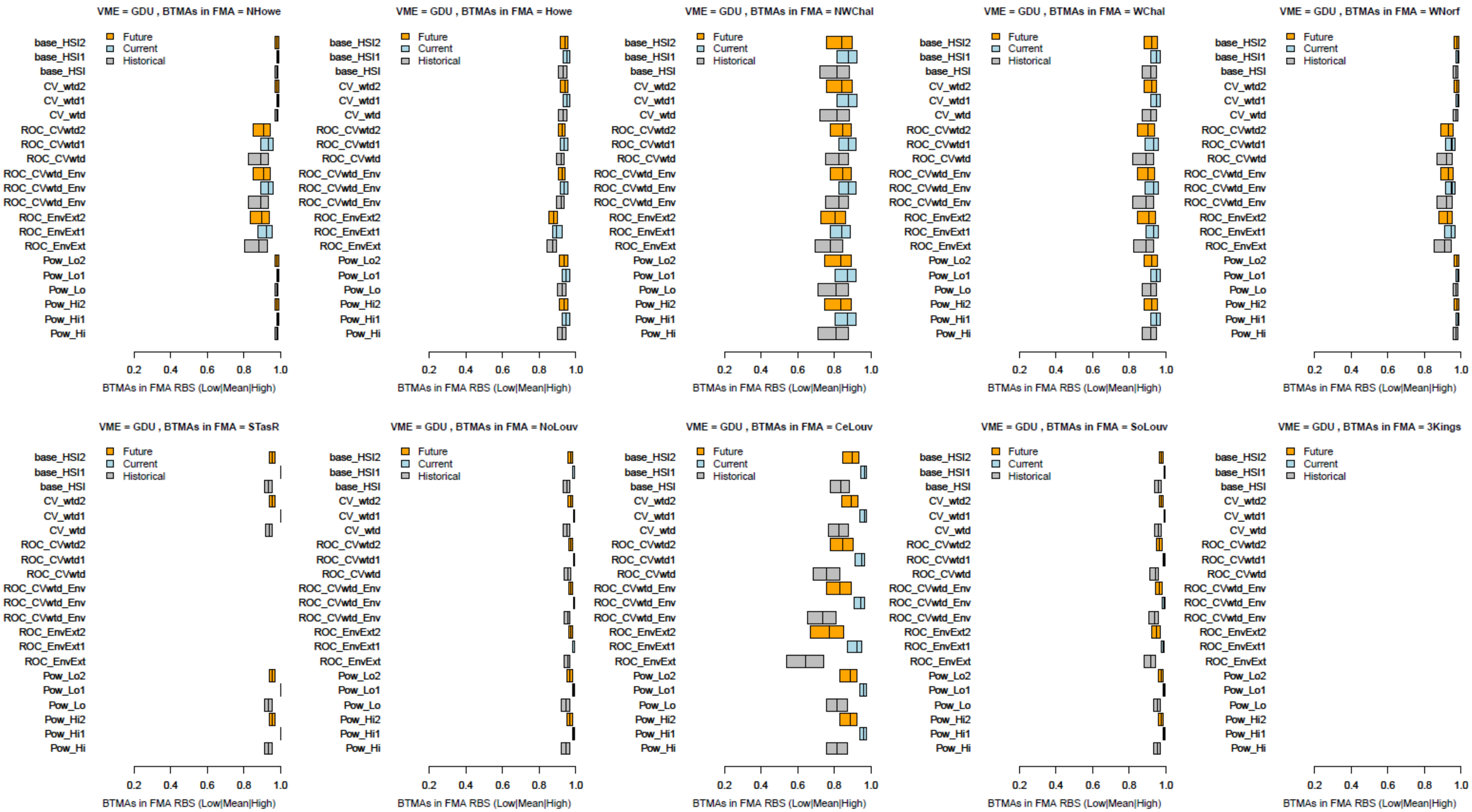

Figure A6.14: Low, mean and high RBS assessment results for *Goniocorella dumosa* (GDU) for Bottom Trawl Management Areas (BTMAs) within ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge. Note that 3Kings does not have any BTMAs.

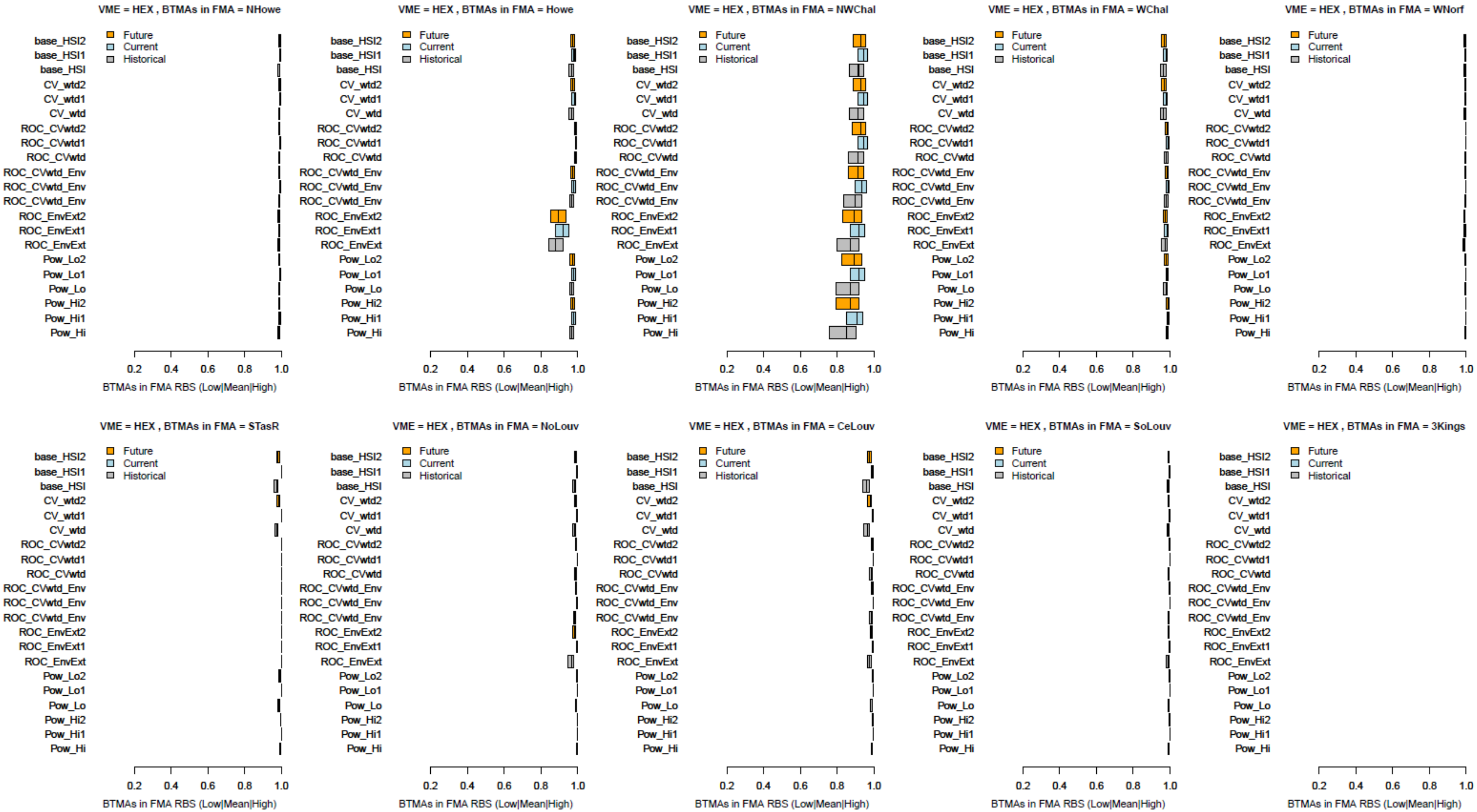

Figure A6.15: Low, mean and high RBS assessment results for Hexactinellida (HEX) for Bottom Trawl Management Areas (BTMAs) within ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge. Note that 3Kings does not have any BTMAs.

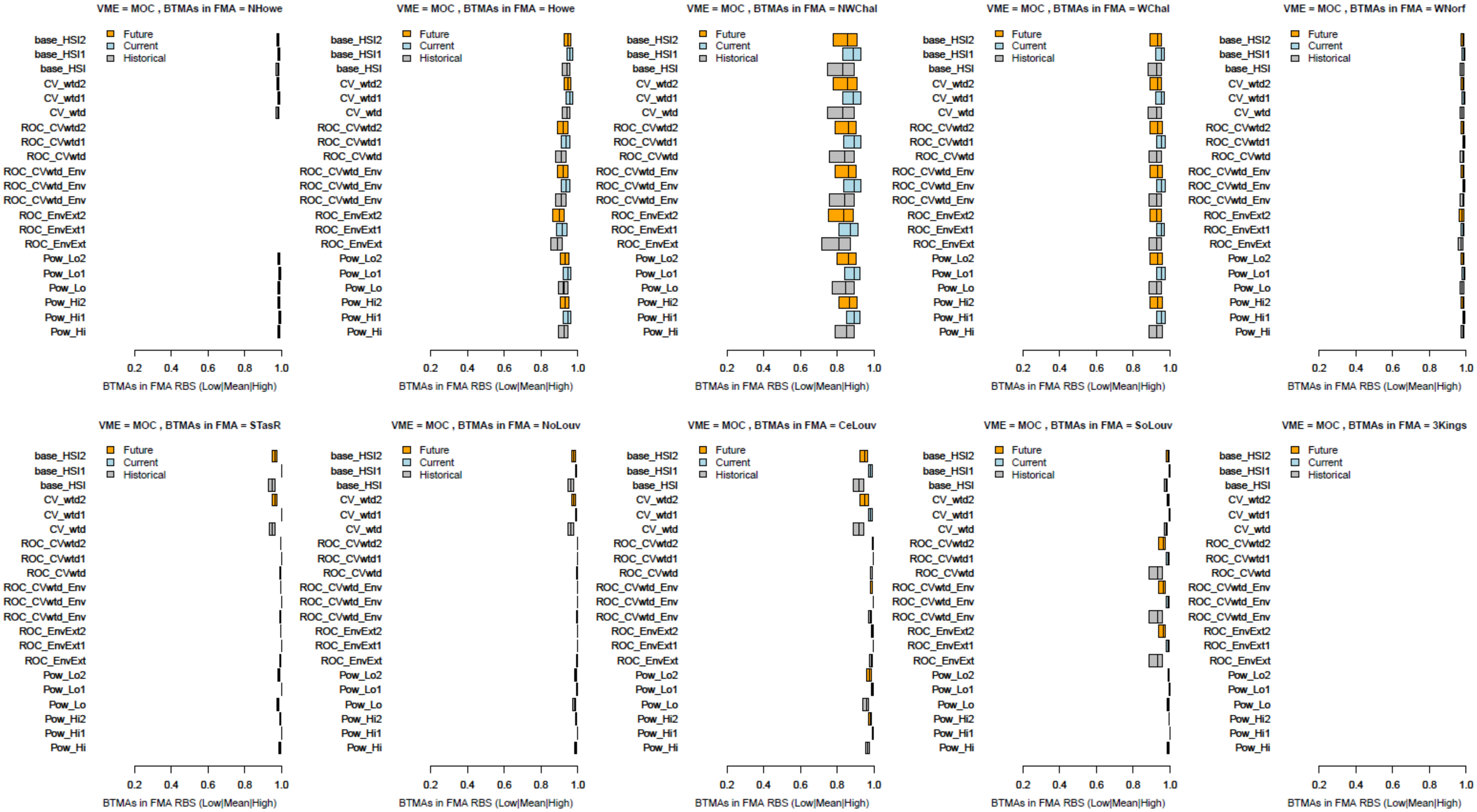

Figure A6.16: Low, mean and high RBS assessment results for *Madrepora oculata* (MOC) for Bottom Trawl Management Areas (BTMAs) within ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge. Note that 3Kings does not have any BTMAs.

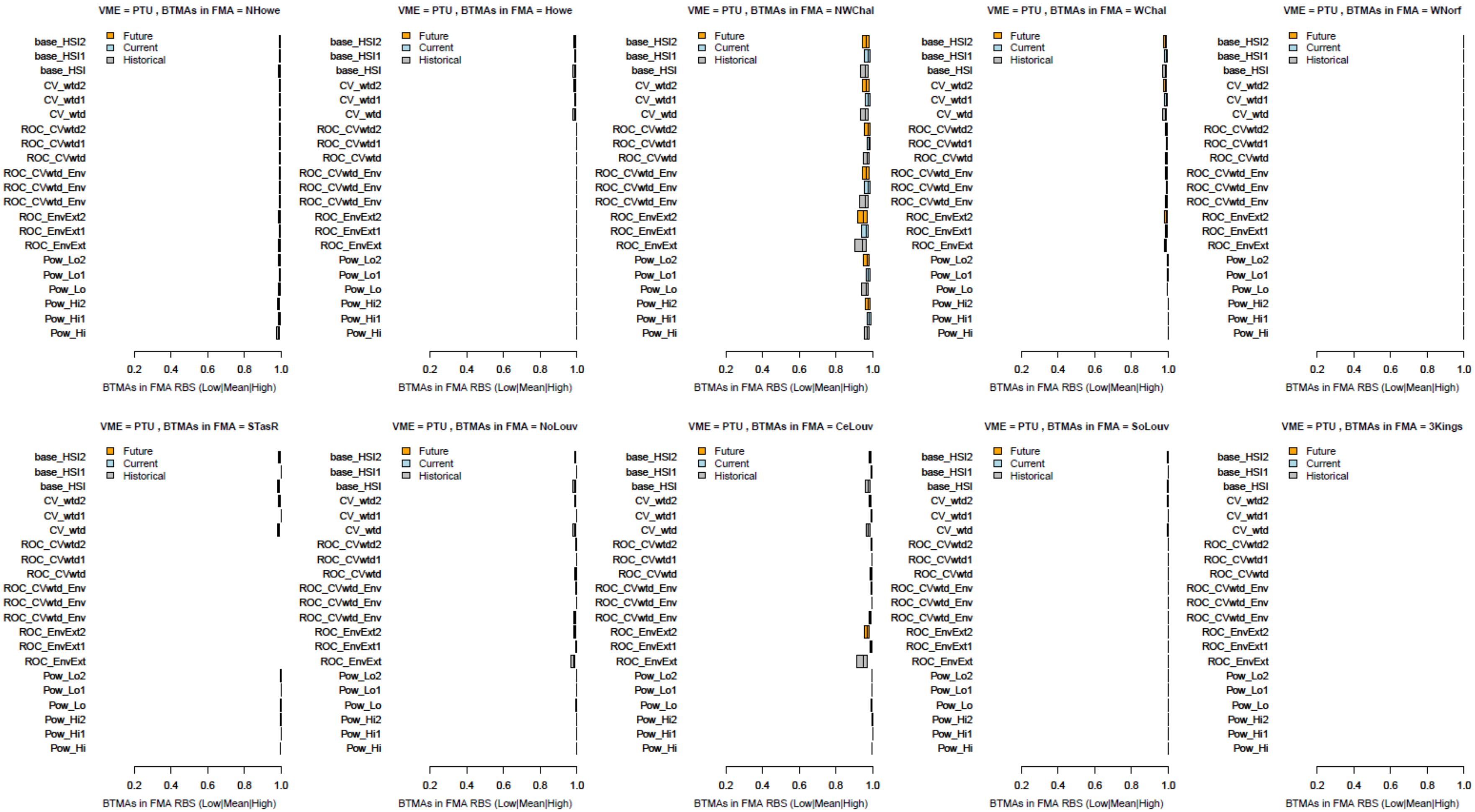

Figure A6.17: Low, mean and high RBS assessment results for Pennatulacea (PTU) for Bottom Trawl Management Areas (BTMAs) within ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge. Note that 3Kings does not have any BTMAs.

