Guidance for the use of decision-support tools for identifying optimal areas for biodiversity conservation

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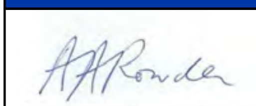	Reviewed by:	Ashley Rowden
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Executive summary

The Department of Conservation (DOC) contracted NIWA to develop a decision-support tool approach to identifying optimal areas for biodiversity conservation under DOC Investigation no. 4758. This approach integrated datasets developed during this investigation, and from DOC investigation no. 4735 (collating key ecological areas datasets), no. 4757 (new broad-scale marine habitat classification system) and no. 4759 (evaluating and updating key ecological areas).

Here we summarise the Pātaka Tohutao, the 'Cookbook' of steps and decisions, to inform the use of decision-support tools for spatial conservation prioritisation to support decision making with respect to marine protected area network design and marine spatial planning. The Pātaka Tohutao details key steps related to the use of available predictive models of taxa distributional patterns, the use of point records and polygon datasets for evaluating the location of areas of importance for key ecological criteria, and the incorporation of uncertainty and overlap in these underpinning data layers. Seven steps where intermediate decisions need to be taken are detailed, including:

1. how to address knowledge gaps, particularly in spatial data coverage, on evaluating spatial priorities for biodiversity conservation;
2. what is the scale for prioritisations, and how to balance both national and regional priorities for biodiversity conservation;
3. how should predictive models of species distributions be utilised, including differing spatial priorities between taxa groups, and the inclusion of uncertainty in these predictive models;
4. how to include key ecological area criteria layers, particularly those represented by point and polygon records rather than comprehensive and/or contiguous spatial layers;
5. can habitat classifications be used as proxies for biodiversity in areas with poor spatial coverage;
6. should both positive (e.g., protected area status) and negative (e.g., threats, stressors) impacts on the condition of biodiversity be included in conservation prioritisations;
7. what approaches should be used to integrate multiple, diverse data types into comprehensive conservation prioritisations.

These steps to using spatial conservation prioritisation software are discussed within the context of available Aotearoa New Zealand data, information gaps, objectives for marine conservation planning, and their ability to support decision making underpinning national and international conservation policies and targets.

1 Introduction

Section 1: Key messages

- NZ has both national and international obligations to protect the marine environment, with several agreements setting clear targets for the proportion of the marine environment to be protected.
- Systematic conservation planning software (e.g., Zonation) based on quantitative spatial analyses can be used to synthesise extensive datasets from diverse origins and have been used for spatial planning extensively both internationally and nationally.
- The software Zonation has a wide range of features that can be used to represent a range of decision points that managers face during marine spatial planning processes. Such flexibility makes Zonation an ideal tool for stakeholder engagement.

Aotearoa New Zealand's oceans are a global hotspot for marine biodiversity (Gordon et al. 2010). New Zealand's EEZ is the fourth largest national EEZ, comprising over 4 million km^2, spanning 30 degrees of latitude, and covering depths ranging from shallow coastal and estuarine ecosystems to deep (10 km) ocean trenches (Figure 1-1). New Zealand's marine fauna and flora have an exceptionally high level of endemism (over 50%) for a number taxonomic groups including sponges, molluscs, ascidians and bryozoans, amongst others (Gordon et al. 2010).

