Use of geospatial data and predictive habitat models to evaluate the likelihood of presence of vulnerable marine ecosystems in the SPRFMO Area

Andrew Penney
Ministry of Fisheries, New Zealand

Introduction

United Nations General Assembly Resolution 61/105 on sustainable fisheries (UNGA 2007) provided the foundation for the bottom fishery interim measures adopted by participants to the 3rd negotiation meeting of the South Pacific Regional Fisheries Management Organisation (SPRFMO) in 2007. These instruments require participants in high-seas bottom fisheries to, *inter-alia,* conduct assessments to ascertain whether proposed fishing areas are "*known or likely*" to contain vulnerable marine ecosystems (VMEs), based on the best available scientific information. Participants are required to close such areas to bottom fishing unless conservation and management measures have been established to prevent significant adverse impacts on vulnerable marine ecosystems and the long-term sustainability of deep sea fish stocks.

There have been virtually no seabed biodiversity surveys conducted in the SPRFMO Area and the SPRFMO Scientific Working Group (SWG) has noted the lack of quantitative data on distribution of VMEs in the high seas of the South Pacific Ocean. In the absence of such data, use must be made of indicators or habitat suitability prediction models to evaluate and predict the likelihood of VMEs occurring in particular areas. This has been recognised in the draft SPRFMO Bottom Fishery Impact Assessment Standard currently under development, which contains a section on '*Indicators to Identify Vulnerable Marine Ecosystems*'. The report of the Deepwater Sub-Group at the 5th SWG meeting in November 2009 notes that "*In the absence of specific information, the indicators listed in this section should form the scientific basis for identifying areas likely to contain VMEs*".

Over the past few years there have been substantial improvements in the oceanographic datasets and predictive modelling techniques for predicting habitat suitability for vulnerable marine species, resulting in the recent publication of global habitat suitability models and predicted distribution maps for species such as scleractinian (stony) corals. The purpose of this paper is to describe some of the currently available geospatial datasets of most use to evaluating the likelihood of occurrence of VMEs in the SPRFMO Area.

Available Geospatial Datasets for the SPRFMO Area

Pending the drafting of a detailed standard for SPRFMO bottom fishery impact assessments, an interim *Benthic Assessment Framework* was adopted at the 4th SPRFMO meeting to guide bottom fishery impact assessments conducted under the SPRFMO bottom fishing interim measures. This framework referred to a number of geospatial data sets of potential relevance to evaluating the likelihood of occurrence of VMEs in the SPRFMO Area. These included the distribution of predicted seamounts by Kitchingman & Lai (2004) and the distribution of seamounts considered to have suitable habitat for stony corals based on environmental niche factor analysis of global coral occurrence data by Clark *et al*. (2006).

At that time, the General Bathymetric Chart of the Oceans provided global bathymetric data at 1° resolution that could also be used to evaluate seabed depth range, steepness and profile as indicators of suitable habitat for benthic communities, as was done by Penney *et al*. (2009) in evaluating the topography of fishing areas constituting the New Zealand bottom trawl fishing footprint in the SPRFMO Area (Ministry of Fisheries 2008).

- ***GEBCO 30 Arc-Second Bathymetric Data***

In 2009, GEBCO released an updated, higher resolution, global 30 arc-second bathymetric dataset. In addition to providing four times the resolution of the 1° data, additional bathymetric data have been incorporated and improvements have been made to gridding algorithms to correct known gridding artefacts. These improvements have corrected some errors in position and topography of seabed features and provide an improved data set with which to evaluate seabed depth range, steepness, profile and topography, and to correctly identify and position features such as seamounts, ridges and canyons which may support VMEs. A colour shaded map of the GEBCO 30 arc-second data for the South Pacific Ocean is shown in Figure 1.

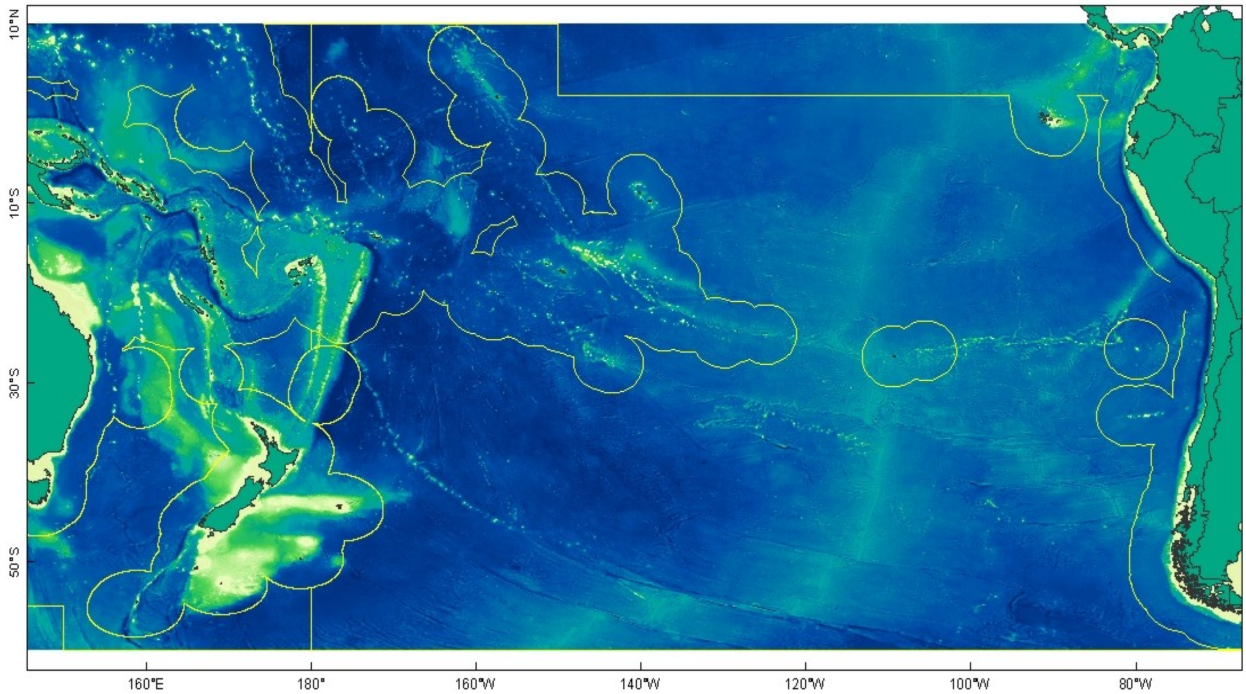

Figure 1. Colour-shaded GEBCO 30 arc-second resolution bathymetric raster data for the South Pacific Ocean. The SPRFMO Area is outlined in yellow.