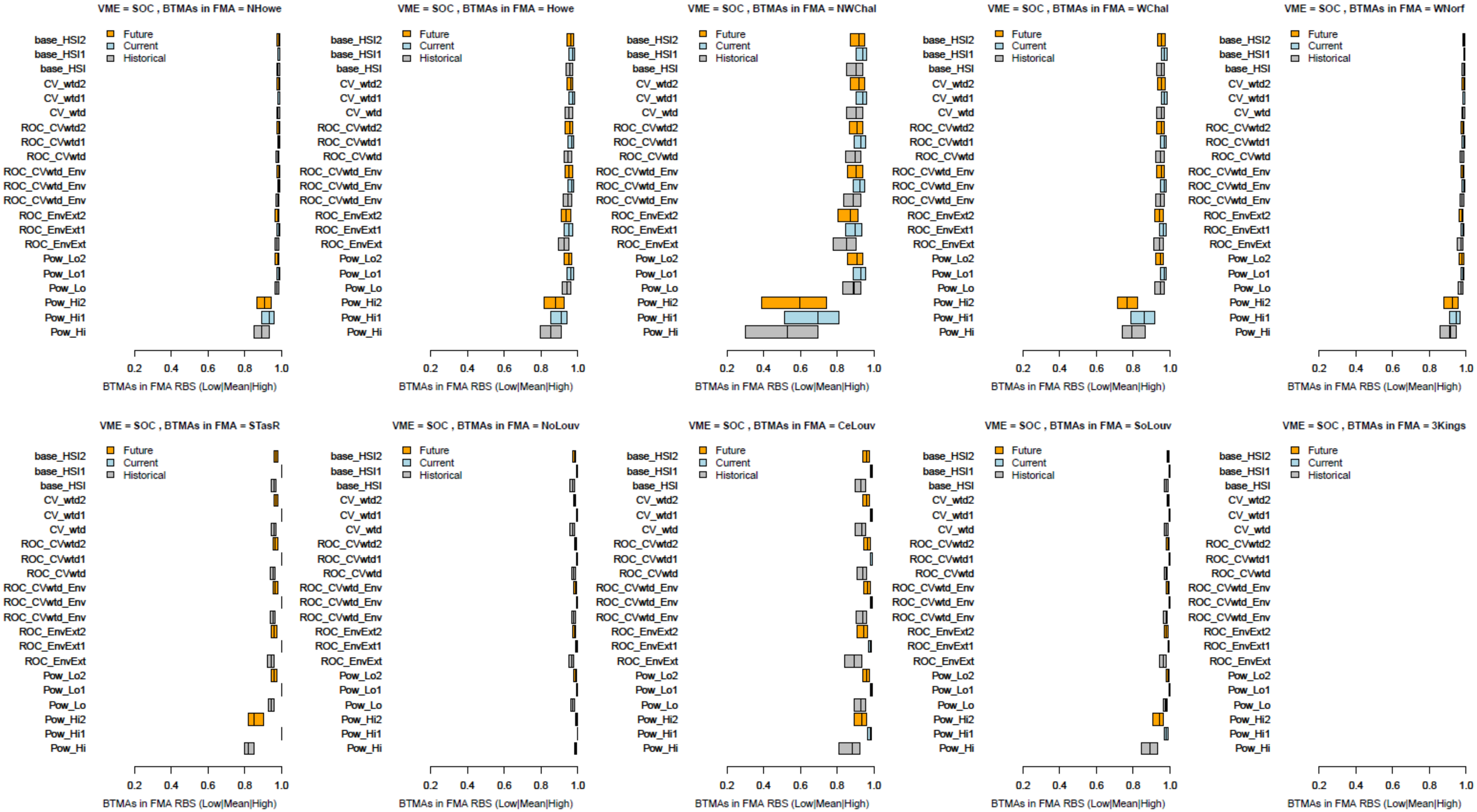

Figure A6.18: Low, mean and high RBS assessment results for Alcyonacea (SOC) for Bottom Trawl Management Areas (BTMAs) within ten orange roughy Fishery Management Areas, three fishing effort scenarios (future, current, historical) and seven abundance sensitivities. Fishing effort scenarios and abundance sensitivities are described in section 4.5.3.1. NHowe = Northern Lord Howe Rise, Howe = Lord Howe Rise, NWChal = Northwest Challenger Plateau, WChal = West Challenger Plateau, WNorf = West Norfolk Ridge, STasR = South Tasman Rise, NoLouv = Northern Louisville Ridge, CeLouv = Central Louisville Ridge, SoLouv = Southern Louisville Ridge , 3Kings = Three Kings Ridge. Note that 3Kings does not have any BTMAs.

Appendix G – HSI-abundance relationships

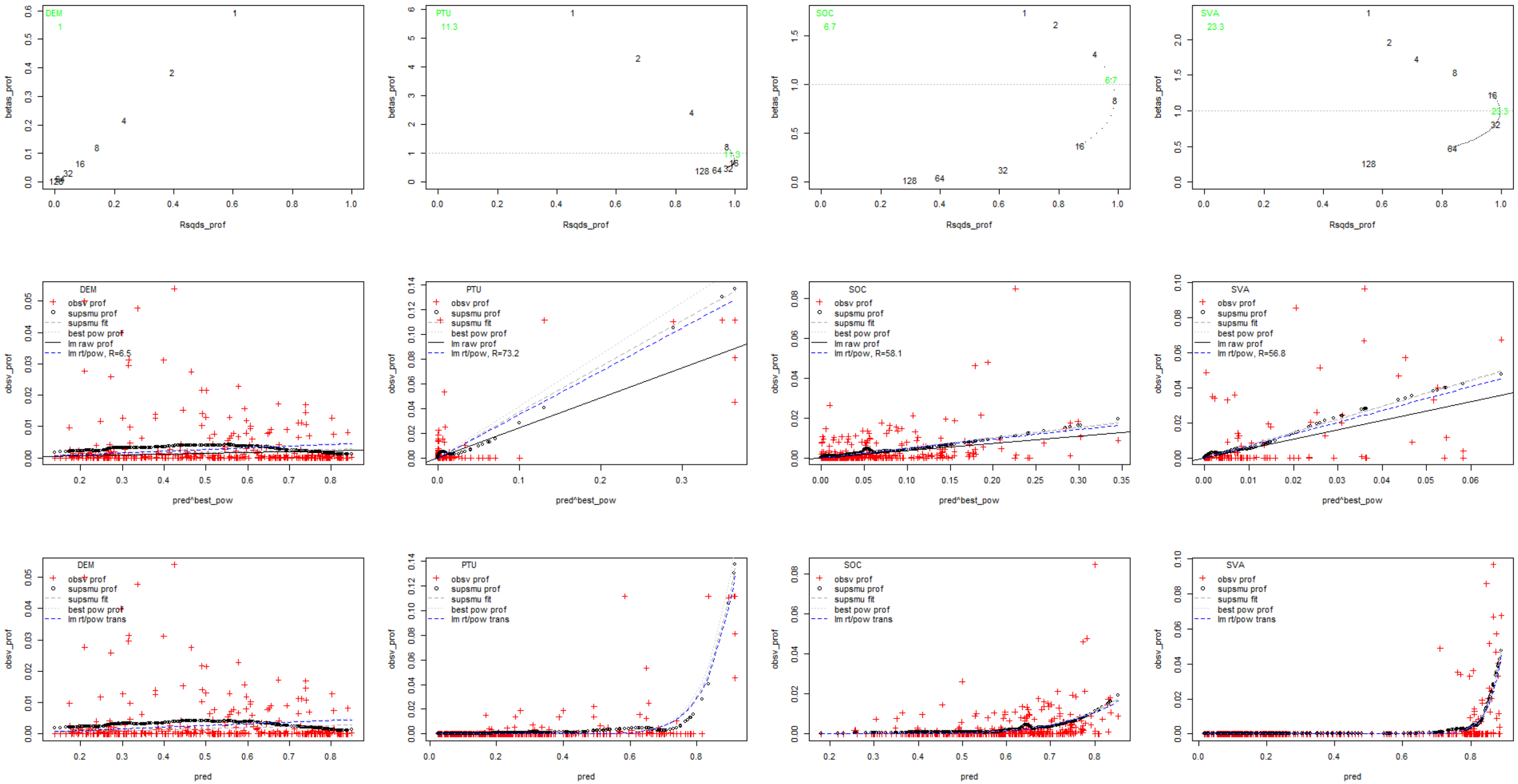

Figure A7.1. Investigation of observed abundance (% cover) versus predicted HSI relationships for VME taxa sampled by tow-video in Australia's southeast marine region: (bottom) raw observations (+) and smooth running mean (○ supsmu) as normalised profiles versus predicted HSI on natural scale; (top) search for best-fit power between predicted HSI and smooth running mean (X-axis: Rsqds of fits, Y-axis: slope (beta) of fits, Labels: base-2 powers, ·····: slope=1), the mean of the powers associated with best Rsqd and slope=1 is shown in green; (middle) observed and running-smooth data versus predicted HSI on mean power transformed scale. Lines and curves indicate fits to: smooth running mean, mean power profile of HSI, untransformed raw profile, and root-transformed raw profile (with Rsq).

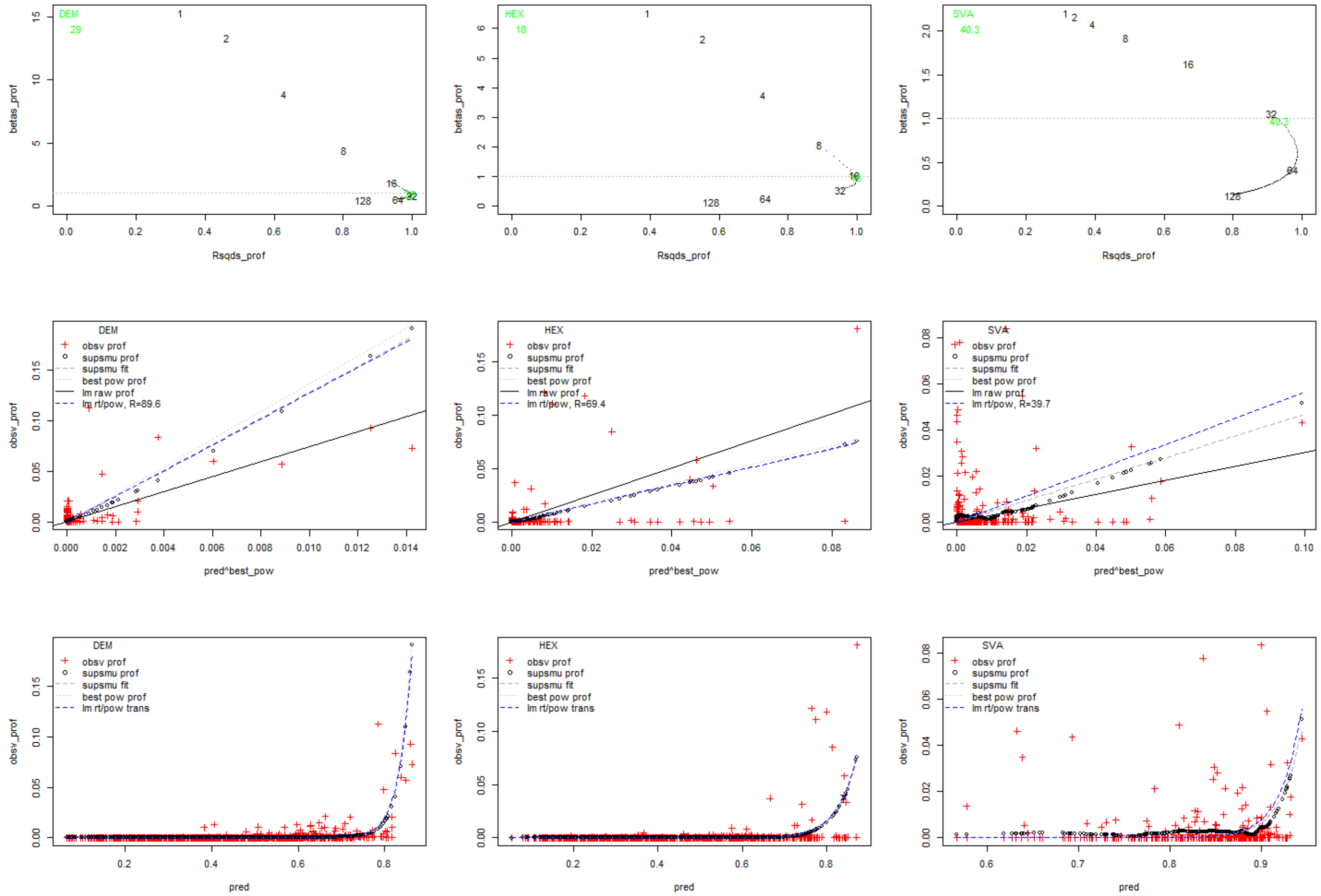

Figure A7.2. Investigation of observed abundance (density) versus predicted HSI relationships for VME taxa sampled by DTIS-video on the Challenger Plateau, Chatham Rise, and Louisville Seamount Chain: (bottom) raw observations (+) and smooth running mean (○ supsmu) as normalised profiles versus predicted HSI on natural scale; (top) search for best-fit power between predicted HSI and smooth running mean (X-axis: Rsqds of fits, Y-axis: slope (beta) of fits, Labels: base-2 powers, ·····: slope=1, green: mean of the powers associated with best Rsqd and slope=1); (middle) observed and running-smooth data versus predicted HSI on mean power transformed scale. Lines and curves indicate fits to: smooth running mean, mean power profile of HSI, untransformed raw profile, and root-transformed raw profile (with Rsq).

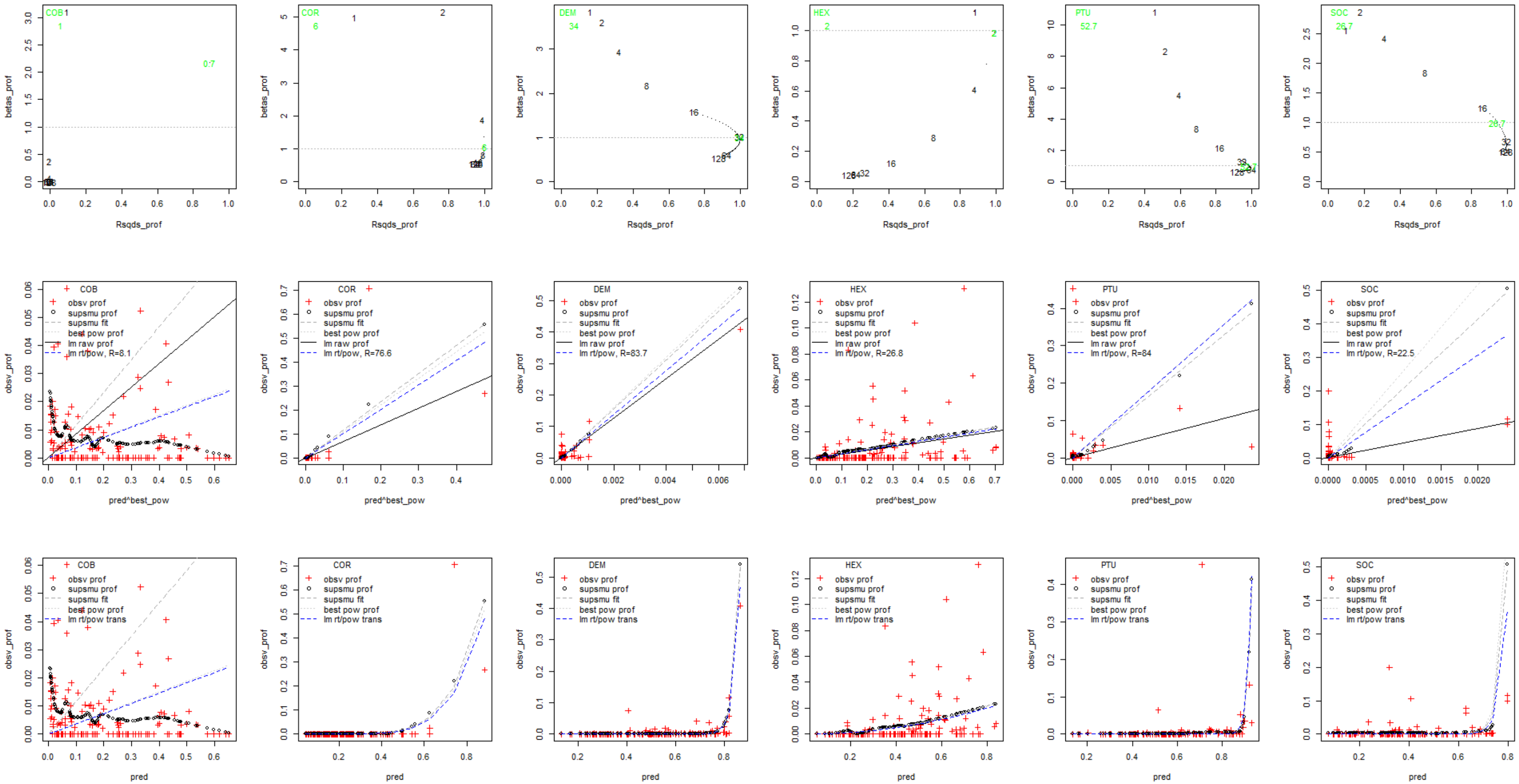

Figure A7.3. Investigation of observed abundance (density) versus predicted HSI relationships for VME taxa sampled by DTIS-video on the Challenger Plateau and Chatham Rise by the OS2020 survey: (bottom) raw observations (+) and smooth running mean (○ supsmu) as normalised profiles versus predicted HSI on natural scale; (top) search for best-fit power between predicted HSI and smooth running mean (X-axis: Rsqds of fits, Y-axis: slope (beta) of fits, Labels: base-2 powers, ·····: slope=1, green: mean of the powers associated with best Rsqd and slope=1); (middle) observed and running-smooth data versus predicted HSI on mean power transformed scale. Lines and curves indicate fits to: smooth running mean, mean power profile of HSI, untransformed raw profile, and root-transformed raw profile (with Rsq).