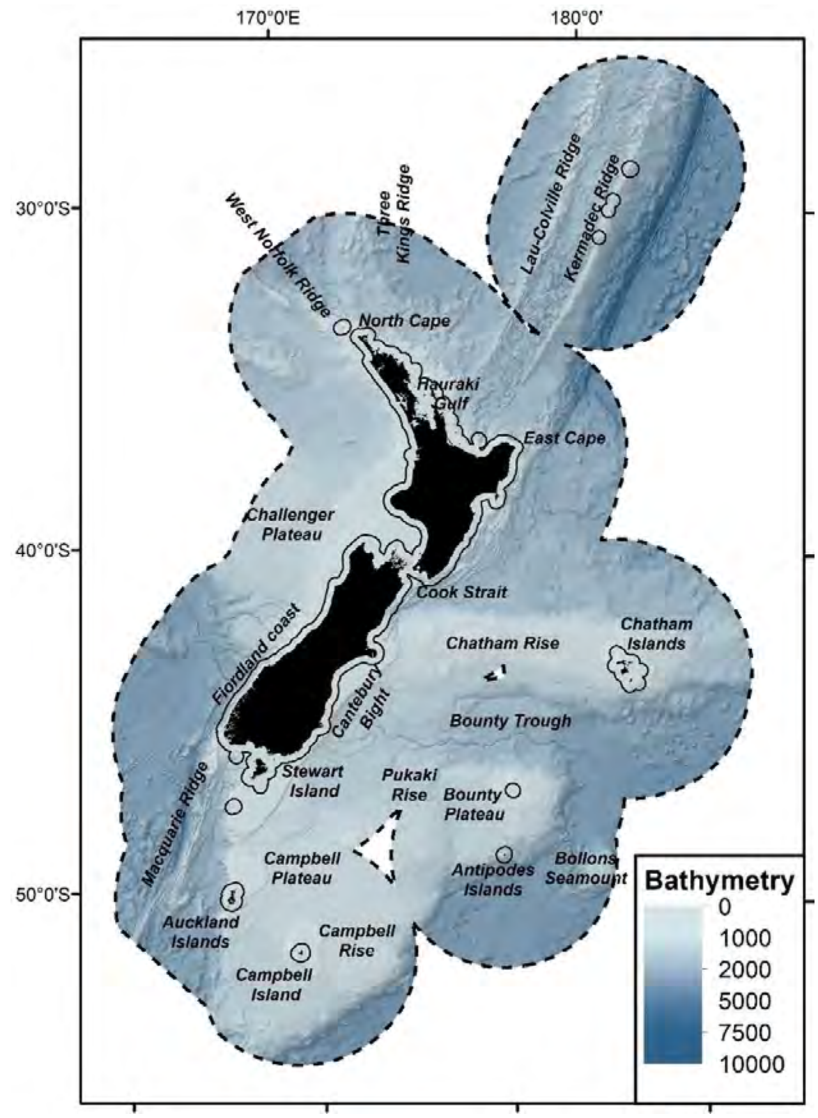

Figure 1-1: The NZ marine environment. An illustration of the NZ marine environment and the major geographic features referred to in this report.

Aotearoa New Zealand has both national and international obligations with respect to the protection of these ocean ecosystems. Under the Convention on Biological Diversity, Aotearoa New Zealand is committed to Aichi Target 11 which states that "*By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes*." New post-2020 international biodiversity targets are currently being negotiated.

The United Nations Sustainable Development Goals, which New Zealand is also committed to, likewise include a target of conserving at least 10 per cent of coastal and marine areas.

The recently released Te Mana o te Taiao – Aotearoa New Zealand Biodiversity Strategy (2020) provides revised national guidance and short, medium, and longer-term goals for the implementation of marine protected areas. Objective 6 states that "*Ecosystems and species are protected, restored, resilient and connected from mountain tops to ocean depths*". Goals with respect to marine protection include Goal 10.6.1 "*a protection standard for coastal and marine ecosystems established and implementation underway*" by 2025; Goal 10.6.2 "*Significant progress made in establishing an effective network of marine protected areas and other protection tools*" by 2030; and Goal 10.6.3 "*An effective network of marine protected areas and other tools, including marine and coastal ecosystems of high biodiversity value is established and is meeting the agreed protection standard*" by 2035.

The Marine Protected Areas Policy and Implementation Plan was developed in order to "*protect marine biodiversity by establishing a network of MPAs that is comprehensive and representative of New Zealand's marine habitats and ecosystems*" (Department of Conservation and Ministry of Fisheries 2005, Ministry of Fisheries and Department of Conservation 2008). The policy covers Aotearoa New Zealand's entire marine environment including the Territorial Sea (the coast out to 12 nm), and the EEZ (12 to 200 nm). The policy includes design principles to ensure representativeness through protection of "*the full range of marine habitats and ecosystems*" as well as those that are rare, distinctive or internationally or nationally important, within each biogeographic region (Department of Conservation and Ministry of Fisheries 2005). Due to the absence of comprehensive data on habitats or species, the policy provided guidance for biophysical surrogates through habitat classifications derived from environmental layers. A coastal habitat classification was developed for depths <200 m, based primarily on variations in depth, exposure and sediment type. The Marine Environments Classification was proposed for the remainder of the EEZ (Ministry of Fisheries and Department of Conservation 2008, Department of Conservation and Ministry of Fisheries 2011, Snelder et al. 2006).

DOC has a current research programme focussed on developing an improved, planned approach to marine protection. This project (Investigation no. 4758) provides spatial prioritisation guidance for identifying optimal areas for protection of marine biodiversity and brings together information collated or developed as part of this and prior DOC investigations. This project complements concurrent work that has developed a new broad-scale marine habitat classification system for New Zealand (Investigation no. 4757, Stephenson et al. 2020b) and has acquired and evaluated the adequacy of layers to inform key ecological criteria (Investigation no. 4759: Lundquist et al. 2020a, Investigation no. 4735: Stephenson et al. 2018b). Together datasets from these projects can be used within transparent, decision-support approaches to inform the process of identifying priority areas that are likely to make the largest contribution to the representation of biodiversity and key ecological areas. Procedural guidance on how to integrate the diverse and extensive datasets will be highly valuable for informing future marine protection decision-making processes and reporting.