- ***Kitchingman & Lai (2004) Predicted Seamounts***

Seamounts are identified in the *FAO International Guidelines for the Management of Deep-Sea Fisheries in the High Seas* (FAO 2009) as topographic features that potentially support vulnerable marine species or communities. Kitchingman & Lai (2004) used satellite sea-surface altimetry data to predict the position of seamounts with a height of 1000m or more, generating a global geospatial database of some 14,287 predicted seamounts, with estimates of summit depth for each seamount.

Recent predictive habitat modelling work (e.g. Clark *et al*. 2006, Tittensor *et al*. 2009, 2010, Davies & Guinotte in prep.) has shown that depth is a key factor determining seabed suitability as a habitat for benthic VME species such as stony corals, largely because depth is often related to other important factors such as temperature, dissolved oxygen content and aragonite saturation. Where no other information is available, seamount summit depth is therefore a reasonable indicator of comparative habitat suitability between a group of adjacent seamounts, with shallower summits tending to be more suitable as habitat for coral species than deeper summits.

- ***Allain et al. (2008) Validated Seamounts***

The Kitchingman & Lai (2004) predicted seamounts data set has been found to incorrectly predict the existence of some seamounts, and to have some inaccuracies in predicted seamount positions. Most of the seamounts in the south Pacific region lie within the EEZs of countries in the region, and so are not particularly relevant to impact assessments for the high-seas SPRFMO Area. Allain *et al.* (2008) therefore cross-checked 20 different data sets to validate seamount existence and position, producing a database of 1,504 validated seamounts occurring within the SPRFMO Area itself. Figure 2 shows a map of these validated seamounts classified by summit depth, as an indicator of suitability for VME species. This shows that shallower (and likely more suitable as coral habitat) seamounts in the SPRFMO Area are concentrated along the West Norfolk Ridge, Louisville Ridge, Foundation Seamounts chain and the Nasca and Salas y Gomez Ridges.

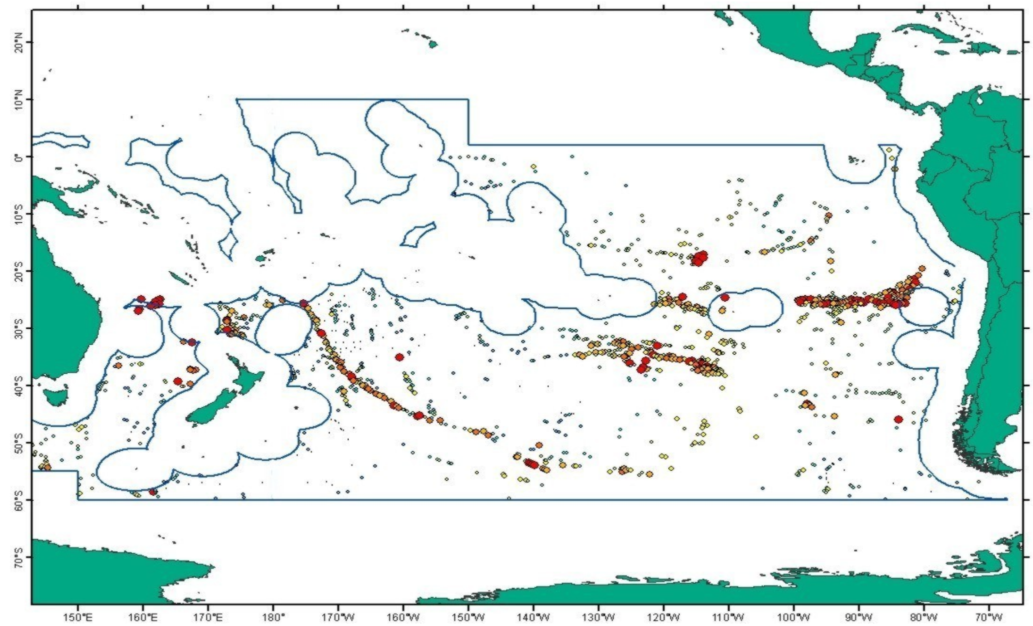

Figure 2. Map of validated seamounts within the SPRFMO Area classified by summit depth from deeper than 5,000m (small, blue circles) to shallower than 500m (large red circles) as an indicator of potential habitat suitability for VME species, with shallower summits being more suitable than deeper summits (Allain *et al.* 2008). The SPRFMO Area is outlined in blue.

- ***Clark et al. (2006) Seamount Habitat Suitability***

While depth is an important factor in determining habitat suitability for VME species such as corals, it is only one of many factors, including latitude, temperature, salinity, dissolved oxygen, CO_2, alkalinity, aragonite saturation, productivity, seabed geo-morphology and currents, that determine habitat suitability for VME species. Predictive modelling approaches have been developed and refined over the past decade to use a variety of such factors to predict habitat suitability for species such as stony corals, for which a fair amount of occurrence data exist to calibrate the models.

Clark *et al.* (2006) used environmental niche factor analysis (ENFA - Hirzel *et al.* 2002) to predict the stony coral habitat suitability of seamounts from the Kitchingman & Lai (2004) predicted seamounts dataset that occur in the south Pacific Ocean. Figure 3 shows the resulting map of seamounts from Clark *et al.* (2006) classified by predicted habitat suitability for coldwater corals. Comparison between Figures 3 and 4 shows that some of the seamounts whose summits may be at suitable (shallower) depths for corals, are not necessarily suitable in terms of other factors used in the ENFA analysis, whereas others are more suitable than depth alone would indicate. For example, a number of the shallower seamounts along the Louisville Ridge are predicted to be only moderately suitable for coldwater corals, whereas a few specific seamounts are predicted to be highly suitable. This predictive habitat model therefore provides a method for evaluating the likelihood of occurrence of (coldwater coral) VMEs on these seamounts based on statistical modelling of a number of predictor variables, calibrated by coral occurrence data available for any part of the modelled area.