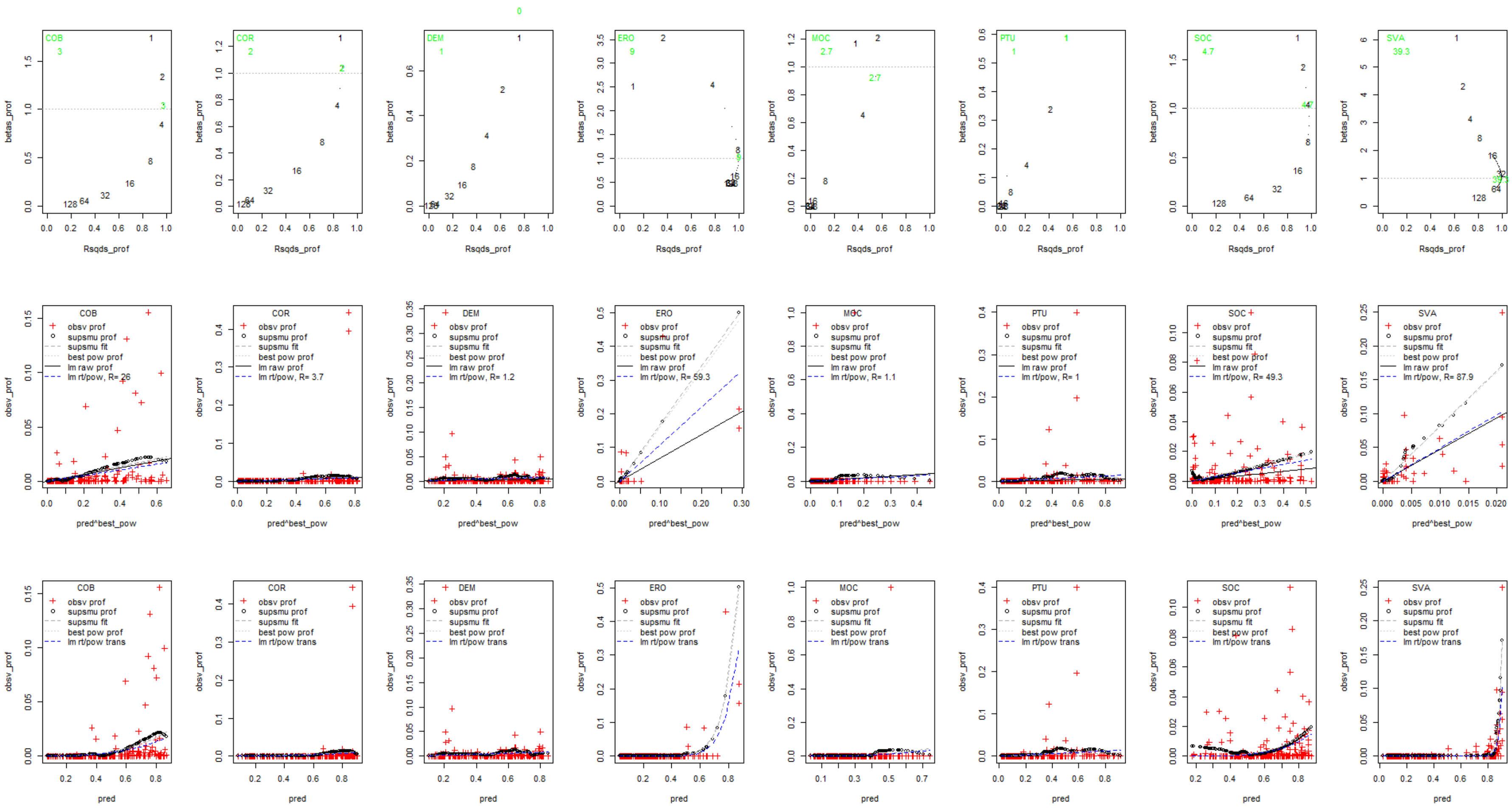

Figure A7.4. Investigation of observed abundance (biomass) versus predicted HSI relationships for VME taxa from benthic sampling in southeast/eastern Australia and Tasman Sea (Howe, Norfolk, Challenger): (bottom) raw observed (+) and smooth running mean (○ supsmu) as normalised profiles versus predicted HSI on natural scale; (top) search for best-fit power between predicted HSI and smooth running mean (X-axis: Rsqds of fits, Y-axis: slope (beta) of fits, Labels: base-2 powers, ·····: slope=1, green: mean of the powers associated with best Rsqd and slope=1); (middle) observed and running-smooth data versus predicted HSI on mean power transformed scale. Lines and curves indicate fits to: smooth running mean, mean power profile of HSI, untransformed raw profile, and root-transformed raw profile (with Rsq).

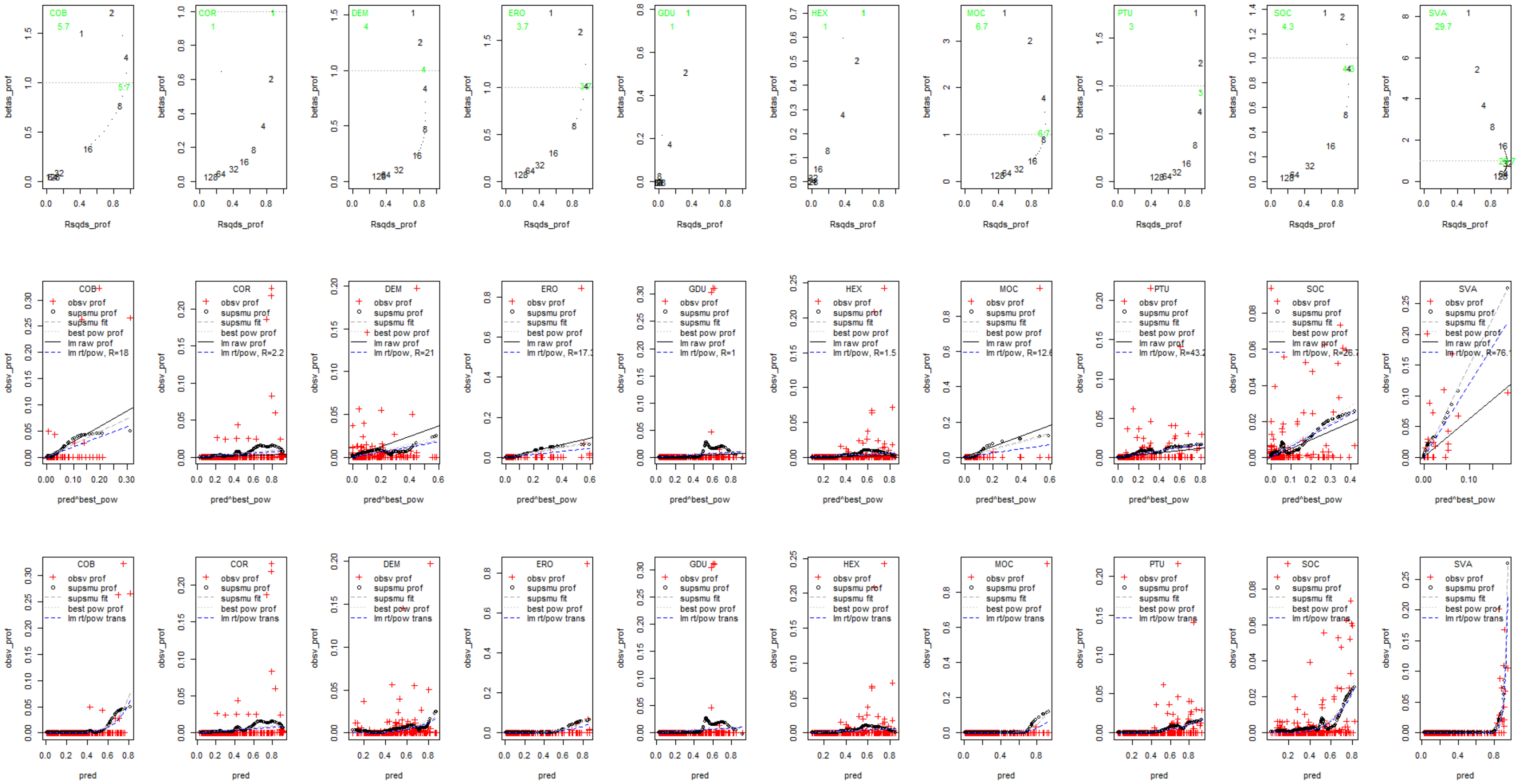

Figure A7.5. Investigation of observed abundance (density) versus predicted HSI relationships for VME taxa from benthic sampling on Challenger Plateau, Chatham Rise, and Louisville Seamount Chain: (bottom) raw observations (+) and smooth running mean (○ supsmu) as normalised profiles versus predicted HSI on natural scale; (top) search for best-fit power between predicted HSI and smooth running mean (X-axis: Rsqds of fits, Y-axis: slope (beta) of fits, Labels: base-2 powers, ⋯⋯: slope=1, green: mean of the powers associated with best Rsqd and slope=1); (middle) observed and running-smooth data versus predicted HSI on mean power transformed scale. Lines and curves indicate fits to: smooth running mean, mean power profile of HSI, untransformed raw profile, and root-transformed raw profile (with Rsq).

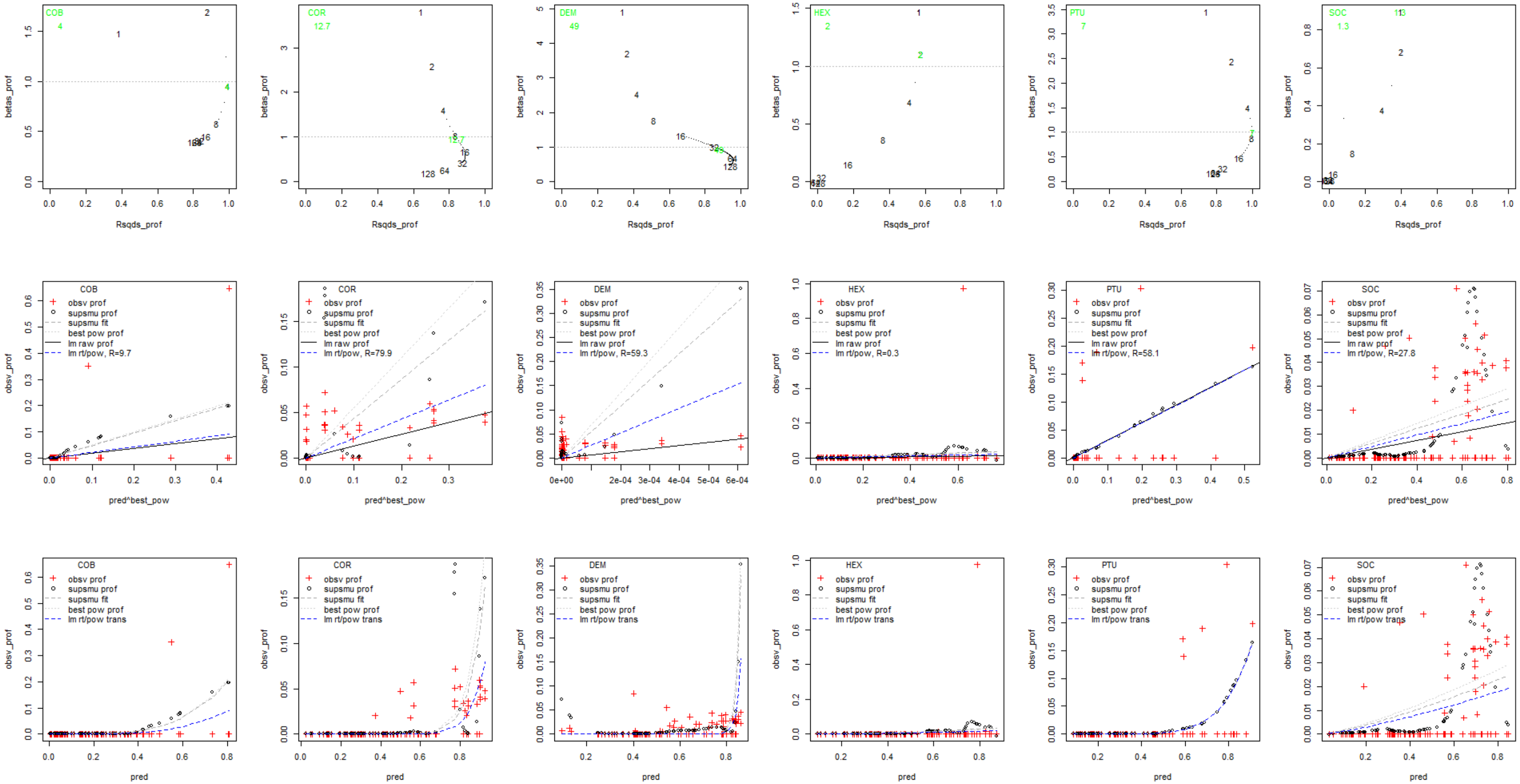

Figure A7.6. Investigation of observed abundance (biomass) versus predicted HSI relationships for VME taxa from benthic sampling on Chatham Rise: (bottom) raw observations (+) and smooth running mean (○ supsmu) as normalised profiles versus predicted HSI on natural scale; (top) search for best-fit power between predicted HSI and smooth running mean (X-axis: Rsqds of fits, Y-axis: slope (beta) of fits, Labels: base-2 powers, ·····: slope=1, green: mean of the powers associated with best Rsqd and slope=1); (middle) observed and running-smooth data versus predicted HSI on mean power transformed scale. Lines and curves indicate fits to: smooth running mean, mean power profile of HSI, untransformed raw profile, and root-transformed raw profile (with Rsq).