Quantitative methods and computational tools for spatial conservation prioritisation (e.g., Zonation: Moilanen et al. 2009, 2014; Marxan: Ball et al. 2009) have been developed in recent decades to allow decision making to balance biodiversity datasets against perceived costs to resource users in selecting optimal areas for biodiversity management.

Zonation has previously been used in Aotearoa New Zealand for assessing the effectiveness of bottom fisheries closures (Benthic Protection Areas) within the New Zealand EEZ (Leathwick et al. 2008), for developing spatial management options for the protection of vulnerable marine ecosystems in the high seas around New Zealand (Rowden et al. 2019, https://www.sprfmo.int/assets/2019-Annual-Meeting/COMM-7/Report/COMM7-report-08Mar.pdf); for evaluating protection of biodiversity provided by marine spatial planning options identified by the Sea Change Tai Timu Tai Pari Hauraki Gulf stakeholder group (e.g., Lundquist et al. 2020b), for evaluating the design of MPA networks in the New Zealand Territorial Sea (Geange et al. 2017); and for informing a number of other regional, national and international spatial management processes. Socialisation and increasing familiarity of the software facilitates its use within an Aotearoa New Zealand MPA context.

The value of Zonation and other decision-support tools is in their ability to bring together extensive geospatial datasets which represent marine biodiversity features, and to use their algorithms to provide outputs that can inform selection of optimal locations that maximise biodiversity objectives (Leslie et al. 2003, Center for Ocean Solutions 2011). These tools have options to simulate typical decisions that occur during marine protected area design processes. Common options include placing higher weighting on features of particular interest for conservation such as protection of threatened species or biogenic habitats. More complex options include the ability to balance or trade-off across multiple priorities (e.g., maximising biodiversity protection while minimising impacts on existing resource users), maximising network connectivity through use of dispersal, incorporation of uncertainty in biodiversity layers such as species distribution models, and discounting of biodiversity features based on existence of threats or stressors that are likely to reduce their contributions to overall biodiversity (Ball et al. 2009, Moilanen et al. 2014).

These decision-support tools have been used within a diversity of international marine protected area and marine spatial planning processes, and provide a useful service in generating a suite of suitable options for biodiversity protection to inform broader conservation planning processes (Figure 1-2) (Center for Ocean Solutions 2011, IUCN-WCPA 2008). Part of the utility of these tools is the ability to quantitatively evaluate the biodiversity protected by different areas within a network, a valuable input to participatory stakeholder processes where a diversity of values and resource uses may influence selection of a suitable network design (Lundquist et al. 2015, Klein et al. 2008, Lundquist and Granek 2005). These decision-support tools provide an informative, transparent process for interpreting information and information gaps to evaluate biodiversity conservation priorities (Gleason et al. 2013). Decision-support tools also provide more efficient solutions for biodiversity protection than is typically achieved through ad-hoc selection processes (e.g., Roberts 2000, Stewart et al. 2003).

Within this report, our objective is to illustrate the use of decision-support tools in informing optimal locations for biodiversity conservation prioritisation, and how decisions about which datasets to include, and how they are utilised, might influence selection of priority areas. While the focus is on identifying biodiversity conservation priorities, biodiversity is often one of many values that would be incorporated during a participatory stakeholder conservation planning process (Lundquist and Granek 2005, Sayce et al. 2013). Depending on the objectives of a process, it is likely that societal, economic, and cultural/mātauranga values will also be incorporated. Spatial optimisation tools, such as Zonation, can also be used to evaluate a suite of options to identify optimal solutions that provide for multiple, often competing, objectives (Klein et al. 2008).

While these decision-support tools have been used in many prior national and international planning processes to select areas for biodiversity objectives, it is often challenging to find illustrations of the decisions that have had to be made along the way toward the final prioritisation scenario. Here, we use a ‘cookbook approach’ to provide guidance for how to combine different information sources, and the steps and decisions that are likely to be encountered within a typical marine conservation or spatial planning process. This suite of examples is envisioned to make the use of these tools more transparent, and to highlight steps where policy decisions or stakeholder input is required. We also use a suite of component scenarios within a broader suite of steps to illustrate how decisions made at individual steps along the way influence prioritisations.