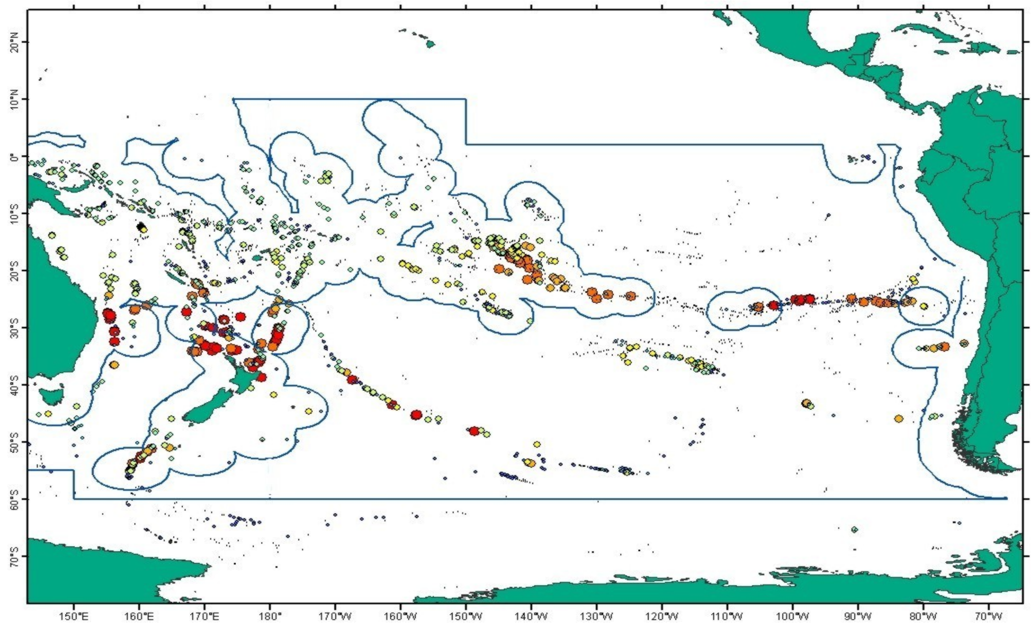

Figure 3. Map of seamounts in the South Pacific Ocean from the Kitchingman & Lai (2004) data set, classified using environmental niche factor analysis (Clark *et al.* 2006), showing predicted habitat suitability of each seamount from 0% (small, blue circles) to 100% (large, red circles). The SPRFMO Area is outlined in blue.

• ***Tittensor et al. (2009, 2010) Global Coral Habitat Suitability***

Improving on the ENFA methods developed by Hirzel *et al.* (2002), methods such as maximum entropy analysis (Maxent - Phillips *et al.* 2006) have improved the precision and robustness of habitat suitability predictions. Tittensor *et al.* (2009, 2010) applied a Maxent modelling approach using a number of environmental predictor variables, including alkalinity, aragonite saturation, depth, oxygen, productivity, nitrates, salinity, CO_2, temperature and currents, to predict global habitat suitability for scleractinian (stony) corals. The model was calibrated using a stony coral database derived from records compiled by Rogers *et al.* (2007), Hall-Spencer *et al.* (2007) and a database of *Lophelia pertusa* records compiled by the United Nations Environment Programme – World Conservation Monitoring Centre (UNEP-WCMC).

This habitat model was used to generate global geospatial stony coral predicted suitability layers for 250m depth strata at 1° spatial resolution. Figure 4 shows part of the global map of predicted habitat suitability of seabed for stony corals in the depth range 1,000m to 1,250m (Tittensor *et al.* 2010). This identifies the north Atlantic and the area around New Zealand and eastern Australia as areas of particularly high predicted suitability for stony corals, and therefore with particularly high likelihood of occurrence of VMEs.

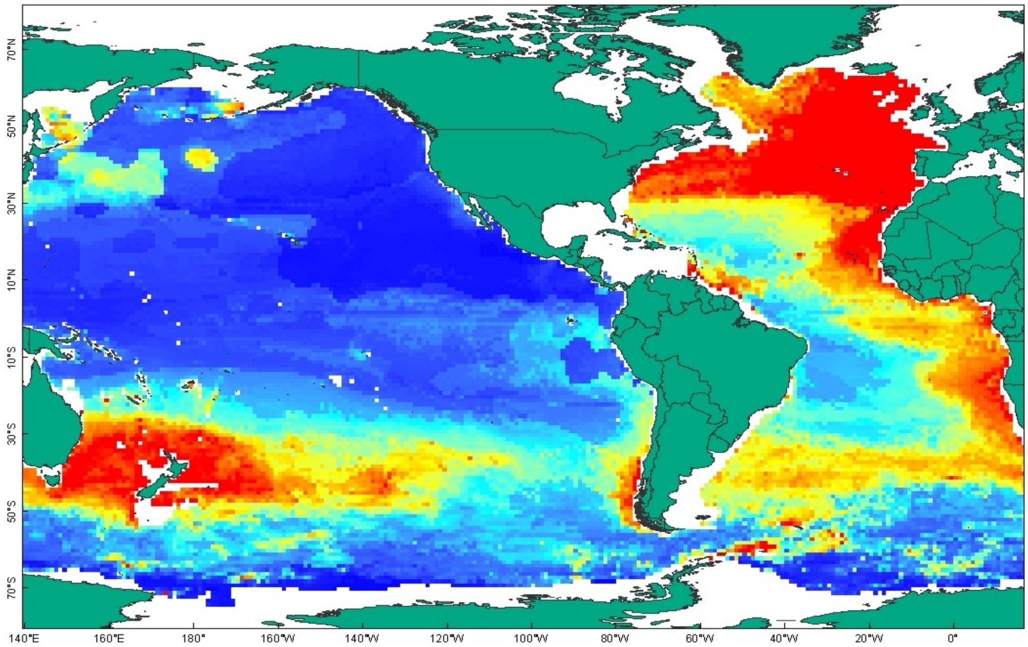

Figure 4. Predicted 1° global scleractinian coral habitat suitability (dark blue=0 to dark red=1) in the 1,000m to 1,250m depth range, from Tittensor *et al*. (2010).