Appendix H – Residuals plots for the fitted relationships between observed abundance and predicted HSI

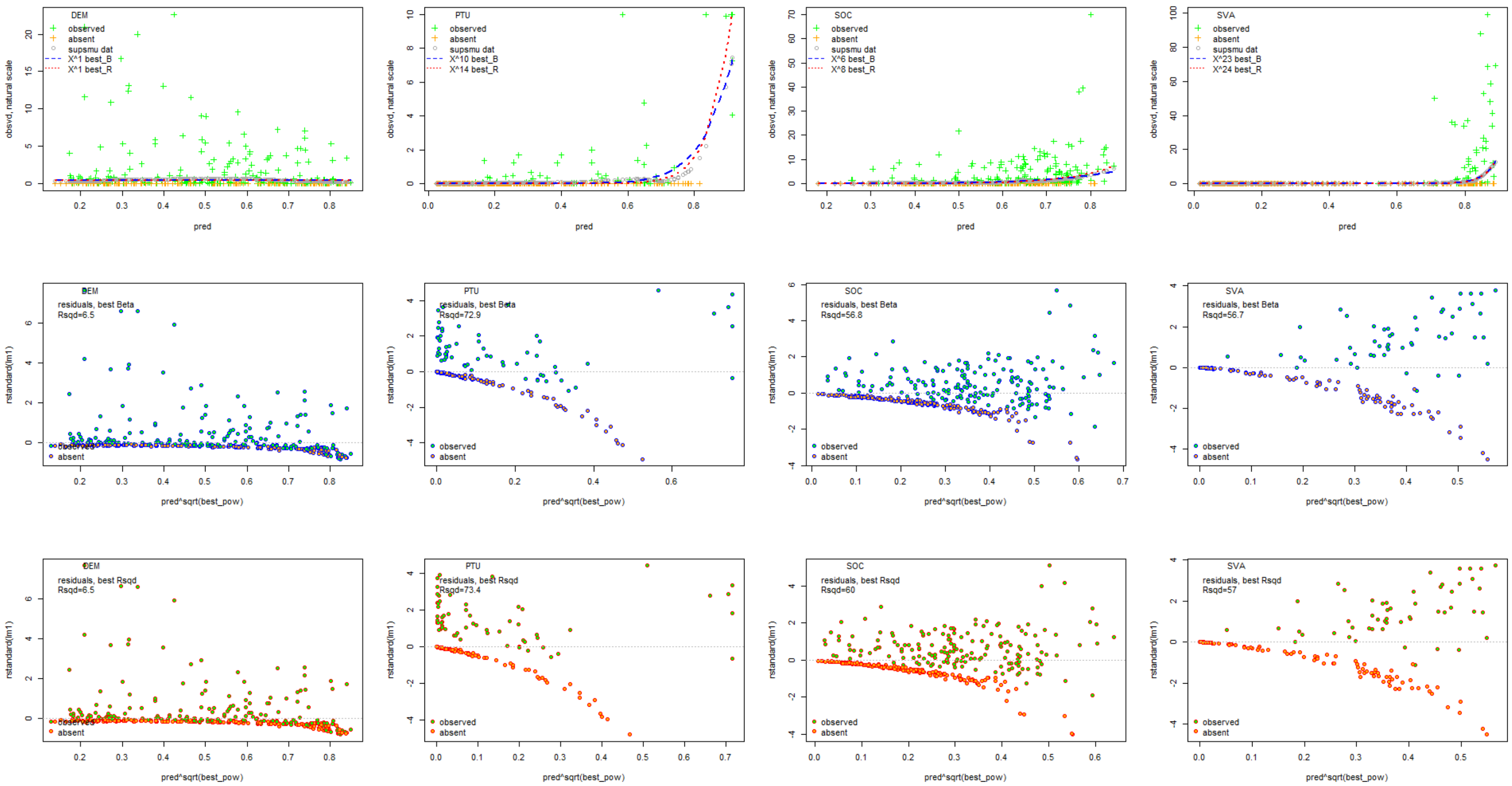

Figure A8.1: Observed abundance and absences versus predicted HSI relationships and standardised residuals plots for VME taxa sampled by tow-video in Australia's southeast marine region. Top row: observed data on the natural scale; curves indicate alternative fits to the data: smooth running mean (supsmu); best power of HSI based on Rsqd (best R); best power of HSI based on slope (best B). Middle & Bottom rows: standardised residuals of fit to root-transformed observations against power-transformed HSI (having same overall power as best R and best B).

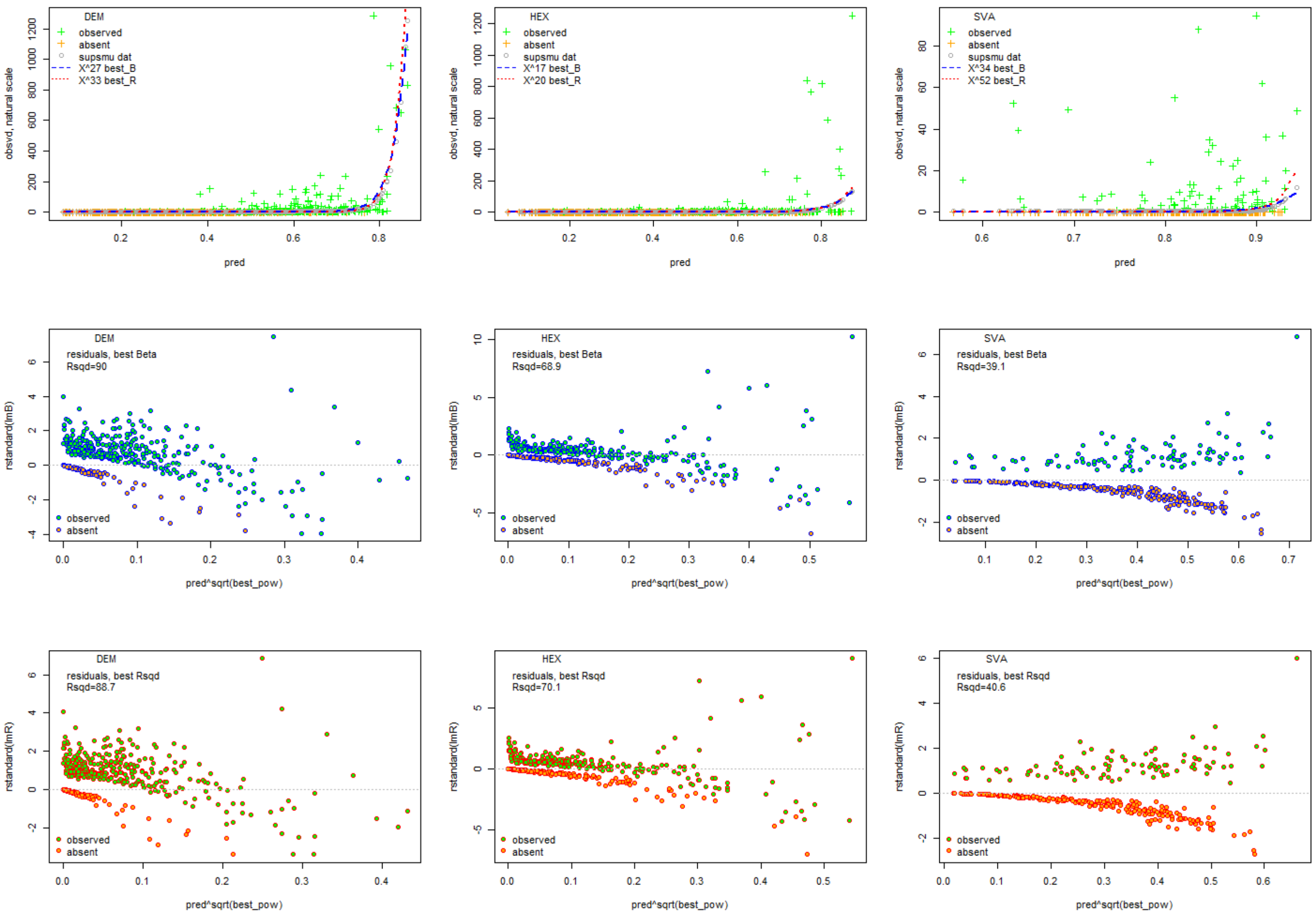

Figure A8.2: Observed abundance and absences versus predicted HSI relationships and standardised residuals plots for VME taxa sampled by tow-video in NZ's Challenger Plateau and Chatham Rise, and on the Louisville Seamount Chain. Top row: observed data on the natural scale; curves indicate alternative fits to the data: smooth running mean (supsmu); best power of HSI based on Rsqd (best R); best power of HSI based on slope (best B). Middle & Bottom rows: standardised residuals of fit to root-transformed observations against power-transformed HSI (having same overall power as best R and best B).

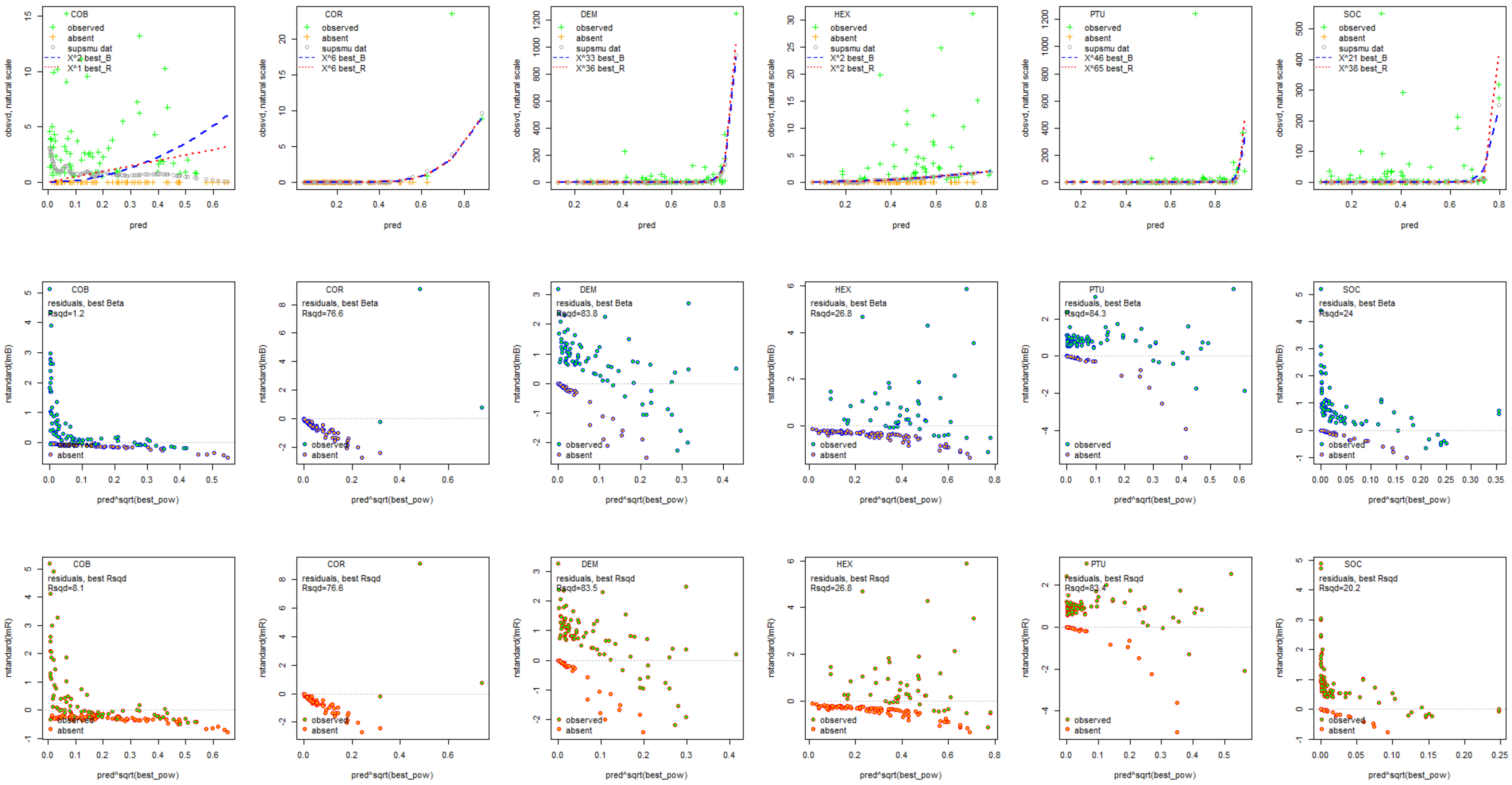

Figure A8.3: Observed abundance and absences versus predicted HSI relationships and standardised residuals plots for VME taxa sampled by tow-video in NZ's Challenger Plateau and Chatham Rise. Top row: observed data on the natural scale; curves indicate alternative fits to the data: smooth running mean (supsmu); best power of HSI based on Rsqd (best R); best power of HSI based on slope (best B). Middle & Bottom rows: standardised residuals of fit to root-transformed observations against power-transformed HSI (having same overall power as best R and best B).

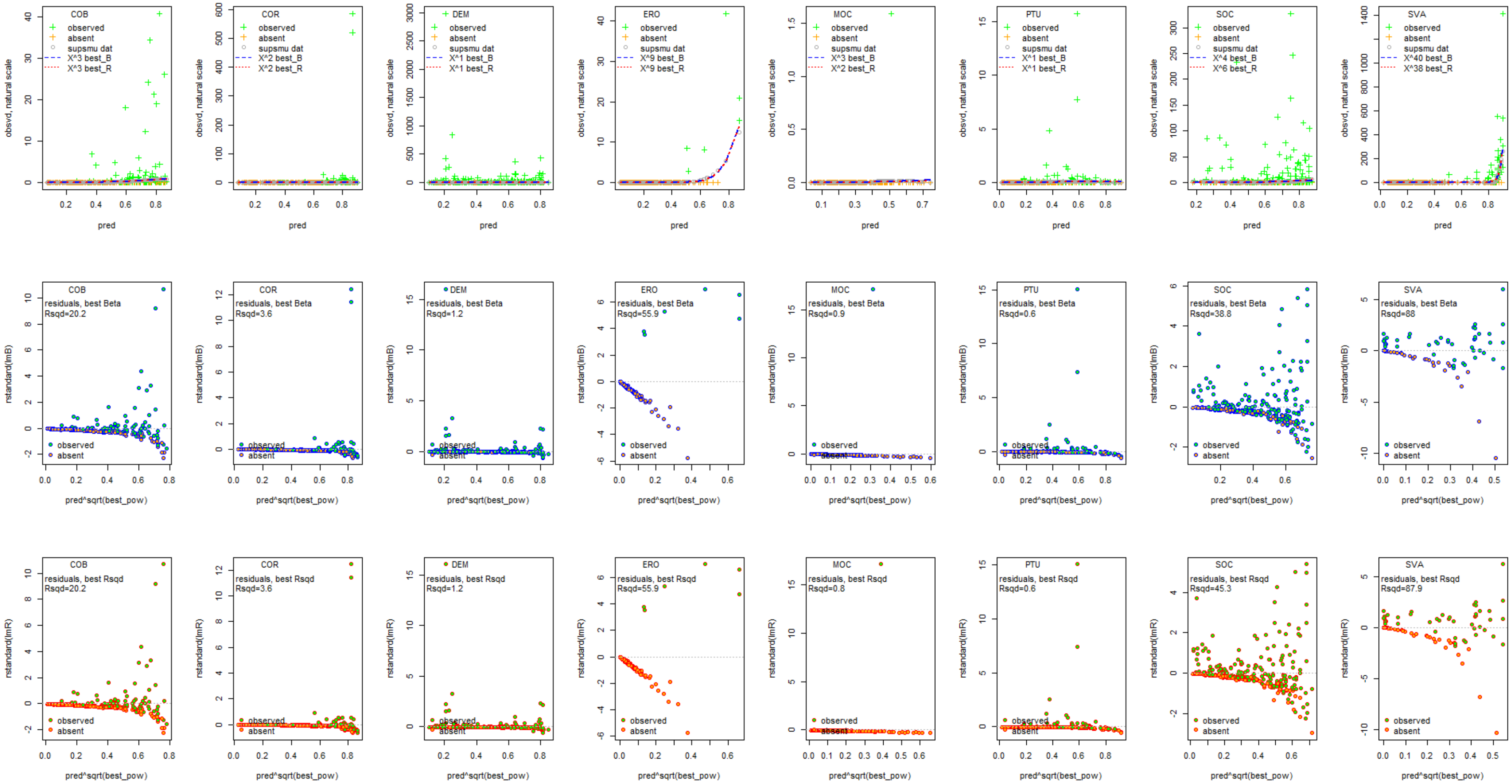

Figure A8.4: Observed abundance and absences versus predicted HSI relationships and standardised residuals plots for VME taxa sampled biomass from benthic sampling in southeast and eastern Australia, and Tasman Sea (Lord Howe, Norfolk and Challenger). Top row: observed data on the natural scale; curves indicate alternative fits to the data: smooth running mean (supsmu); best power of HSI based on Rsqd (best R); best power of HSI based on slope (best B). Middle & Bottom rows: standardised residuals of fit to root-transformed observations against power-transformed HSI (having same overall power as best R and best B).