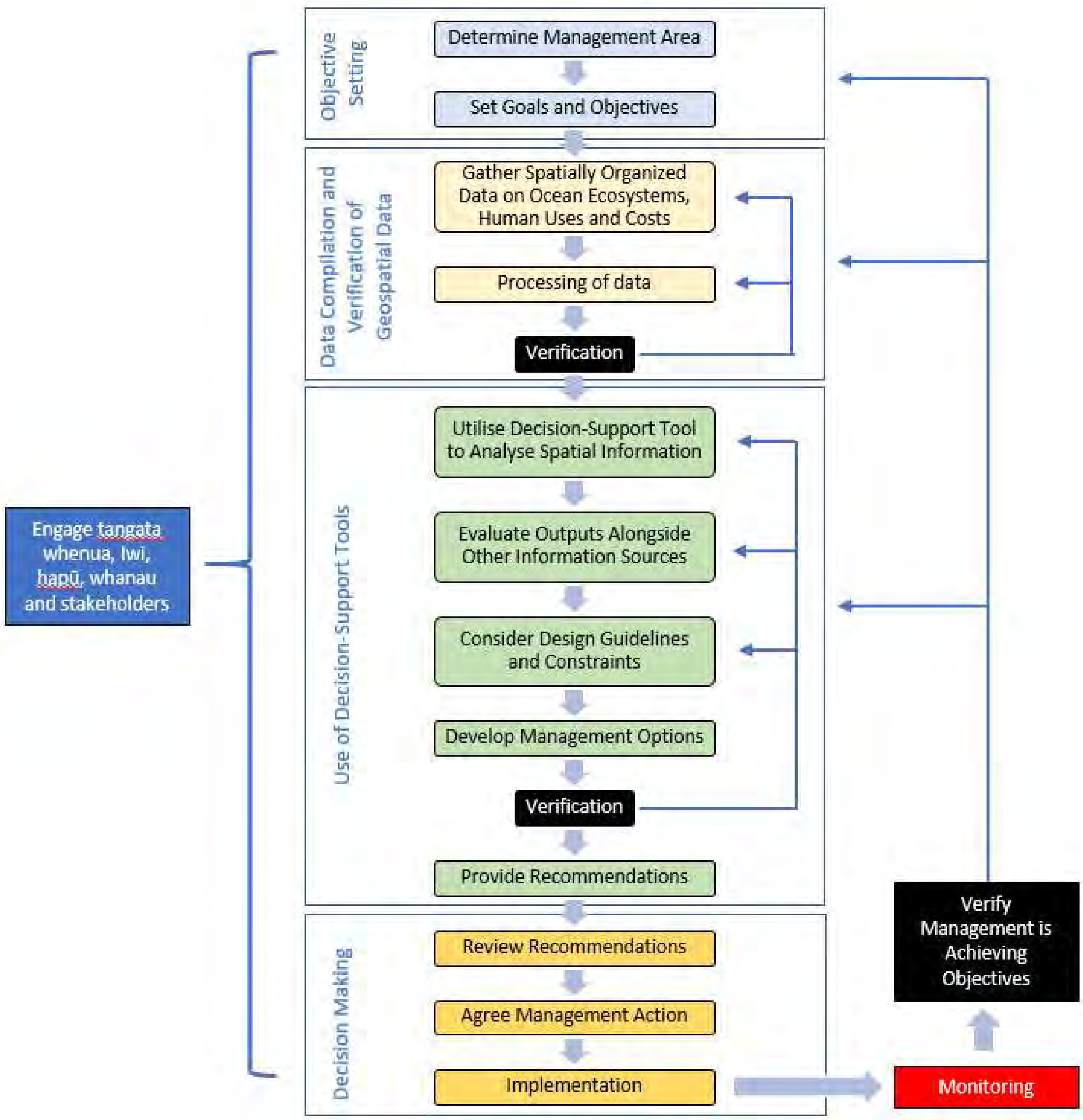

Figure 1-2: Schematic of conservation planning process, identifying where the compilation of available geospatial datasets and the use of decision-support tools fits within the process.

2 Datasets available to inform spatial optimisation

Section 2: Key messages

- Currently, primary datasets for spatial optimisation include predictive models on species/habitat distributions, habitat classifications, datasets used to inform Key Ecological Areas (KEA) and layers that represent stressors to biodiversity.
- Data that are used to identify KEAs represent nine distinct criteria. However several criteria have significant gaps in the available information used to represent them.
- Several KEA datasets are presence only records represented by points or polygon features. It may be best to use these datasets as 'silent' or zero weighted layers, as spatial biases in sampling may misrepresent their distributions.