Comparative maps of predicted coral suitability for different 250m depth strata show the strong effect that depth (and depth-related variables) has on predicted habitat suitability. Figures 5 and 6 show comparative maps of predicted coral habitat suitability from Tittensor *et al*. (2010) for the 750m - 1,000m and the 1,750m - 2,000m depth ranges in the SPRFMO Area. Whereas highly suitable coral habitat conditions extend from Australia eastwards to about 130° W at 750m-1,000m depth, there is almost no habitat exceeding 50% predicted coral habitat suitability in the SPRFMO Area at 1,750 - 2,000m depth.

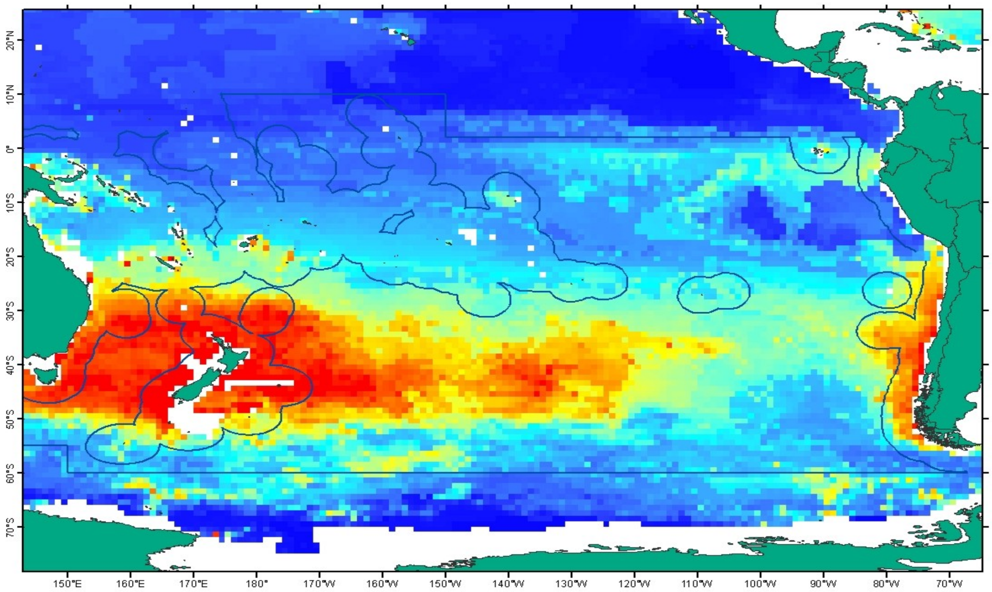

Figure 5. Predicted 1° global scleractinian coral habitat suitability (dark blue=0 to dark red=1) in the 750m to 1,000m depth range, from Tittensor *et al*. (2010). The SPRFMO Area is outlined in blue.

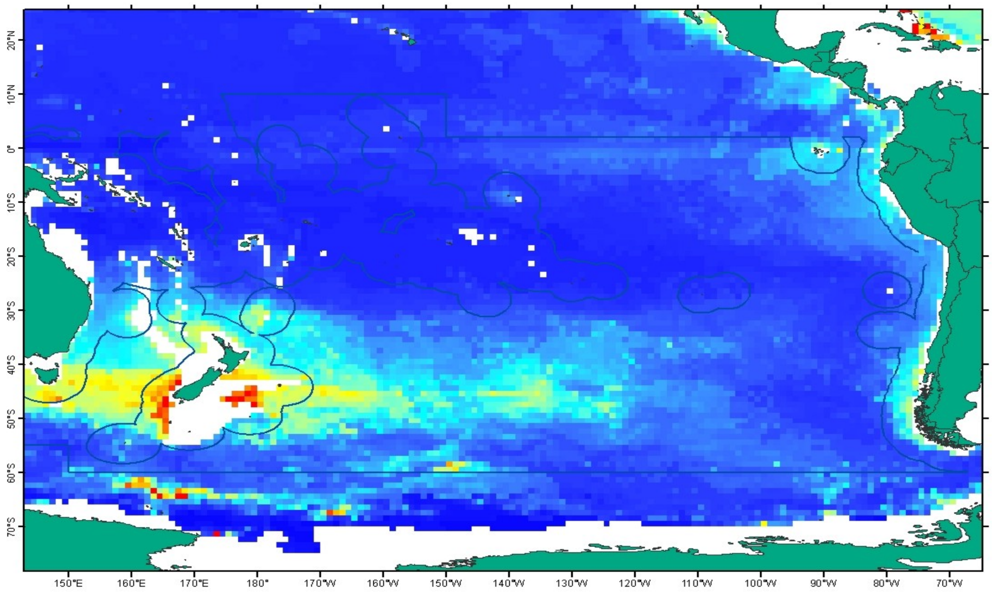

Figure 6. Predicted 1° global scleractinian coral habitat suitability (dark blue=0 to dark red=1) in the 1,750m to 2,000m depth range, from Tittensor *et al.* (2010). The SPRFMO Area is outlined in blue.

• ***Tittensor et al. (2009) Seamount Habitat Suitability***

These global coral habitat suitability layers can be used to predict the suitability of seabed, such as the summits of seamounts, within 250m depth x 1° spatial strata. Similar to the ENFA-based seamount classification of Clark *et al.* (2006), Tittensor *et al.* (2009) used their Maxent global scleractinian habitat suitability models to predict the suitability of the Kitchingman & Lai (2004) seamounts based on seamount summit depths.