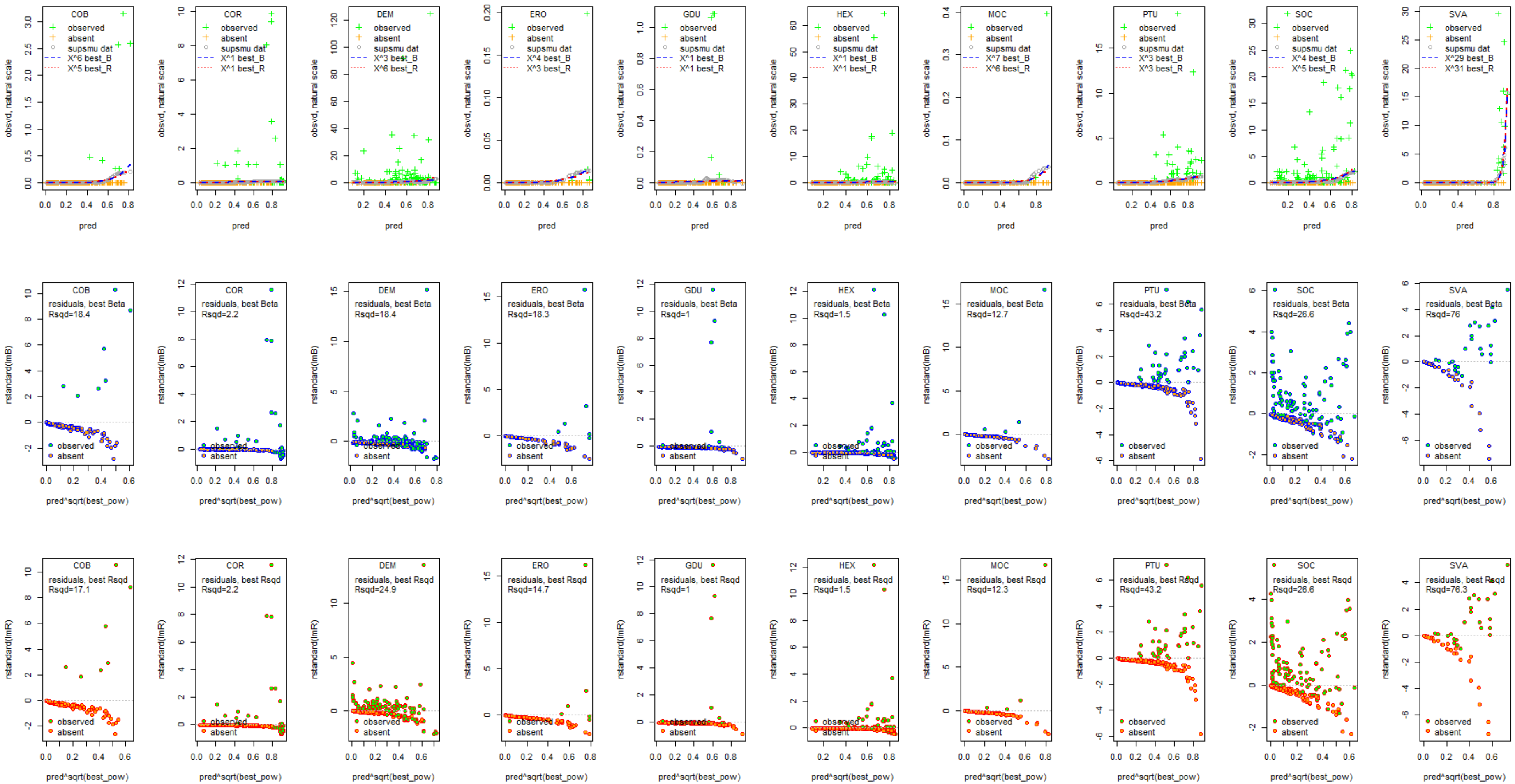

Figure A8.5: Observed abundance and absences versus predicted HSI relationships and standardised residuals plots for VME taxa sampled counts from benthic sampling on NZ's Challenger Plateau and Chatham Rise, and on the Louisville Seamount Chain. Top row: observed data on the natural scale; curves indicate alternative fits to the data: smooth running mean (supsmu); best power of HSI based on Rsqd (best R); best power of HSI based on slope (best B). Middle & Bottom rows: standardised residuals of fit to root-transformed observations against power-transformed HSI (having same overall power as best R and best B).

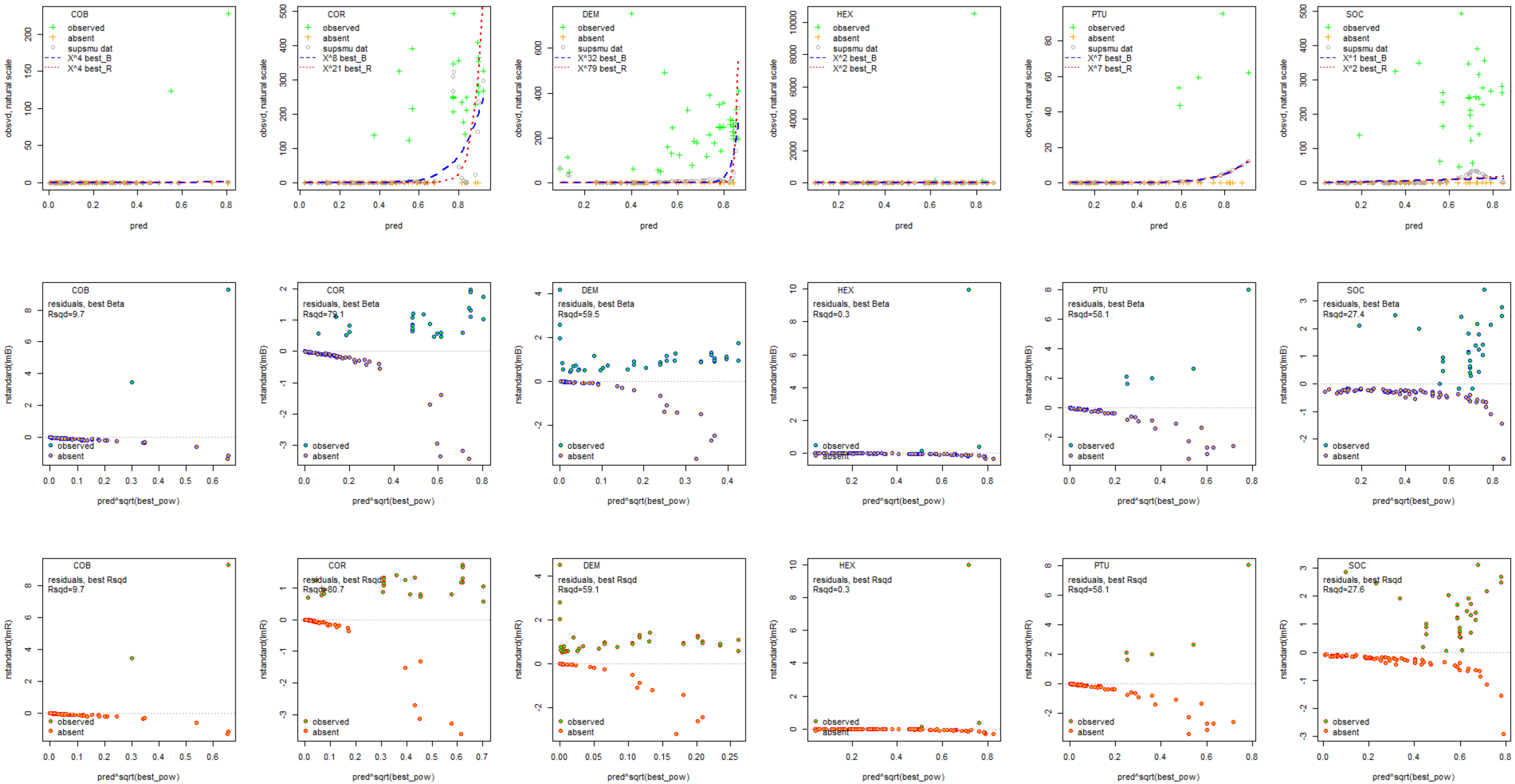

Figure A8.6: Observed abundance and absences versus predicted HSI relationships and standardised residuals plots for VME taxa sampled biomass from benthic sampling on NZ's Chatham Rise. Top row: observed data on the natural scale; curves indicate alternative fits to the data: smooth running mean (supsmu); best power of HSI based on Rsqd (best R); best power of HSI based on slope (best B). Middle & Bottom rows: standardised residuals of fit to root-transformed observations against power-transformed HSI (having same overall power as best R and best B).

Appendix I Details of post-accounting results to estimate the proportion of each VME indicator taxon outside the bottom trawl management areas

This appendix includes the detailed post-accounting results at scales finer than the Evaluated Area: the relevant bioregions (after Costello et al. 2017), five broad fisheries administrative units as used in the 2018 assessment to support CMM 03-2019, and the nine orange roughy fishery management areas.

Table J.1: Estimated percentage of each modelled VME indicator taxon within bioregion 15 (Tasman Sea and SW Pacific Ocean, Costello et al. 2017) and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	**Code**		**ROC**		**Power_Low**		**Power_High**		**Linear**
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	24.79	95.34	21.91	97.02	17.39	99.02	27.28	97.08
	GDU	1.76	97.57	22.29	97.58	22.29	97.58	22.24	97.67
	MOC	31.89	99.98	28.08	99.80	28.94	99.91	24.66	98.91
	SVA	7.75	100.00	0.11	100.00	0.02	100.00	20.29	99.04
Other VME indicators	COB	27.71	90.46	26.94	91.51	27.38	88.81	26.22	96.34
	COR	7.58	99.98	6.48	99.91	5.13	99.99	19.54	98.52
	DEM	28.35	99.33	17.74	99.98	9.81	100.00	26.85	98.50
	HEX	24.89	99.73	9.95	99.90	4.10	99.99	25.91	98.73
	PTU	29.79	98.35	34.67	99.92	21.60	100.00	29.52	98.57
	SOC	27.32	96.00	25.40	95.48	17.39	55.83	27.04	97.69

Table J.2: Estimated percentage of each modelled VME indicator taxon within bioregion 30 (Southern Ocean, Costello et al. 2017) and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	Code	ROC		Power_Low		Power_High		Linear	
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	13.35	77.45	15.17	76.22	16.75	68.47	24.68	97.56
	GDU	7.32	96.65	26.25	99.10	26.25	99.10	26.33	99.04
	MOC	19.23	98.53	20.53	98.59	15.74	97.97	28.40	99.14
	SVA	38.98	97.36	1.91	99.84	0.39	99.96	33.04	98.72
Other VME indicators	COB	5.24	94.97	10.00	97.44	3.89	96.44	21.88	98.64
	COR	49.43	98.09	45.96	98.96	43.24	99.60	34.33	98.96
	DEM	3.95	100.00	0.16	100.00	0.06	100.00	22.43	99.40
	HEX	24.40	99.98	29.05	100.00	18.80	100.00	23.43	99.53
	PTU	23.89	100.00	6.86	100.00	0.80	100.00	23.13	99.71
	SOC	25.52	98.38	27.38	98.30	24.82	89.68	26.09	98.95

Table J.3: Estimated percentage of each modelled VME indicator taxon within bioregion 28 (New Zealand, Costello et al. 2017) and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	**Code**	**ROC**		**Power_Low**		**Power_High**		**Linear**	
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	57.78	57.94	59.88	63.00	64.43	65.02	39.96	80.06
	GDU	76.75	81.84	40.05	82.04	40.05	82.04	40.85	82.19
	MOC	42.61	70.41	43.70	73.68	49.31	68.92	38.48	86.89
	SVA	31.87	78.01	33.89	16.33	28.60	10.65	34.57	85.87
Other VME indicators	COB	48.82	61.48	49.41	64.82	57.41	58.32	40.73	79.93
	COR	29.56	92.84	37.06	94.34	44.19	96.05	36.66	90.00
	DEM	50.80	98.85	74.90	95.28	88.91	91.77	41.18	91.94
	HEX	38.00	90.20	52.59	97.77	71.98	99.51	40.85	89.85
	PTU	36.49	93.20	50.54	98.43	73.86	99.38	39.76	91.86
	SOC	34.01	84.66	35.16	83.71	51.85	50.34	37.70	87.26

Table J.4: Estimated percentage of each modelled VME indicator taxon within bioregion 17 (Mid-South Tropical Pacific, Costello et al. 2017) and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	**Code**	**ROC**		**Power_Low**		**Power_High**		**Linear**	
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	2.94	100.00	1.87	99.65	0.75	99.95	5.07	95.17
	GDU	14.13	85.02	7.64	90.28	7.64	90.28	7.92	90.20
	MOC	4.33	93.66	4.93	94.38	3.91	94.97	5.98	94.16
	SVA	21.18	88.02	64.09	83.07	71.00	83.90	9.75	90.28
Other VME indicators	COB	16.96	91.50	11.82	90.91	10.53	89.35	8.43	92.24
	COR	12.29	88.71	8.80	88.16	5.39	88.22	6.76	91.17
	DEM	6.46	96.77	4.09	97.06	0.67	90.97	5.80	93.95
	HEX	6.52	94.99	6.20	95.27	4.69	95.97	6.33	94.04
	PTU	3.06	96.95	0.94	99.27	0.07	100.00	4.23	94.59
	SOC	8.62	92.37	7.93	93.02	5.73	96.98	6.64	93.00

Table J.5: Estimated overall percentage of each modelled VME indicator taxon within bioregion 16 (Tropical Australia & Coral Sea, Costello et al. 2017) and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	Code	ROC		Power_Low		Power_High		Linear	
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	1.14	100.00	1.17	100.00	0.67	100.00	4.44	100.00
	GDU	0.01	100.00	3.73	100.00	3.73	100.00	3.72	100.00
	MOC	1.89	100.00	2.73	100.00	2.07	100.00	4.55	100.00
	SVA	0.16	100.00	<0.01	100.00	<0.01	100.00	3.35	100.00
Other VME indicators	COB	1.27	100.00	1.82	100.00	0.78	100.00	4.05	100.00
	COR	1.06	100.00	1.66	100.00	2.03	100.00	3.93	100.00
	DEM	10.43	100.00	3.11	100.00	0.56	100.00	6.07	100.00
	HEX	6.17	100.00	2.22	100.00	0.43	100.00	5.63	100.00
	PTU	6.73	100.00	6.98	100.00	3.67	100.00	6.38	100.00
	SOC	4.51	100.00	4.11	100.00	0.21	100.00	5.20	100.00

Table J.6: Estimated percentage of each modelled VME indicator taxon within Tasman Sea Administrative Area and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	**Code**		**ROC**		**Power_Low**		**Power_High**		**Linear**
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	80.19	67.94	80.75	71.77	81.80	72.24	56.02	86.45
	GDU	60.00	87.10	50.58	88.22	50.58	88.22	50.58	88.22
	MOC	55.86	78.65	55.01	79.44	60.14	74.69	51.81	90.82
	SVA	12.82	85.45	0.12	92.54	0.02	98.09	40.17	91.66
Other VME indicators	COB	70.94	71.23	68.55	73.94	79.33	68.36	56.50	86.11
	COR	20.24	97.71	28.84	98.95	36.60	99.75	44.17	93.13
	DEM	73.03	98.77	53.37	93.38	38.08	80.78	55.82	94.30
	HEX	51.63	92.60	33.82	96.90	25.67	99.01	52.34	92.54
	PTU	56.95	94.06	69.24	97.17	91.93	86.12	56.90	93.85
	SOC	50.70	89.03	50.67	87.87	59.99	44.48	53.28	91.18