An extensive suite of marine biodiversity, habitats and ecosystems datasets have been collated or developed as part of this investigation (no. 4758) and other DOC investigations (nos. 4735, 4759, and 4757) (Table 2-1). These datasets represent the most comprehensive data on marine ecosystems available to date for New Zealand, though there are still gaps in both spatial coverage and comprehensiveness of some data layers such as biogenic habitats (reviewed in Lundquist et al. 2020a) and thus guidance is required for their use.

The primary datasets used to inform spatial optimisation encompass four data types: predictive models, habitat classification groups, key ecological areas and layers which represent stressors on biodiversity (Figure 1-2, Table 2-1). First, predictive species distribution models (including models of species occurrence, abundance or habitat suitability) have been developed for 613 taxa to date. These modelled layers cover 30 cetacean species, subspecies and species complexes (Stephenson et al. 2020a), and extensive models developed for this project, and reported within the second KEA report (239 demersal fish species, 51 reef fish species, 207 invertebrate genera and 86 macroalgal species, Lundquist et al. 2020a). Modelled layers include primarily common species for which sufficient records (typically >50 unique locations) are available within New Zealand's EEZ, and modelled layers are not available for the majority of New Zealand's biodiversity. These layers can be used as *.tif files in the Zonation software, and directly used as input layers to represent individual taxa distributions (Table 2-1).

Secondly, a new broad-scale marine habitat classification system has been developed in DOC investigation no. 4757 (Stephenson et al. 2020b). This Seafloor Community Classification (SCC) includes 75 representative community groups based on Gradient Forest statistical techniques that integrate both environmental and biological data. Additional layers that represent intra- and inter-group similarity within and between SCC classification groups can be used to represent differences between groups and can be directly input into Zonation.

Thirdly, Stephenson et al. (2018b) compiled 27 key ecological areas datasets following workshops with leading national biodiversity experts that identified existing datasets that satisfied one or more Key Ecological Area (KEA) criteria. KEA criteria were as defined in Freeman et al. (2017): 1) Vulnerability, Fragility, Sensitivity or Slow Recovery, 2) Uniqueness / Rarity / Endemism, 3) Special Importance for Life History Stages, 4) Importance for Threatened / Declining Species and Habitats, 5) Biological Productivity, 6) Biological Diversity, 7) Naturalness, 8) Ecological Function, and 9) Ecological Services. Some of these datasets build on prior efforts by central government to collate and analyse national marine biodiversity information (e.g., Anderson et al. 2019, Lundquist et al. 2014). Lundquist et al. (2020a) updated these datasets, filling some gaps, and providing a detailed evaluation of the datasets collated for the nine KEA criteria to assess their utility and comprehensiveness in providing a robust spatial representation of each criterion should it be used in marine conservation planning.

A fourth set of layers includes datasets that provide a spatial representation of other uses of the marine environment that may represent stressors to biodiversity, or resource uses that are not compatible with marine protected areas. Many of these layers were collated within the Naturalness KEA criterion, and reflect resource uses or other stressors or impacts that may reduce the ecological condition or health of marine biodiversity and habitats. Here, we illustrate how these layers could be used to explore decreases in naturalness, and could also be used in selecting areas that balance priorities between multiple objectives that may or may not conflict in marine ecosystems (e.g., tourism, fishing, oil and gas exploration). As this project is focussed on biodiversity objectives, exploring cost trade-offs of marine protection with other uses or stakeholder values is beyond the scope of this project, but can easily be supported through the decision-support tools presented here.

As per the evaluation of KEA datasets presented in Lundquist et al. 2020a, there are gaps in available information to populate many of the KEA criteria (e.g., ecosystem function: 6 layers, biological productivity: 5 layers, ecosystem services: 1 layer) (Table 2-1). KEA data layers also vary in their data type (e.g., contiguous modelled layers, point records, polygons) and most point records layers are from ad-hoc compilations of survey or citizen science data, which lack comprehensive spatial coverage of the EEZ (Table 2-1). As we illustrate steps for marine spatial planning, we note a number of layers (particularly polygon or point 'presence only' records with significant spatial biases in their available records), that, if used in a prioritisation, would bias priority areas toward locations that have been sampled, as opposed to prioritising based on comprehensive understanding of biodiversity patterns (Figure 2-1). Zonation provides a number of options to incorporate these layers (see section 4), from standard inclusion within the prioritisation, to upweighting of known locations for key species or habitats, to down weighting or discounting for spatial biases of knowledge of a particular biodiversity feature. Layers can also be used solely for reporting purposes (i.e., zero weighted or 'silent' layers) to determine if prioritisations based on other features are sufficient to serve as proxies for data layers limited in spatial extent or understanding.