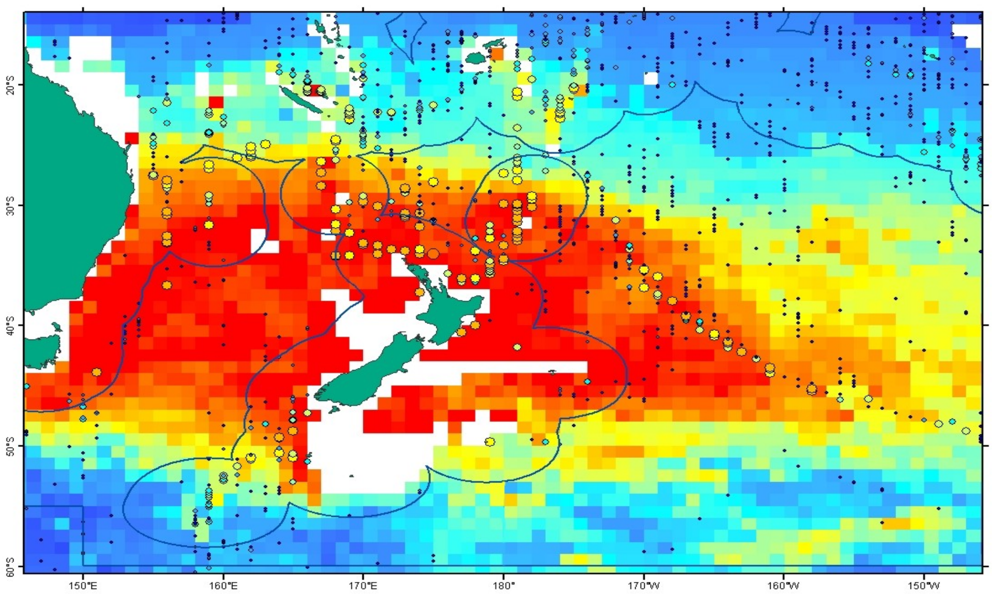

Figure 7. Predicted stony coral habitat suitability in the 1,000m to 1,250m depth range in the New Zealand region (data from Tittensor *et al.* 2010), overlaid with the predicted suitability of seamounts in the region (data Tittensor *et al.* 2009) (small dark blue circles = 0 to large dark red circles = 1). The SPRFMO Area is outlined in blue.

Figure 7 shows the map of predicted habitat suitability from Tittensor *et al*. (2010) in the 1,000m – 1,250m depth range around New Zealand, overlaid with the Kitchingman & Lai (2004) seamounts classified by Tittensor *et al*. (2009) in terms of their individual stony coral suitability. (Note that seamount positions have been aligned with 1° longitude lines in this modelling exercise.) This classification provides an index, like that of Clark *et al*. (2006), of the likelihood of occurrence of (stony coral) VMEs on the seamounts concerned.

Evaluation of Likelihood of Occurrence of VMEs

In the absence of data on actual seabed biodiversity and benthic community composition, predictive habitat models such as those described above provide methods for evaluating the likelihood of occurrence of VMEs in a particular area. As was done for seamount summits by Tittensor *et al*. (2009), the suitability-by-depth layers can be used to classify the predicted suitability of seabed at any depth. As an example, Figure 8 shows the result of classifying the GEBCO 30 arc-second bathymetric data in the area northwest of New Zealand using the suitability predictions of Tittensor *et al*. (2010).

This predicted seabed coral suitability map was generated by stratifying the GEBCO 30 arc-second bathymetric data points for the area shown into 250m depth strata. The respective Tittensor *et al*. (2010) predicted suitability values by 1° block and 250m depth stratum were then applied to each bathymetric data point using ArcView®. Missing predicted suitability values for a few of the 1° x 250m depth strata (presumably where the model was told that seabed did not occur in that depth in that area) were extrapolated using the average of neighbouring 1° blocks in that depth stratum. Tittensor *et al*. (2010) did not provide suitability predictions for depths exceeding 2,500m. Predicted suitability in the 2,250m - 2,500m depth range in this area is generally predicted to be between 1% and 5%, and continuing to decline. For the purposes of this example analysis, a value of 1% was assumed for depths exceeding 2,500m (the dark blue areas in Figure 8), given that much of this seabed lies at the depth of the abyssal plain, below 4,000m depth.

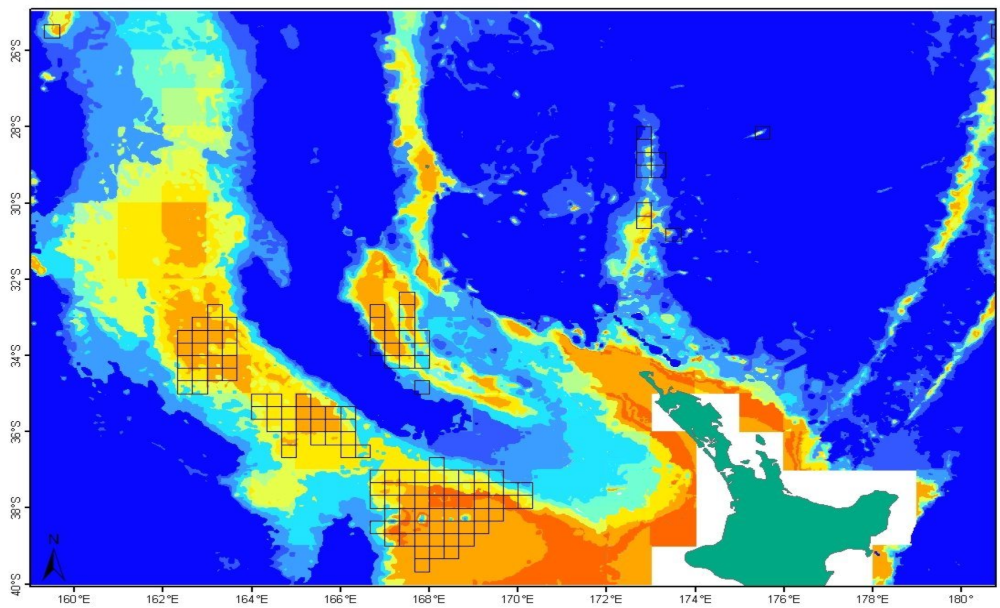

Figure 8. Map of predicted scleractinian coral habitat suitability in the Challenger Plateau, Lord Howe Rise, West Norfolk Ridge and Three Kings Ridge fishing areas northwest of New Zealand, using the habitat suitability of Tittensor *et al*. (2010) to classify the predicted habitat suitability of GEBCO 30 arc-second bathymetric data. The 20 minute blocks constituting the New Zealand bottom trawl fishing footprint in this area are shown.