Table J.7: Estimated percentage of each modelled VME indicator taxon within South Tasman Rise Administrative Area and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	**Code**	**ROC**		**Power_Low**		**Power_High**		**Linear**	
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	13.39	80.23	4.77	75.59	16.74	68.46	12.82	95.79
	GDU	0.15	100.00	8.78	97.91	8.78	97.91	8.78	97.91
	MOC	14.21	98.04	11.60	97.58	10.32	96.95	10.78	98.06
	SVA	33.25	96.90	1.13	99.95	0.13	100.00	16.91	97.71
Other VME indicators	COB	1.53	88.15	3.57	93.76	1.38	91.41	7.90	96.84
	COR	35.76	97.38	24.11	98.03	11.84	98.56	16.38	97.94
	DEM	0.76	100.00	0.03	100.00	<0.00	100.00	6.96	98.32
	HEX	0.24	99.91	0.05	99.77	0.01	100.00	4.83	98.12
	PTU	7.79	100.00	8.85	100.00	2.26	100.00	8.83	99.42
	SOC	21.49	98.10	20.17	97.80	24.30	89.46	12.63	98.01

Table J.8: Estimated percentage of each modelled VME indicator taxon within North Louisville Administrative Area and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	**Code**	**ROC**		**Power_Low**		**Power_High**		**Linear**	
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	<0.00	<0.00	0.04	85.31	<0.00	75.58	1.43	86.95
	GDU	6.92	92.02	3.40	88.49	3.40	88.49	3.40	88.49
	MOC	1.06	73.68	1.27	83.44	0.81	80.12	2.01	87.38
	SVA	12.31	83.76	63.51	83.21	70.84	83.93	4.59	85.75
Other VME indicators	COB	7.40	88.50	5.20	87.49	4.76	86.71	3.43	87.54
	COR	7.00	80.64	5.81	82.11	4.23	84.97	3.29	85.06
	DEM	2.42	90.91	1.14	89.42	0.27	77.77	2.16	87.07
	HEX	2.84	88.84	3.05	90.42	2.14	91.16	2.44	88.21
	PTU	1.19	89.74	0.11	82.59	0.01	99.90	1.55	87.65
	SOC	3.76	86.26	3.32	87.02	2.35	92.93	2.51	87.13

Table J.9: Estimated percentage of each modelled VME indicator taxon within Central Louisville Administrative Area and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	**Code**		**ROC**		**Power_Low**		**Power_High**		**Linear**
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	<0.00	<0.00	0.02	83.04	<0.00	59.96	0.70	74.10
	GDU	9.50	69.30	2.42	68.24	2.42	68.24	2.42	68.24
	MOC	0.54	86.52	0.64	80.24	0.39	81.66	1.01	73.32
	SVA	7.67	57.35	25.40	14.37	21.47	9.24	2.53	62.10
Other VME indicators	COB	3.42	72.32	2.51	71.23	2.41	71.10	1.66	69.87
	COR	1.92	24.11	1.94	20.63	1.75	14.71	1.29	58.88
	DEM	0.05	33.87	<0.00	13.85	<0.00	1.92	0.73	68.54
	HEX	0.95	76.47	0.45	72.62	0.26	63.47	0.98	71.97
	PTU	0.23	82.74	<0.00	88.95	<0.00	99.93	0.59	74.35
	SOC	1.41	70.86	1.19	70.94	0.14	76.33	1.14	69.63

Table J.10: Estimated percentage of each modelled VME indicator taxon within South Louisville Administrative Area and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	Code	ROC		Power_Low		Power_High		Linear	
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	<0.00	<0.00	0.02	52.15	<0.00	37.81	0.71	53.59
	GDU	13.63	51.65	2.88	50.87	2.88	50.87	2.88	50.87
	MOC	0.48	93.92	0.72	72.92	0.44	77.31	1.01	58.14
	SVA	5.93	43.47	8.55	20.61	7.24	15.52	2.22	49.27
Other VME indicators	COB	3.81	45.56	2.79	44.78	2.79	38.74	1.72	50.30
	COR	0.41	21.55	0.33	20.00	0.17	3.97	1.07	52.89
	DEM	0.01	83.33	<0.00	84.13	<0.00	95.89	0.60	54.90
	HEX	0.24	60.87	0.04	67.17	<0.00	65.86	0.72	54.98
	PTU	0.30	64.88	<0.00	61.38	<0.00	11.91	0.56	56.75
	SOC	1.13	44.22	1.01	47.59	0.13	28.98	1.07	50.90

Table J.11: Estimated percentage of each modelled VME indicator taxon within the South Lord Howe Rise FMA and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	**Code**		**ROC**		**Power_Low**		**Power_High**		**Linear**
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	35.67	74.50	42.96	72.63	52.81	70.97	9.85	79.26
	GDU	1.00	79.75	5.65	81.80	5.65	81.80	5.69	81.81
	MOC	8.23	76.61	7.29	77.61	7.80	74.78	5.39	84.16
	SVA	1.60	72.90	<0.01	69.26	<0.01	69.17	4.57	84.95
Other VME indicators	COB	18.06	76.55	20.86	72.76	32.89	68.94	8.77	79.60
	COR	0.01	<0.01	0.02	68.87	<0.01	8.46	3.31	85.20
	DEM	0.98	99.77	0.05	99.47	<0.01	99.80	3.98	89.60
	HEX	3.47	97.52	2.54	99.45	2.01	99.96	4.56	89.64
	PTU	3.11	93.67	2.40	97.54	1.09	99.53	4.13	89.89
	SOC	6.41	73.99	7.14	71.14	26.05	43.59	5.64	80.71

Table J.12: Estimated percentage of each modelled VME indicator taxon within the North Lord Howe Rise FMA and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	**Code**		**ROC**		**Power_Low**		**Power_High**		**Linear**
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	11.23	89.72	9.61	93.22	7.54	97.75	8.40	90.46
	GDU	0.05	12.50	5.33	89.88	5.33	89.88	5.25	90.09
	MOC	0.76	99.29	1.13	94.94	0.76	96.56	3.69	92.63
	SVA	1.11	100.00	<0.01	100.00	<0.01	100.00	3.47	94.32
Other VME indicators	COB	17.71	85.08	15.04	84.80	17.65	82.64	8.93	89.24
	COR	<0.01	<0.01	0.04	85.97	<0.01	58.39	3.84	92.42
	DEM	10.00	98.10	2.67	99.88	0.74	100.00	6.19	93.40
	HEX	4.27	98.44	1.26	99.18	0.24	99.88	5.34	93.75
	PTU	6.22	92.09	2.33	98.79	0.42	100.00	5.88	92.73
	SOC	10.30	89.39	8.99	87.22	12.19	36.97	6.96	90.90

Table J.13: Estimated percentage of each modelled VME indicator taxon within the NW Challenger FMA and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	Code	ROC		Power_Low		Power_High		Linear	
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	17.64	26.84	13.82	36.91	11.51	48.46	10.02	51.69
	GDU	60.90	91.62	14.47	74.14	14.47	74.14	15.01	74.67
	MOC	15.87	44.24	15.75	47.32	21.41	45.68	8.91	65.36
	SVA	1.40	89.16	<0.01	99.93	<0.01	100.00	4.89	65.85
Other VME indicators	COB	14.20	26.37	12.83	35.73	14.04	32.06	10.12	55.28
	COR	0.37	99.49	0.56	94.83	0.07	98.24	7.16	75.86
	DEM	11.23	95.48	7.88	55.23	7.99	8.40	8.65	74.90
	HEX	6.61	52.51	2.60	62.73	0.86	71.34	7.90	63.82
	PTU	7.88	73.41	8.00	91.13	13.77	96.70	8.50	72.65
	SOC	5.30	64.45	5.96	67.53	1.84	71.79	7.85	68.18

Table J.14: Estimated percentage of each modelled VME indicator taxon within the West Norfolk Ridge FMA and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	Code		ROC		Power_Low		Power_High		Linear
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	3.26	47.55	2.33	53.62	1.27	43.71	3.44	84.23
	GDU	1.12	38.36	2.92	81.56	2.92	81.56	3.11	82.10
	MOC	5.72	77.51	4.91	80.43	5.38	79.10	3.63	86.62
	SVA	2.85	67.86	<0.01	89.09	<0.01	94.22	3.12	82.09
Other VME indicators	COB	8.02	84.07	6.68	82.32	6.69	76.72	4.58	86.47
	COR	15.09	97.98	22.06	98.83	30.87	99.71	4.66	89.65
	DEM	10.29	99.63	18.83	99.99	16.13	100.00	3.95	92.17
	HEX	2.65	90.96	1.18	95.32	0.38	98.22	2.94	88.98
	PTU	1.75	90.84	0.24	90.06	<0.01	90.68	2.26	90.14
	SOC	4.64	87.00	4.57	84.08	14.94	38.00	3.54	87.65

Table J.15: Estimated percentage of each modelled VME indicator taxon within the North Louisville Ridge FMA and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	**Code**		**ROC**		**Power_Low**		**Power_High**		**Linear**
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	<0.01	<0.01	0.02	76.69	<0.01	67.41	0.87	78.85
	GDU	1.87	70.41	1.76	77.73	1.76	77.73	1.87	77.75
	MOC	0.71	60.65	0.73	71.27	0.49	67.03	1.14	78.61
	SVA	7.95	74.85	45.66	76.65	53.71	78.81	3.04	77.85
Other VME indicators	COB	4.70	81.90	3.34	80.51	3.23	80.42	2.13	79.40
	COR	5.57	75.65	4.86	78.60	3.71	82.89	2.16	76.75
	DEM	0.99	77.67	0.22	45.95	0.07	11.10	1.33	77.96
	HEX	1.61	80.32	1.63	82.07	1.23	84.57	1.52	80.06
	PTU	0.46	80.26	0.04	82.94	<0.01	99.20	0.90	80.05
	SOC	2.48	79.22	2.25	80.88	2.15	92.27	1.64	79.63

Table J.16: Estimated percentage of each modelled VME indicator taxon within the Central Louisville Ridge FMA and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	**Code**		**ROC**		**Power_Low**		**Power_High**		**Linear**
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	<0.01	<0.01	0.01	58.69	<0.01	22.44	0.44	59.66
	GDU	5.87	45.27	1.66	53.86	1.66	53.86	1.71	54.01
	MOC	0.25	76.09	0.42	69.58	0.25	71.30	0.69	61.30
	SVA	6.24	55.93	25.06	13.18	21.36	8.78	2.11	53.48
Other VME indicators	COB	2.13	54.66	1.64	55.98	1.57	55.62	1.18	56.39
	COR	1.96	24.11	1.94	20.31	1.75	14.70	1.04	48.39
	DEM	0.05	26.83	<0.01	13.67	<0.01	1.92	0.56	57.35
	HEX	0.52	61.69	0.31	60.50	0.23	58.22	0.71	60.01
	PTU	0.05	67.83	<0.01	70.41	<0.01	97.50	0.38	62.38
	SOC	1.14	63.94	0.95	63.46	0.14	75.56	0.90	59.67

Table J.17: Estimated percentage of each modelled VME indicator taxon within the South Louisville Ridge FMA and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	**Code**	**ROC**		**Power_Low**		**Power_High**		**Linear**	
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	<0.01	<0.01	0.01	47.26	<0.01	34.67	0.60	47.46
	GDU	11.97	44.30	2.60	45.65	2.60	45.65	2.62	45.23
	MOC	0.33	95.88	0.63	68.99	0.38	74.01	0.90	53.04
	SVA	5.41	42.40	8.52	20.31	7.23	15.49	2.09	44.00
Other VME indicators	COB	3.57	41.43	2.51	38.60	2.52	32.22	1.55	44.48
	COR	0.36	13.61	0.32	18.64	0.17	3.90	0.97	47.04
	DEM	<0.01	100.00	<0.01	81.14	<0.01	95.79	0.56	49.57
	HEX	0.19	63.20	0.04	66.82	<0.01	65.92	0.67	50.25
	PTU	0.01	67.57	<0.01	63.27	<0.01	18.46	0.42	52.60
	SOC	1.07	39.69	0.92	42.39	0.13	25.89	1.01	45.53

Table J.18: Estimated percentage of each modelled VME indicator taxon within the South Tasman Rise FMA and outside the areas open to fishing for each of three post-accounting methods. ROC = percent of suitable habitat estimated using a HSI cutoff estimated from the receiver operating characteristic (ROC) curve; Linear = percent of total abundance estimated by assuming a linear relationship between habitat suitability indices (HSI) and abundance; Power_High and Power_Low = percent of total abundance estimated by assuming power relationships between HSI and abundance where Power_Low is the mean estimated relationship minus 1 standard deviation and Power_High is the mean estimated relationship plus 1 standard deviation. Taxa within each group as in Table 33.

Group	Code	ROC		Power_Low		Power_High		Linear	
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas
Stony corals	ERO	13.05	76.93	14.08	74.39	16.67	68.32	10.13	94.67
	GDU	0.02	100.00	6.83	97.32	6.83	97.32	6.83	97.32
	MOC	13.39	97.89	10.23	97.26	9.43	96.66	8.50	97.54
	SVA	23.56	95.86	0.85	99.94	0.11	100.00	12.53	96.91
Other VME indicators	COB	1.69	86.93	2.83	92.14	1.15	89.67	6.10	95.90
	COR	14.95	93.70	9.72	95.12	3.52	95.15	11.69	97.11
	DEM	0.34	100.00	0.02	100.00	<0.01	100.00	5.20	97.74
	HEX	0.06	100.00	0.02	99.26	<0.01	99.95	3.72	97.56
	PTU	6.21	100.00	4.45	100.00	0.79	100.00	6.77	99.17
	SOC	15.85	97.58	15.79	97.18	21.42	88.05	9.85	97.45

No analysis is presented for the Three Kings FMA because it contains no defined fishing area and all estimates of the proportion outside fishing areas are 100%.

Appendix J – Sensitivity analysis for excluding areas of low environmental coverage in HSI model inputs

Sensitivity trial 1 using ROC threshold post-accounting

This post-accounting approach estimates the proportion of suitable habitat outside of the areas open to fishing. Results are given for the entire Evaluated Area (Table K1), for each relevant bioregion (after Costello et al. 2017, Tables J2–J6) and for each orange roughy management area (FMA, Tables K7–K14). For the sensitivity run in each location, the domain was clipped to cells with good environmental coverage for the respective ensemble habitat suitability model (>0.05 following Stephenson et al. 2020). No discounting for naturalness is included.