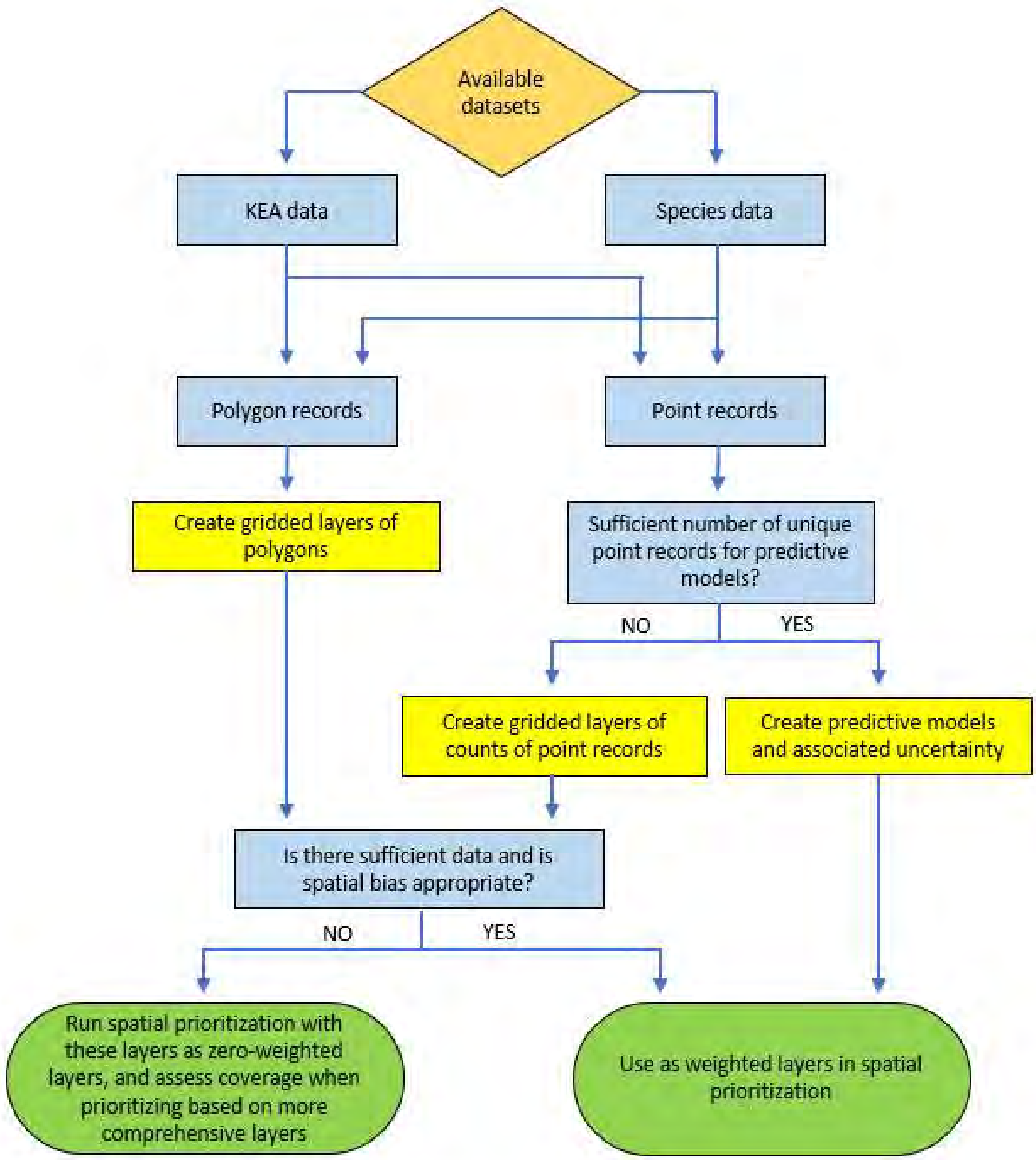

Figure 2-1: Flow chart of types of data available to inform marine spatial optimisation processes.

Table 2-1: Datasets compiled as part of the Key Ecological Areas criteria projects. Extent, resolution and guidance for use of layers in spatial prioritisations based on Figure 8-1 from Lundquist et al. (2020a).