Seabed suitability maps such as that shown in Figure 8 can be used to evaluate the average seabed habitat suitability in any particular area of interest. For example, of direct relevance to conducting impact assessments for proposed bottom fishing operations in the SPRFMO Area, such seabed suitability maps can be used to evaluate the average coral habitat suitability, and therefore the likelihood of presence of such VMEs, in any of the 20-minute blocks constituting the SPRFMO bottom fishing footprint.

As an example of such an analysis, Figure 9 is an extract from the overall seabed habitat suitability map in Figure 8, showing detail of the Tittensor *et al*. (2010) predicted seabed habitat suitability within each of the 20-minute blocks constituting the New Zealand SPRFMO bottom trawl fishing footprint in the Lord Howe Rise, Northwest Challenger Plateau and West Norfolk Ridge fishing areas. The 1600 habitat-suitability-classified GEBCO 30 arc-second depth points within each block can then be averaged to provide an average predicted stony coral habitat suitability index for each footprint block.

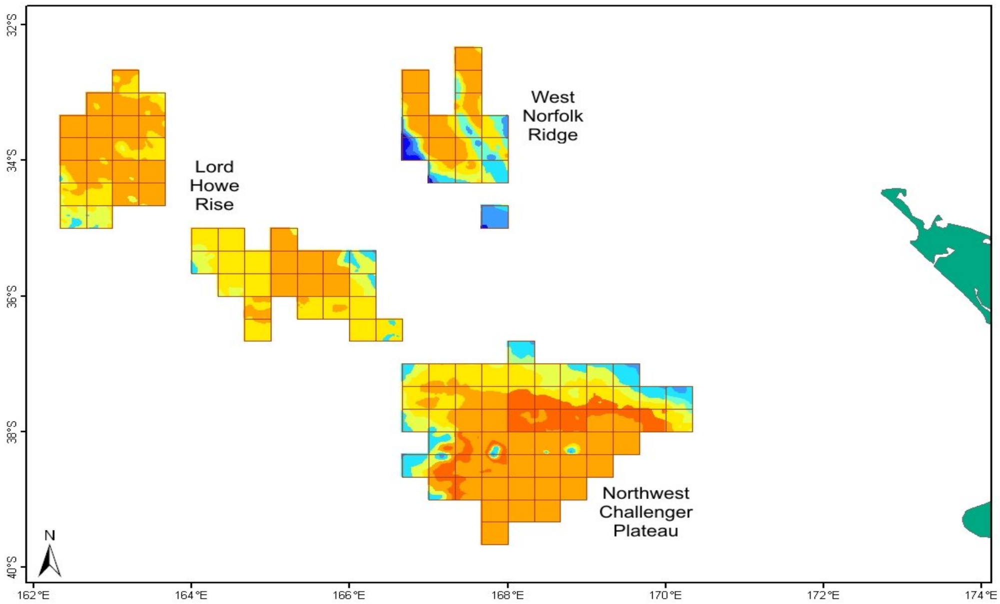

Figure 9. Detail of the Tittensor *et al*. (2010) predicted scleractinian coral habitat suitability within the New Zealand bottom trawl footprint blocks in the Lord Howe Rise, Northwest Challenger Plateau and West Norfolk Ridge bottom trawl fishing footprint areas, extracted from the overall seabed habitat suitability map shown in Figure 8.

The strong effect of depth on predicted coral habitat suitability has already been noted. Stony coral habitat suitability declines rapidly as depth increases, particularly at depths exceeding 1500m. This effect of depth is clearly evident in the predicted coral habitat suitability map for the area northwest of New Zealand shown in Figure 8, which resembles the bathymetric chart for this area.

In terms of the Tittensor *et al*. (2009, 2010) Maxent predictive models, the most suitable predicted habitat for scleractinian corals in the western SPRFMO area occurs in the depth range of 250m to 1,500m, which closely corresponds to the targeted bottom-trawl fishing depth range in these areas, which is 500m to 1,500m (Ministry of Fisheries 2008). If the usually fished depth range of 500m - 1,500m is considered to be the 'fishable depth' for this fishery, then the proportion of fishable depth in a particular area is, in fact, an accurate indicator of the predicted coral habitat suitability.

This is shown in Figure 10, in which the average Tittensor *et al.* (2010) average predicted habitat suitability values from the analysis illustrated in Figure 8 are plotted against the percentage fishable depth (defined as 500m - 1,500m) for each of the 20-minute blocks constituting the New Zealand bottom trawl fishing footprint in the SPRFMO Area: a) west (Lord Howe, Challenger, West Norfolk and Three Kings areas); and b) east (Louisville Ridge area) of New Zealand.

Particularly in areas such as the Louisville Ridge (Figure 10 b), which consists of seamount features with steep flanks and limited fishable depth surrounded by deep abyssal areas, there is a strong linear relationship between percentage fishable depth and the average habitat suitability of a particular footprint block. In such areas, across which predicted suitability is not changing rapidly with latitude or longitude, and where depth is the main determinant of habitat suitability, the percentage fishable depth is therefore a direct indicator of the likelihood of occurrence of (stony coral) VMEs in the area.