Table K1: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within the Evaluated Area and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Taxa included	Code	Base ROC approach	ROC, restricted to good environmental coverage	% difference
Stony corals	*Enallopsammia rostrata*	ERO	71.53	71.42	-0.11
	Goniocorella dumosa	GDU	83.65	80.75	-2.90
	Madrepora oculata	MOC	86.83	76.76	-10.07
	Solenosmilia variabilis	SVA	89.42	83.98	-5.44
Other VME indicators	Antipatharia (black corals)	COB	76.85	72.66	-4.19
	Stylasteridae (hydrocorals)	COR	95.55	92.10	-3.45
	Demospongiae (demosponges)	DEM	99.02	97.03	-1.99
	Hexactinellida (glass sponges)	HEX	95.88	83.92	-11.96
	Pennatulacea (sea pens)	PTU	96.93	85.32	-11.61
	Alcyonacea (gorgonian taxa only)	SOC	92.62	85.63	-6.99

Table K2: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within bioregion 15 (Tasman Sea - SW Pacific) and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base ROC approach		ROC, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	24.79	95.34	26.51	92.97	-2.37
	GDU	1.76	97.57	2.09	96.64	-0.93
	MOC	31.89	99.98	21.67	99.92	-0.06
	SVA	7.75	100.00	7.58	100.00	0
Other VME indicators	COB	27.71	90.46	30.72	89.49	-0.97
	COR	7.58	99.98	12.49	99.94	-0.04
	DEM	28.35	99.33	27.15	97.51	-1.82
	HEX	24.89	99.73	26.07	98.24	-1.49
	PTU	29.79	98.35	38.45	94.12	-4.23
	SOC	27.32	96.00	29.02	92.02	-3.98

Table K3: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within bioregion 30 (Southern Ocean) and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base ROC approach		ROC, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	13.35	77.45	13.39	80.42	2.97
	GDU	7.32	96.65	4.69	95.46	-1.19
	MOC	19.23	98.53	7.55	92.88	-5.65
	SVA	38.98	97.36	26.38	94.62	-2.74
Other VME indicators	COB	5.24	94.97	2.41	91.33	-3.64
	COR	49.43	98.09	24.47	93.40	-4.69
	DEM	3.95	100.00	1.06	100.00	0
	HEX	24.40	99.98	1.11	97.85	-2.13
	PTU	23.89	100.00	4.85	100.00	0
	SOC	25.52	98.38	15.13	94.53	-3.85

Table K4: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within bioregion 28 (New Zealand) and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base ROC approach		ROC, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	57.78	57.94	55.17	60.71	2.77
	GDU	76.75	81.84	80.16	81.77	-0.07
	MOC	42.61	70.41	63.75	68.35	-2.06
	SVA	31.87	78.01	39.76	75.27	-2.74
Other VME indicators	COB	48.82	61.48	53.72	60.70	-0.78
	COR	29.56	92.84	41.37	91.14	-1.70
	DEM	50.80	98.85	63.81	97.50	-1.35
	HEX	38.00	90.20	59.57	77.48	-12.72
	PTU	36.49	93.20	47.91	75.96	-17.24
	SOC	34.01	84.66	42.88	77.70	-6.96

Table K5: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within bioregion 17 (Mid-South Tropical Pacific) and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base ROC approach		ROC, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	2.94	100.00	3.64	99.96	-0.04
	GDU	14.13	85.02	13.02	82.19	-2.83
	MOC	4.33	93.66	5.03	93.80	0.14
	SVA	21.18	88.02	26.19	85.93	-2.09
Other VME indicators	COB	16.96	91.50	12.15	87.57	-3.93
	COR	12.29	88.71	20.70	88.99	0.28
	DEM	6.46	96.77	4.82	88.77	-8.00
	HEX	6.52	94.99	10.45	89.66	-5.33
	PTU	3.06	96.95	3.25	86.38	-10.57
	SOC	8.62	92.37	10.57	88.33	-4.04

Table K6: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within bioregion 16 (Tropical Australia & Coral Sea) and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	**Code**	**Base ROC approach**		**ROC, restricted to good environmental coverage**		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	1.14	100.00	1.30	100.00	0
	GDU	0.01	100.00	0.01	100.00	0
	MOC	1.89	100.00	1.89	100.00	0
	SVA	0.16	100.00	0.04	100.00	0
Other VME indicators	COB	1.27	100.00	1.00	100.00	0
	COR	1.06	100.00	0.85	100.00	0
	DEM	10.43	100.00	3.15	100.00	0
	HEX	6.17	100.00	2.74	100.00	0
	PTU	6.73	100.00	5.46	100.00	0
	SOC	4.51	100.00	2.36	100.00	0

Table K7: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within the South Lord Howe Rise FMA and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base ROC approach		ROC, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	35.67	74.50	32.08	74.52	0.02
	GDU	1.00	79.75	2.27	72.20	-7.55
	MOC	8.23	76.61	14.45	76.53	-0.08
	SVA	1.60	72.90	1.39	63.01	-9.89
Other VME indicators	COB	18.06	76.55	21.92	75.94	-0.61
	COR	0.01	<0.00	0.01	<0.00	<0.00
	DEM	0.98	99.77	0.50	99.03	-0.74
	HEX	3.47	97.52	6.80	97.31	-0.21
	PTU	3.11	93.67	6.99	93.19	-0.48
	SOC	6.41	73.99	11.87	71.92	-2.07

Table K8: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within the North Lord Howe Rise FMA and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base ROC approach		ROC, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	11.23	89.72	13.16	86.01	-3.71
	GDU	0.05	12.50	0.18	58.73	46.23
	MOC	0.76	99.29	1.48	98.77	-0.52
	SVA	1.11	100.00	0.93	100.00	0.00
Other VME indicators	COB	17.71	85.08	20.84	84.63	-0.45
	COR	<0.00	<0.00	0.01	33.33	33.33
	DEM	10.00	98.10	16.18	95.79	-2.31
	HEX	4.27	98.44	11.51	95.96	-2.48
	PTU	6.22	92.09	20.00	88.68	-3.41
	SOC	10.30	89.39	18.26	87.26	-2.13

Table K9: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within the NW Challenger FMA and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base ROC approach		ROC, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	17.64	26.84	18.47	25.98	-0.86
	GDU	60.90	91.62	62.54	88.60	-3.02
	MOC	15.87	44.24	28.15	44.09	-0.15
	SVA	1.40	89.16	1.51	94.97	5.81
Other VME indicators	COB	14.20	26.37	16.69	24.98	-1.39
	COR	0.37	99.49	1.34	98.14	-1.35
	DEM	11.23	95.48	17.17	91.47	-4.01
	HEX	6.61	52.51	17.10	29.60	-22.91
	PTU	7.88	73.41	23.46	55.98	-17.43
	SOC	5.30	64.45	7.51	55.48	-8.97

Table K10: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within the West Norfolk Ridge FMA and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base ROC approach		ROC, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	3.26	47.55	3.47	52.82	5.27
	GDU	1.12	38.36	1.75	40.57	2.21
	MOC	5.72	77.51	10.31	77.34	-0.17
	SVA	2.85	67.86	3.65	69.23	1.37
Other VME indicators	COB	8.02	84.07	8.48	82.53	-1.54
	COR	15.09	97.98	21.94	96.43	-1.55
	DEM	10.29	99.63	16.21	99.07	-0.56
	HEX	2.65	90.96	5.92	82.49	-8.47
	PTU	1.75	90.84	4.37	82.33	-8.51
	SOC	4.64	87.00	7.89	84.91	-2.09

Table K11: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within the North Louisville Ridge FMA and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base ROC approach		ROC, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	<0.00	<0.00	<0.00	<0.00	0
	GDU	1.87	70.41	1.36	57.05	-13.36
	MOC	0.71	60.65	0.56	47.35	-13.30
	SVA	7.95	74.85	10.31	72.96	-1.89
Other VME indicators	COB	4.70	81.90	3.84	75.73	-6.17
	COR	5.57	75.65	9.27	74.54	-1.11
	DEM	0.99	77.67	2.25	74.89	-2.78
	HEX	1.61	80.32	4.46	75.85	-4.47
	PTU	0.46	80.26	1.75	76.50	-3.76
	SOC	2.48	79.22	3.99	75.71	-3.51

Table K12: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within the Central Louisville Ridge FMA and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base ROC approach		ROC, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	<0.00	<0.00	<0.00	<0.00	0
	GDU	5.87	45.27	5.27	44.44	-0.83
	MOC	0.25	76.09	0.20	74.42	-1.67
	SVA	6.24	55.93	9.16	50.76	-5.17
Other VME indicators	COB	2.13	54.66	2.15	51.54	-3.12
	COR	1.96	24.11	3.28	23.06	-1.05
	DEM	0.05	26.83	0.14	29.31	2.48
	HEX	0.52	61.69	2.14	57.65	-4.04
	PTU	0.05	67.83	0.31	68.80	0.97
	SOC	1.14	63.94	2.11	62.43	-1.51

Table K13: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within the South Louisville Ridge FMA and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base ROC approach		ROC, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	<0.00	<0.00	<0.00	<0.00	0
	GDU	11.97	44.30	11.49	40.93	-3.37
	MOC	0.33	95.88	0.41	89.89	-5.99
	SVA	5.41	42.40	7.23	35.14	-7.26
Other VME indicators	COB	3.57	41.43	3.40	36.50	-4.93
	COR	0.36	13.61	0.66	22.81	9.20
	DEM	<0.00	100.00	0.01	75.00	-25.00
	HEX	0.19	63.20	0.82	55.83	-7.37
	PTU	0.01	67.57	0.48	44.88	-22.69
	SOC	1.07	39.69	1.91	38.42	-1.27

Table K14: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of suitable habitat for each modelled VME indicator taxon within the South Tasman Rise FMA and outside the areas open to fishing. The base approach here sums cells whose HSI exceeds the threshold calculated from the receiver operating characteristic (ROC) curve for the ensemble model for that taxon. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base ROC approach		ROC, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	13.05	76.93	12.81	79.17	2.24
	GDU	0.02	100.00	0.05	100.00	0.00
	MOC	13.39	97.89	6.49	91.95	-5.94
	SVA	23.56	95.86	21.15	93.03	-2.83
Other VME indicators	COB	1.69	86.93	1.51	86.52	-0.41
	COR	14.95	93.70	17.28	90.26	-3.44
	DEM	0.34	100.00	0.33	100.00	0.00
	HEX	0.06	100.00	0.14	99.39	-0.61
	PTU	6.21	100.00	3.97	100.00	0.00
	SOC	15.85	97.58	12.77	93.63	-3.95

No sensitivity analysis is presented for the Three Kings FMA because it contains no defined fishing areas.

Sensitivity trial 2 using Linear scaling post-accounting

This post-accounting approach estimates the proportion of the abundance of each taxon outside of the areas open to fishing assuming a linear relationship between HSI and abundance. Results are given for the entire Evaluated Area (Table K15), for each relevant bioregion (after Costello et al. 2017, Tables J16–J20) and for each orange roughy management area (FMA, Tables J21–J28). For the sensitivity run in each location, the domain was clipped to cells with good environmental coverage for the respective ensemble habitat suitability model (>0.05 following Stephenson et al. 2020). No discounting for naturalness or uncertainty is included.

Table K15: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within the Evaluated Area and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Taxa included	Code	Base linear approach	Linear, restricted to good environmental coverage	% difference
Stony corals	*Enallopsammia rostrata*	ERO	90.48	80.56	-9.92
	Goniocorella dumosa	GDU	91.31	82.32	-8.99
	Madrepora oculata	MOC	94.26	83.93	-10.33
	Solenosmilia variabilis	SVA	93.64	84.86	-8.78
Other VME indicators	Antipatharia (black corals)	COB	90.06	80.15	-9.91
	Stylasteridae (hydrocorals)	COR	95.21	87.91	-7.30
	Demospongiae (demosponges)	DEM	95.95	88.56	-7.39
	Hexactinellida (glass sponges)	HEX	95.24	85.30	-9.94
	Pennatulacea (sea pens)	PTU	96.19	85.32	-10.87
	Alcyonacea (gorgonian taxa only)	SOC	94.12	84.71	-9.41

Table K16: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within bioregion 15 (Tasman Sea - SW Pacific) and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base linear approach		Linear, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	27.28	97.08	28.08	94.32	-2.76
	GDU	22.24	97.67	20.76	94.36	-3.31
	MOC	24.66	98.91	23.16	96.45	-2.46
	SVA	20.29	99.04	19.77	97.29	-1.75
Other VME indicators	COB	26.22	96.34	28.24	92.95	-3.39
	COR	19.54	98.52	21.26	96.21	-2.31
	DEM	26.85	98.50	27.19	95.39	-3.11
	HEX	25.91	98.73	26.02	95.69	-3.04
	PTU	29.52	98.57	31.19	94.72	-3.85
	SOC	27.04	97.69	27.22	93.84	-3.85

Table K17: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within bioregion 30 (Southern Ocean) and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base linear approach		Linear, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	24.68	97.56	12.27	89.72	-7.84
	GDU	26.33	99.04	8.45	94.48	-4.56
	MOC	28.40	99.14	9.98	93.41	-5.73
	SVA	33.04	98.72	17.05	93.79	-4.93
Other VME indicators	COB	21.88	98.64	7.86	92.82	-5.82
	COR	34.33	98.96	14.90	93.66	-5.30
	DEM	22.43	99.40	6.56	93.90	-5.50
	HEX	23.43	99.53	5.51	93.81	-5.72
	PTU	23.13	99.71	7.39	96.85	-2.86
	SOC	26.09	98.95	11.74	93.90	-5.05

Table K18: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within bioregion 28 (New Zealand) and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base linear approach		Linear, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	39.96	80.06	51.27	68.61	-11.45
	GDU	40.85	82.19	59.14	75.19	-7.00
	MOC	38.48	86.89	55.93	75.47	-11.42
	SVA	34.57	85.87	46.39	75.38	-10.49
Other VME indicators	COB	40.73	79.93	52.00	69.04	-10.89
	COR	36.66	90.00	50.06	82.11	-7.89
	DEM	41.18	91.94	55.70	84.05	-7.89
	HEX	40.85	89.85	56.82	78.48	-11.37
	PTU	39.76	91.86	51.71	76.85	-15.01
	SOC	37.70	87.26	49.45	76.06	-11.20

Table K19: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within bioregion 17 (Mid-South Tropical Pacific) and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base linear approach		Linear, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	5.07	95.17	5.67	91.24	-3.93
	GDU	7.92	90.20	9.54	85.64	-4.56
	MOC	5.98	94.16	7.69	88.74	-5.42
	SVA	9.75	90.28	15.01	85.86	-4.42
Other VME indicators	COB	8.43	92.24	9.27	87.13	-5.11
	COR	6.76	91.17	11.55	88.05	-3.12
	DEM	5.80	93.95	7.39	87.71	-6.24
	HEX	6.33	94.04	8.72	88.40	-5.64
	PTU	4.23	94.59	6.01	86.24	-8.35
	SOC	6.64	93.00	8.74	87.84	-5.16

Table K20: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within bioregion 16 (Tropical Australia & Coral Sea) and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base linear approach		Linear, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	4.44	100.00	2.67	100.00	0
	GDU	3.72	100.00	2.05	100.00	0
	MOC	4.55	100.00	3.17	100.00	0
	SVA	3.35	100.00	1.69	100.00	0
Other VME indicators	COB	4.05	100.00	2.59	100.00	0
	COR	3.93	100.00	2.14	100.00	0
	DEM	6.07	100.00	3.11	100.00	0
	HEX	5.63	100.00	2.87	100.00	0
	PTU	6.38	100.00	3.64	100.00	0
	SOC	5.20	100.00	2.80	100.00	0

Table K21: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within the South Lord Howe Rise FMA and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	**Code**	**Base linear approach**		**Linear, restricted to good environmental coverage**		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	9.85	79.26	18.57	77.54	-1.72
	GDU	5.69	81.81	10.37	79.99	-1.82
	MOC	5.39	84.16	12.04	81.67	-2.49
	SVA	4.57	84.95	8.47	83.46	-1.49
Other VME indicators	COB	8.77	79.60	15.61	77.46	-2.14
	COR	3.31	85.20	5.95	81.59	-3.61
	DEM	3.98	89.60	7.35	86.94	-2.66
	HEX	4.56	89.64	9.04	85.74	-3.90
	PTU	4.13	89.89	9.71	86.71	-3.18
	SOC	5.64	80.71	11.66	77.47	-3.24

Table K22: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within the North Lord Howe Rise FMA and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	**Code**	**Base linear approach**		**Linear, restricted to good environmental coverage**		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	8.40	90.46	14.68	89.14	-1.32
	GDU	5.25	90.09	9.73	87.96	-2.13
	MOC	3.69	92.63	8.22	90.01	-2.62
	SVA	3.47	94.32	6.67	91.97	-2.35
Other VME indicators	COB	8.93	89.24	15.61	87.24	-2.00
	COR	3.84	92.42	8.10	90.04	-2.38
	DEM	6.19	93.40	13.67	90.82	-2.58
	HEX	5.34	93.75	12.49	91.02	-2.73
	PTU	5.88	92.73	15.56	89.41	-3.32
	SOC	6.96	90.90	14.38	88.34	-2.56

Table K23: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within the NW Challenger FMA and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base linear approach		Linear, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	10.02	51.69	17.12	44.18	-7.51
	GDU	15.01	74.67	28.76	72.96	-1.71
	MOC	8.91	65.36	20.56	58.70	-6.66
	SVA	4.89	65.85	9.44	57.85	-8.00
Other VME indicators	COB	10.12	55.28	17.58	49.37	-5.91
	COR	7.16	75.86	14.81	71.76	-4.10
	DEM	8.65	74.90	18.59	69.18	-5.72
	HEX	7.90	63.82	16.87	51.16	-12.66
	PTU	8.50	72.65	20.89	59.32	-13.33
	SOC	7.85	68.18	15.03	60.01	-8.17