Criterion	Dataset description	Extent and resolution	Gaps and caveats
Vulnerability, Fragility, Sensitivity or Slow Recovery			
Sensitive habitats – macroalgae.	Point records of large brown algae, algal meadows, rhodolith beds, coralline turfs and crusts.	EEZ wide	Largely from herbarium records – presence only point records.
Sensitive habitats – bryozoans.	Species occurrence models (SDMs) of 11 taxa.	EEZ wide	Based on limited number (typically <50) point records.
Sensitive habitats – other biogenic habitats.	Point records.	EEZ wide	Point records, spatial bias in coverage by region and to primarily trawlable depths or locations of survey effort. New records not yet available from MBIE Bottlenecks project.
Vulnerable marine ecosystems.	Raster layers of 12 VME taxa, updated from KEA1.	EEZ wide.	Robust species occurrence models including uncertainty; exploration of correlation between species occurrence and species abundance in process for MPI (SPRFMO).
Uniqueness / Rarity / Endemism			
Cetacean	Cetacean endemic (2) and rare species (1) – Point records and species occurrence models.	EEZ scale including offshore observations.	RES model for false killer whales based upon 28 points only.
Seals and sea lions	One endemic species (NZ sea lion) – point records of haul out and breeding colonies	Coastal locations, national scale.	May not be up to date as new colonies/haul outs established with expanding range of NZ sea lions.
Seabirds	Points records of endemic species.	EEZ wide but patchy.	Data pooled from many sources – integration not straightforward. Presence only data. Challenge of how to incorporate terrestrial habitat use.
Demersal fish	Point records of 54 and SDMs for 47 endemic species. Raster layers of species turnover and classification groups.	EEZ wide, rasters at 1 km resolution.	Records dominated by trawlable depths; species occurrence less certain beyond this. Correlation between species occurrence and abundance assumed, but not tested.

Criterion	Dataset description	Extent and resolution	Gaps and caveats
Rocky reef fish	Point records for 92 and SDMs for 19 endemic species.	Reef habitat in territorial sea and offshore islands.	Location of reef habitat not necessarily accurate. Sampling restricted to shallow reefs, bias towards sheltered sites. Poor coverage elsewhere.
Benthic invertebrates	Point records and SDMs of endemic species.	EEZ wide.	Records dominated by depths less than 2000 m. Models at genera scale, often including both endemic and non-endemic species.
Macroalgae	Point records and SDMs endemic species.	Reef habitat in territorial sea and offshore islands.	Location of reef habitat not necessarily accurate. Sampling restricted to shallow reefs, bias towards sheltered sites. Poor coverage elsewhere.
Seamounts	Point records.	EEZ wide.	Seamounts already identified due to overlap with vulnerability criteria.
Special Importance for Life History Stages			
Cetaceans			No information available to populate this criterion. Potential for modelling of seasonal spatial distributions and correlation with temporal variation in environmental drivers.
Seal and sea lions	NZ sea lion, fur seal and elephant seal breeding colonies. Point and polygon records.	Coastal locations, national scale.	May not be up to date as new colonies/haul outs established with expanding range of NZ sea lions and fur seals. 'Occasional' breeding colonies may not be accurate, particularly for historic records of southern elephant seal on the mainland.
Seabirds	Location of breeding colonies for 92 species of seabird. Some foraging and roosting locations.	EEZ wide.	Data pooled from many sources – integration not straightforward. Presence only data, though likely mostly complete due to strong public interest.
Demersal fish	Fish spawning areas for 39 species, polygon layer.	Mainly territorial sea.	Polygons often represent large areas – coarse resolution. No spatial distributions available for juvenile distributions.
Freshwater fish	Freshwater fish species (26) point record and spawning locations.	Riverine habitat – North and South Island.	Mainly inland rivers and streams; no metric to assess relative importance of individual estuaries as spawning locations.
Rocky reef fish	Spawning locations for 8 species.	Mainly territorial sea.	Polygons often represent large areas – coarse resolution.