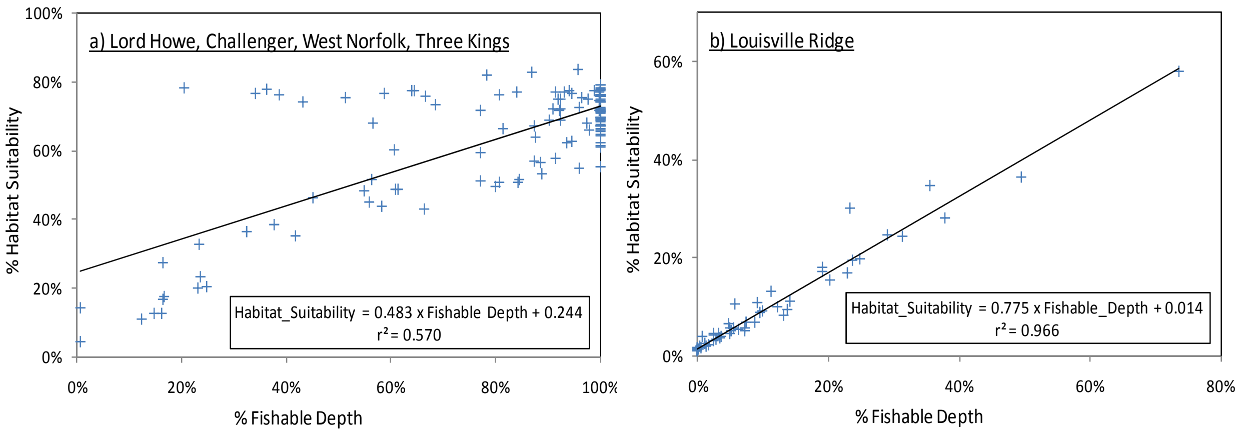

Figure 10. Relationship between predicted average coral habitat suitability (from Tittensor *et al.* 2010) and area of fishable depth (defined as the range 500m - 1,500m) within the 20 minute blocks constituting the New Zealand bottom trawl footprint in the a) Lord Howe / Challenger / West Norfolk / Three Kings Ridge area, and b) along the Louisville Ridge.

Discussion and Recommendations

Access to higher resolution oceanographic geospatial data sets, and the development of improved predictive techniques to model dependant relationships between environmental predictor variables and the distribution of benthic species, have provided us with methods for predicting the occurrence of vulnerable benthic species across large areas for which benthic community composition data are sparse. In the absence of widespread data on seabed biodiversity, predictive modelling provides the most cost-effective option for evaluating the likelihood of occurrence of VMEs in areas of concern.

Access to predicted average habitat suitability indices across large areas now even make it feasible to conduct quantitative risk assessments, similar to the Level 2 assessments described in the *Ecological Risk Assessment for Effects of Fishing* (ERAEF - Hobday *et al.* 2007), using predicted habitat suitability values as integrated indicators of '*productivity*', i.e. likelihood of VMEs, by area. Some measure of historical or intended fishing effort could provide indices of '*susceptibility*' by area. These sorts of predictive approaches should therefore form an integral component of every risk / impact assessment for any bottom fishery in the SPRFMO Area.

There remain, however, a number of limitations and deficiencies in the currently available geospatial data, and in the existing predictive habitat models:

- Depth is clearly one of the most important variables determining seabed suitability for benthic species such as stony corals, either directly, or as an alias for factors such as temperature, dissolved oxygen concentration, alkalinity, aragonite saturation or productivity. There are still problems with the GEBCO 30-arc-second bathymetric data for parts of the SPRFMO Area. For example, the GEBCO data indicate that there is no seabed shallower than 1,500m in 20 of the 66 x 20-minute blocks constituting the New Zealand bottom trawl fishing footprint along the Louisville Ridge, whereas fishing effort data confirm the existence of seabed at fishable depth (shallower than 1,500m) in all of those blocks.
- Current global habitat prediction models suffer from the necessary limitation of moderate resolution (such as the 1° spatial resolution of the Tittensor *et al*. (2009, 2010) Maxent models), to make calculations tractable at a global scale. This results in the same value for predicted suitability across large areas. For example, each 1° grid square in the Tittensor *et al*. (2009, 2010) models could potentially cover nine 20-minute SPRFMO fishing footprint blocks.
- Most predictive habitat models, particularly the global models described in this paper, have focussed on the scleractinian corals, for which the greatest number of occurrence records, samples and photographic images exist. However, the FAO Deep-Sea Guidelines (FAO 2009) describe characteristics, and provide examples, of numerous species which may potentially constitute VMEs. While stony corals are likely to form significant components of SPRFMO VME communities on higher-profile, rocky seabed, benthic communities on other geo-morphological seabed types could be dominated by sponges, gorgonians or soft corals.
- The reliability of all habitat prediction models based on environmental predictor variables is dependent on the availability of data on actual occurrence of benthic species with which to calibrate the models. There are currently very few such data available for the SPRFMO Area.

The following recommendations are made to address the limitations identified above:

- Collection and provision of accurate bathymetric data should be a requirement of all bottom fishing operations conducted in the SPRFMO Area. All such data should be used to improve the gridded bathymetric data for the Area. All research cruises in the SPRFMO Area should also collect accurate bathymetric data, including high resolution multi-beam swath bathymetry for areas of particular interest or concern.
- Access to high-resolution swath bathymetry and seabed photographic images is increasingly confirming that habitat suitability, and benthic community composition, can change substantially over relatively short distances. Higher resolution predictive models are required to correctly represent these finer spatial changes. Such models should be specifically developed for the SPRFMO Area, or for parts of the SPRFMO Area within which bottom fishing has occurred, or will occur.
- Habitat suitability models developed for predicting the likelihood of occurrence of VMEs in the SPRFMO Area should be calibrated for all of the taxa used in the SPRFMO VME encounter protocols, and not just for stony corals.
- Models developed specifically for the SPRFMO Area should be supported by collection of benthic community composition samples or photographic images in selected areas, particularly if these models are to be calibrated for a wider range of species than stony corals. Given the ship's time expense of collecting such data, options for collaborative research cruises need to be explored.

There are already higher resolution global habitat prediction models under development. Figure 11 provides an example map from a global high resolution (1 km grid) predicted scleractinian habitat suitability model, showing the distribution of predicted stony coral suitability in the area northwest of New Zealand, in relation to the New Zealand bottom trawl footprint in this area (provided by Davies & Guinotte, in prep, pers comm). Comparison of this higher resolution map with Figure 8 shows the improved detail and spatial resolution of predicted suitability provided by modelling at this resolution.

Emphasis needs to be placed over the next few years on supporting the development of high resolution predictive habitat models such as these, specifically for the SPRFMO Area, and calibrated for the main taxa considered to contribute to VMEs in the SPRFMO Area.