Table K24: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within the West Norfolk Ridge FMA and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base linear approach		Linear, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	3.44	84.23	6.06	81.15	-3.08
	GDU	3.11	82.10	5.50	79.29	-2.81
	MOC	3.63	86.62	7.86	83.79	-2.83
	SVA	3.12	82.09	6.63	79.66	-2.43
Other VME indicators	COB	4.58	86.47	7.52	84.03	-2.44
	COR	4.66	89.65	11.18	88.91	-0.74
	DEM	3.95	92.17	8.44	89.58	-2.59
	HEX	2.94	88.98	6.36	83.89	-5.09
	PTU	2.26	90.14	6.16	85.28	-4.86
	SOC	3.54	87.65	7.20	84.47	-3.18

Table K25: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within the North Louisville Ridge FMA and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	**Code**	**Base linear approach**		**Linear, restricted to good environmental coverage**		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	0.87	78.85	1.33	71.98	-6.87
	GDU	1.87	77.75	2.39	69.79	-7.96
	MOC	1.14	78.61	2.08	70.66	-7.95
	SVA	3.04	77.85	5.70	72.97	-4.88
Other VME indicators	COB	2.13	79.40	3.09	73.72	-5.68
	COR	2.16	76.75	4.50	73.81	-2.94
	DEM	1.33	77.96	2.86	73.14	-4.82
	HEX	1.52	80.06	3.26	75.00	-5.06
	PTU	0.90	80.05	2.50	74.22	-5.83
	SOC	1.64	79.63	3.06	74.62	-5.01

Table K26: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within the Central Louisville Ridge FMA and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	**Code**	**Base linear approach**		**Linear, restricted to good environmental coverage**		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	0.44	59.66	0.83	55.21	-4.45
	GDU	1.71	54.01	2.87	48.24	-5.77
	MOC	0.69	61.30	1.55	55.96	-5.34
	SVA	2.11	53.48	4.46	48.21	-5.27
Other VME indicators	COB	1.18	56.39	2.05	52.08	-4.31
	COR	1.04	48.39	2.34	42.96	-5.43
	DEM	0.56	57.35	1.33	50.53	-6.82
	HEX	0.71	60.01	1.89	54.95	-5.06
	PTU	0.38	62.38	1.26	57.16	-5.22
	SOC	0.90	59.67	1.92	55.17	-4.50

Table K27: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within the South Louisville Ridge FMA and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base linear approach		Linear, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	0.60	47.46	1.06	41.03	-6.43
	GDU	2.62	45.23	4.45	39.92	-5.31
	MOC	0.90	53.04	1.88	45.88	-7.16
	SVA	2.09	44.00	4.20	38.24	-5.76
Other VME indicators	COB	1.55	44.48	2.57	38.98	-5.50
	COR	0.97	47.04	1.95	41.56	-5.48
	DEM	0.56	49.57	1.24	42.86	-6.71
	HEX	0.67	50.25	1.66	44.54	-5.71
	PTU	0.42	52.60	1.42	44.27	-8.33
	SOC	1.01	45.53	2.07	40.33	-5.20

Table K28: Sensitivity to excluding areas of poor environmental coverage of the estimated overall percentage of each modelled VME indicator taxon within the South Tasman Rise FMA and outside the areas open to fishing. The base approach here assumes a linear relationship between HSI from the ensemble model for that taxon and abundance. For the sensitivity run, the domain was clipped to locations with good environmental coverage.

Group	Code	Base linear approach		Linear, restricted to good environmental coverage		
		% of taxon within region	% of taxon outside fishing areas	% of taxon within region	% of taxon outside fishing areas	% difference outside fishing areas
Stony corals	ERO	10.13	94.67	10.87	88.62	-6.05
	GDU	6.83	97.32	6.14	93.53	-3.79
	MOC	8.50	97.54	8.14	92.31	-5.23
	SVA	12.53	96.91	13.89	92.80	-4.11
Other VME indicators	COB	6.10	95.90	6.30	91.62	-4.28
	COR	11.69	97.11	11.76	92.27	-4.84
	DEM	5.20	97.74	5.01	92.50	-5.24
	HEX	3.72	97.56	4.04	92.34	-5.22
	PTU	6.77	99.17	6.08	96.50	-2.67
	SOC	9.85	97.45	9.83	93.05	-4.40

No sensitivity analysis is presented for the Three Kings FMA because it contains no defined fishing areas.

Appendix K - Sensitivity analysis of a fishable depth cutoff in post-accounting

In this sensitivity analysis, the proportion of suitable habitat (using the ROC post-accounting method) and the proportion of estimated abundance (using the Power-Low post-accounting method) for each VME indicator taxon are re-calculated after assuming that there will be no fishing-related disturbance deeper than 1400 m. Over the 30-year history of the bottom trawl fishery for orange roughy, virtually all bottom trawl tows have been shallower than 1250 m (see Figure 8) and the depth distribution of tows has shown no directional change. Two post-accounting methods are applied, calculating the percentage of suitable habitat estimated using a HSI cutoff from the receiver operating characteristic (ROC) curve, see Table 32, and the percentage of total abundance estimated by assuming a power relationships between HSI and abundance where (in this analysis, the mean estimated relationship minus 1 standard deviation). It is acknowledged that there is limited information as to the abundance of a number of taxa below these depths. Taxa within each group as in Table K1.

Table L1: Sensitivity to an assumed lower depth limit for bottom trawling of estimated percentage of habitat (ROC post accounting method) or abundance (using a power curve relationship between model HSI and abundance) of each modelled VME indicator taxon within the South Lord Howe Rise FMA and outside the areas open to fishing.

Taxon	ROC				Power			
	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff
ERO	35.67	74.50	74.50	0	42.96	72.63	72.63	0
GDU	1	79.75	79.75	0	5.65	81.80	81.80	0
MOC	8.23	76.61	76.78	0.17	7.29	77.61	77.61	0
SVA	1.6	72.90	80.80	7.90	<0.01	69.26	69.26	0
COB	18.06	76.55	76.56	0.01	20.86	72.76	72.76	0
COR	0.01	<0.01	<0.01	<0.01	0.02	68.87	68.87	0
DEM	0.98	99.77	99.77	0	0.05	99.47	99.47	0
HEX	3.47	97.52	99.62	2.10	2.54	99.45	99.45	0
PTU	3.11	93.67	97.53	3.86	2.40	96.12	96.12	0
SOC	6.41	73.99	75.61	1.62	7.14	71.14	71.14	0

Table L2: Sensitivity to an assumed lower depth limit for bottom trawling of estimated percentage of habitat (ROC post accounting method) or abundance (using a power curve relationship between model HSI and abundance) of each modelled VME indicator taxon within the North Lord Howe Rise FMA and outside the areas open to fishing.

Taxon	ROC				Power			
	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff
ERO	11.23	89.72	89.72	0	9.61	93.22	93.22	0
GDU	0.05	12.50	12.50	0	5.33	89.88	89.88	0
MOC	0.76	99.29	99.29	0	1.13	94.94	94.94	0
SVA	1.11	100.00	100.00	0	<0.01	100.00	100.00	0
COB	17.71	85.08	85.08	0	15.04	84.80	84.80	0
COR	<0.01	<0.01	<0.01	<0.01	0.04	85.97	85.97	0
DEM	10	98.10	98.10	0	2.67	99.88	99.88	0
HEX	4.27	98.44	98.44	0	1.26	99.18	99.18	0
PTU	6.22	92.09	92.09	0	2.33	98.53	98.53	0
SOC	10.3	89.39	89.39	0	8.99	87.22	87.22	0

Table L3: Sensitivity to an assumed lower depth limit for bottom trawling of estimated percentage of habitat (ROC post accounting method) or abundance (using a power curve relationship between model HSI and abundance) of each modelled VME indicator taxon within the NW Challenger FMA and outside the areas open to fishing.

Taxon	ROC				Power			
	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff
ERO	17.64	26.84	26.84	0	13.82	36.91	36.92	0.01
GDU	60.9	91.62	91.62	0	14.47	74.14	75.05	0.91
MOC	15.87	44.24	44.44	0.20	15.75	47.32	47.68	0.36
SVA	1.4	89.16	89.16	0	<0.01	99.93	99.93	0
COB	14.2	26.37	26.37	0	12.83	35.73	35.91	0.18
COR	0.37	99.49	99.49	0	0.56	94.83	94.86	0.03
DEM	11.23	95.48	95.61	0.13	7.88	55.23	55.23	0
HEX	6.61	52.51	58.19	5.68	2.60	62.73	67.41	4.68
PTU	7.88	73.41	78.13	4.72	8.00	84.03	92.21	8.18
SOC	5.3	64.45	68.64	4.19	5.96	67.53	70.82	3.29

Table L4: Sensitivity to an assumed lower depth limit for bottom trawling of estimated percentage of habitat (ROC post accounting method) or abundance (using a power curve relationship between model HSI and abundance) of each modelled VME indicator taxon within the West Norfolk Ridge FMA and outside the areas open to fishing.

Taxon	ROC				Power			
	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff
ERO	3.26	47.55	48.27	0.72	2.33	53.62	54.09	0.47
GDU	1.12	38.36	38.36	0	2.92	81.56	87.57	6.01
MOC	5.72	77.51	79.63	2.12	4.91	80.43	82.82	2.39
SVA	2.85	67.86	83.05	15.19	<0.01	89.09	91.01	1.92
COB	8.02	84.07	87.74	3.67	6.68	82.32	85.73	3.41
COR	15.09	97.98	97.99	0.01	22.06	98.83	98.88	0.05
DEM	10.29	99.63	99.88	0.25	18.83	99.99	99.99	0
HEX	2.65	90.96	98.62	7.66	1.18	95.32	99.38	4.06
PTU	1.75	90.84	99.43	8.59	0.24	85.71	99.93	14.22
SOC	4.64	87.00	89.95	2.95	4.57	84.08	88.29	4.21

Table L5: Sensitivity to an assumed lower depth limit for bottom trawling of estimated percentage of habitat (ROC post accounting method) or abundance (using a power curve relationship between model HSI and abundance) of each modelled VME indicator taxon within the North Louisville Ridge FMA and outside the areas open to fishing.

Taxon	ROC				Power			
	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff
ERO	<0.01	<0.00	100.00	100.00	0.02	76.69	94.59	17.90
GDU	1.87	70.41	73.11	2.70	1.76	77.73	90.11	12.38
MOC	0.71	60.65	100.00	39.35	0.73	71.27	98.37	27.10
SVA	7.95	74.85	85.00	10.15	45.66	76.65	79.84	3.19
COB	4.7	81.9	86.89	4.99	3.34	80.51	87.23	6.72
COR	5.57	75.65	82.95	7.30	4.86	78.60	82.91	4.31
DEM	0.99	77.67	90.47	12.80	0.22	45.95	48.33	2.38
HEX	1.61	80.32	96.95	16.63	1.63	82.07	98.7	16.63
PTU	0.46	80.26	95.46	15.20	0.04	78.68	96.43	17.75
SOC	2.48	79.22	91.87	12.65	2.25	80.88	92.33	11.45

Table L6: Sensitivity to an assumed lower depth limit for bottom trawling of estimated percentage of habitat (ROC post accounting method) or abundance (using a power curve relationship between model HSI and abundance) of each modelled VME indicator taxon within the Central Louisville Ridge FMA and outside the areas open to fishing.

Taxon	ROC				Power			
	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff
ERO	<0.01	0	100.00	100.00	0.01	58.69	90.19	31.50
GDU	5.87	45.27	69.68	24.41	1.66	53.86	79.83	25.97
MOC	0.25	76.09	100.00	23.91	0.42	69.58	98.31	28.73
SVA	6.24	55.93	82.49	26.56	25.06	13.18	29.82	16.64
COB	2.13	54.66	74.12	19.46	1.64	55.98	74.78	18.80
COR	1.96	24.11	60.19	36.08	1.94	20.31	48.63	28.32
DEM	0.05	26.83	48.78	21.95	<0.01	13.67	23.82	10.15
HEX	0.52	61.69	91.82	30.13	0.31	60.50	92.24	31.74
PTU	0.05	67.83	98.55	30.72	<0.01	85.88	99.49	13.61
SOC	1.14	63.94	88.49	24.55	0.95	63.46	87.59	24.13

Table L7: Sensitivity to an assumed lower depth limit for bottom trawling of estimated percentage of habitat (ROC post accounting method) or abundance (using a power curve relationship between model HSI and abundance) of each modelled VME indicator taxon within the South Louisville Ridge FMA and outside the areas open to fishing.

Taxon	ROC				Power			
	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff
ERO	<0.01	<0.01	<0.01	<0.01	0.01	47.26	88.84	41.58
GDU	11.97	44.30	72.70	28.40	2.60	45.65	80.23	34.58
MOC	0.33	95.88	100.00	4.12	0.63	68.99	99.35	30.36
SVA	5.41	42.40	80.29	37.89	8.52	20.31	53.39	33.08
COB	3.57	41.43	81.54	40.11	2.51	38.60	75.65	37.05
COR	0.36	13.61	87.43	73.82	0.32	18.64	91.32	72.68
DEM	<0.01	100.00	100.00	0	<0.01	81.14	89.43	8.29
HEX	0.19	63.20	99.12	35.92	0.04	66.82	99.32	32.50
PTU	0.01	67.57	100.00	32.43	<0.01	55.46	99.98	44.52
SOC	1.07	39.69	78.15	38.46	0.92	42.39	79.88	37.49

Table L8: Sensitivity to an assumed lower depth limit for bottom trawling of estimated percentage of habitat (ROC post accounting method) or abundance (using a power curve relationship between model HSI and abundance) of each modelled VME indicator taxon within the South Tasman Rise FMA and outside the areas open to fishing.

Taxon	ROC				Power			
	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff	% of taxon within region	% of taxon outside fishing areas	% of taxon outside fishing areas or >1400 m	% Difference after depth cutoff
ERO	13.05	76.93	76.93	0	14.08	74.39	74.39	0
GDU	0.02	100.00	100.00	0	6.83	97.32	97.32	0
MOC	13.39	97.89	97.89	0	10.23	97.26	97.26	0
SVA	23.56	95.86	95.86	0	0.85	99.94	99.94	0
COB	1.69	86.93	86.93	0	2.83	92.14	92.14	0
COR	14.95	93.70	93.70	0	9.72	95.12	95.12	0
DEM	0.34	100.00	100.00	0	0.02	100.00	100.00	0
HEX	0.06	100.00	100.00	0	0.02	99.26	99.26	0
PTU	6.21	100.00	100.00	0	4.45	100.00	100.00	0
SOC	15.85	97.58	97.58	0	15.79	97.18	97.18	0

No sensitivity analysis is presented for the Three Kings FMA because it contains no defined fishing areas.

Appendix L **Sensitivity analysis for of post-accounting results to different models**

Table M1: Estimated proportion of biodiversity value (calculated as the sum of predicted habitat suitability scores) outside the areas open to fishing within the Evaluated Area for the 2018 ensemble model, the 2020 ensemble model (ENS) and the 2020 random forest model (RF). All calculations conducted without naturalness (no discounting for the impacts of previous fishing).

Group	Taxon	Name	2018 Ensemble models (Georgian et al. 2019)	2020 Ensemble models	2020 Random forest models
Stony coral	ERO	*Enallopsammia rostrata*	78.96	88.27	91.07
	GDU	*Goniocorella dumosa*	86.28	87.31	91.92
	MOC	*Madrepora oculata*	79.28	93.91	94.84
	SVA	*Solenosmilia variabilis*	89.12	92.88	93.99
Other VME indicator	COB	Antipatharia	78.71	88.09	90.25
	COR	Stylasteridae	86.35	95.23	96.06
	DEM	Demospongiae	85.34	96.24	96.33
	HEX	Hexactinellida	85.99	95.24	95.37
	PTU	Pennatulacea	89.69	96.41	96.05
	SOC	Alcyonacea	84.63	93.66	94.21
Mean, all VME indicator taxa			85.12	94.15	94.71
Mean, stony corals			83.41	90.59	92.96
Mean, other VME indicator taxa			84.44	92.72	94.01