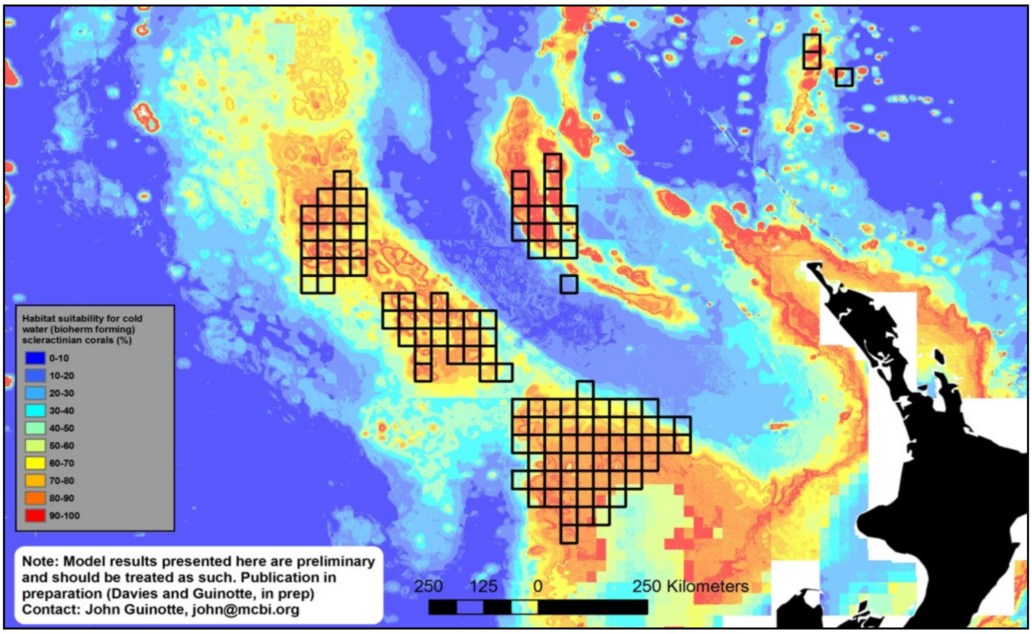

Figure 11. Extract from a global high resolution (1 km grid) predicted scleractinian habitat suitability map, showing the distribution of predicted suitability in the northern Tasman Sea area in relation to the bottom trawl footprint in this area (provided by Davies & Guinotte, in prep).

References

Allain, V., J-A. Kerandel, S. Andréfouët, F. Magron, M.R. Clark, D.S. Kirby, F.E. Muller-Karger, 2008. Enhanced seamount location database for the western and central Pacific Ocean: Screening and cross-checking of 20 existing datasets. *Deep-Sea Research I*, 55: 1035– 1047.

Clark, M.R., D. Tittensor, A.D. Rogers, P. Brewin, T. Schlacher, A. Rowden, K. Stocks and M. Consalvey, 2006. Seamounts, deep-sea corals and fisheries: vulnerability of deep-sea corals to fishing on seamounts beyond areas of national jurisdiction. Census of Marine Life on Seamounts (CenSeam) Data Analysis Working Group, UNEP-WCMC, Cambridge, UK, 84 pp.

FAO, 2009. International guidelines for the management of deep-sea fisheries in the high seas. Food and Agriculture Organisation of the United Nations, Rome, 73 pp.

Hall-Spencer J., A.D. Rogers, J. Davies and A. Foggo, 2007. Deep-sea coral distribution on seamounts, oceanic islands and continental slopes in the Northeast Atlantic. In: George R.Y., Cairns S.D. (Eds), Conservation and Adaptive Management of Seamount and Deep-Sea Coral Ecosystems. University of Miami: 135–146.

Hirzel, A.H., J. Hausser, D. Chessel and N. Perrin (2002). Ecological-niche factor analysis: how to compute habitat-suitability maps without absence data? *Ecology*, 83: 2027 - 2036.

Hobday, A.J., A. Smith, H. Webb, R. Daley, S. Wayte, C. Bulman, J. Dowdney, A. Williams, M. Sporcic, J. Dambacher, M. Fuller and T. Walker, 2007. Ecological Risk Assessment for Effects of Fishing. Report R04/1072 for the Australian Fisheries Management Authority, Canberra, 174 pp.

Kitchingman A. and S. Lai, 2004. Inferences on potential seamount locations from mid-resolution bathymetric data. In: *Seamounts: Biodiversity and Fisheries* (eds T. Morato and D. Pauly) UBC Fisheries Centre, 78, p. 261, Vancouver, British Columbia, Canada.

Ministry of Fisheries, 2008. Bottom Fishery Impact Assessment: Bottom Fishing Activities by New Zealand Vessels Fishing in the High Seas in the SPRFMO Area during 2008 and 2009. Report to SPRFMO, 102 pp.

Penney, A.J., S.J. Parker and J.H. Brown, 2009. Protection measures implemented by New Zealand for vulnerable marine ecosystems in the South Pacific Ocean. *Mar. Ecol. Prog. Ser.*, 397: 341 – 354.

Phillips, S.J., R.P. Anderson and R.E. Schapire, 2006. Maximum entropy modelling of species geographic distributions. *Ecological Modelling*, 190, 231–259.

Rogers A.D., A. Baco, H.J. Griffiths and J.M. Hall-Spencer, 2007. Corals on seamounts. In: Pitcher A., Morato T., Hart P.J.B., Clark M.R., Haggan N., Santos R.S. (Eds), Seamounts: Ecology, Fisheries and Conservation. *Fisheries and Aquatic Resource Series,* Blackwell Scientific, Oxford: 141–169.

Tittensor, D.P., A.R. Baco, P.E. Brewin, M.R. Clark, M. Consalvey, J. Hall-Spencer, A.A. Rowden, T. Schlacher, K.I. Stocks and A.D. Rogers 2009. Predicting global habitat suitability for stony corals on seamounts. *J. Biogeogr.,* 36: 1111–1128.

Tittensor, D.P., A.R. Baco, J.M. Hall-Spencer, J.C. Orr and A.D. Rogers, 2010. Seamounts as refugia from ocean acidification for cold-water stony corals. *Mar. Ecol.* (in press)

UN General Assembly, 2007. Resolution 61/105 Sustainable fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and related instruments. UNGA A/RES/61/105, 21pp.