Criterion	Dataset description	Extent and resolution	Gaps and caveats
Invertebrates and macroalgae			No information available to populate this criterion.
Importance for Threatened / Declining Species and Habitats			
Cetaceans	Threatened species (5) point records and SDM raster layers.	EEZ wide, including offshore areas, 1 km resolution for SDMs.	Point records are spatially biased to areas with more survey effort. SDMs may not be accurate offshore due to lack of sightings. Large proportion of species are data deficient, and threatened status is unknown.
Seal and sea lions	Threatened species (2) haul out and breeding colony point and polygon records.	Coastal locations, national scale.	May not be up to date as new colonies/haul outs established with expanding range of NZ sea lions.
Reptiles	Internationally threatened sea turtles.	Point records, typically coastal.	Sparse point records; only one marine reptile (sea snake) is known to breed in New Zealand.
Seabirds	Threatened species point records.	EEZ wide.	Presence only data.
Macroalgae	Threatened species point records (n = 6).	Reef habitat in territorial sea and offshore islands.	Presence only data.
Biological Primary Productivity			
Coastal vegetation	Polygons for mangroves, limited polygons and mostly point records for seagrass, limited information for saltmarsh.	Coastal, national scale.	Inconsistencies of regional and temporal scale reporting. Few layers present at polygons. No spatial information for historical distributions (though anecdotal evidence of significant declines of seagrass and saltmarsh).
Satellite remote sensing primary productivity	Modelled layer.	EEZ wide at 1 km resolution; coastal at 400 m scale.	Poor understanding of coastal primary productivity and extrapolation of chlorophyll a when co-occurring with high levels of particulate matter.
Biological Diversity			
Cetaceans	Species richness raster layer created by stacking SDMS of 30 cetacean species.	EEZ wide, including offshore areas, 1 km resolution for SDMs.	Accuracy of underlying SDMs may be compromised by lack of sightings data – particularly offshore and for rare species. Use of layer should be guided by environmental coverage.

Criterion	Dataset description	Extent and resolution	Gaps and caveats
Seabirds	Species richness – within ASCV and IBA sites only.	Within regional council ASCV sites.	Point records, some sites with multiple species recorded.
Demersal fish	Species richness raster layer created by stacking SDMS of 241 fish species. Species turnover and classification group rasters.	EEZ wide at 1 km resolution.	Primarily trawlable depths, few deep records used to produce SDMs - use of layers should be guided by environmental coverage. Relative absences were generated from demersal fish occurrence records.
Rocky reef fish	Species richness raster layer created by stacking SDMS of 51 fish species. Species turnover and classification group rasters.	Reef habitat in territorial sea and offshore islands, 250 m resolution.	Location of reef habitat not necessarily accurate. Sampling restricted to shallow reefs, bias towards sheltered sites. Poor coverage elsewhere. Relative absences were generated from rocky reef fish occurrence records.
Benthic invertebrates	Species richness raster layer created by stacking SDMS of 207 invertebrate species. Species turnover and classification group rasters.	EEZ wide, rasters at 1 km resolution.	Primarily trawlable depths, few deep records used to produce SDMs - use of layers should be guided by environmental coverage. Coarse taxonomic scale (genera). Complex interpretation of absences due to differences in sampling gear.
Macroalgae	Species richness raster layer created by stacking SDMS of 88 species. Species turnover and classification group rasters.	Reef habitat in territorial sea and offshore islands, 250 m resolution.	Location of reef habitat not necessarily accurate. Sampling restricted to shallow reefs, bias towards sheltered sites. Poor coverage elsewhere. Complex interpretation of absences due to records being presence only herbaria specimens.
		Naturalness	
Land use	Polygon layer summarising land use categories by adjacent catchment.	Territorial sea.	Currently no connection of catchments along coast, other land use effects (sediment/nutrient loads, erosion, population density etc.,) not included. Pathway forward identified to further quantify this layer.
Oil and gas	Feature class layer denoting locations of offshore platforms and submarine pipelines.	Territorial sea.	Point records, lines. No assessment of impacts or risk of their occurrence.
Invasive species	Presence of invasive marine species at 74 unique locations.	Coastal sea.	Strongly biased to survey locations (i.e., ports). No assessment of impact or risk to naturalness by species.

Criterion	Dataset description	Extent and resolution	Gaps and caveats
Fisheries metrics	Bottom fishing footprint, fishery metrics for commercial and recreational fishing.	EEZ wide.	Limited surveys and validation of recreational fishing to coastal areas; commercial fisheries metrics updated regularly. A naturalness layer to quantify degradation from bottom fishing impacts is under development.
Existing spatial management areas	Marine reserves, benthic protection areas, depth refuges from fishing impacts, and other use restrictions.	Polygons, EEZ wide.	Typically static areas/regulations.
		Ecological Function	
Mesopelagic fish	Point records of 25 genera.	EEZ wide.	Initial exploration shows promise of modelling of this important mesopelagic group.
Benthic invertebrate functional groups.	Point records for genera classified into five function groups.	EEZ wide.	Not an exhaustive list of genera by group. More work required to link species and genera to functional groups.
		Ecological Services	
Biogenic habitat provision.	Predictive models based on ecosystem principles approach.	Territorial Seas, national scale, rasters at 1 km resolution.	Empirically validated in northern New Zealand; dependent on environmental layers that may be poorly resolved in some regions.
Other ecosystem services.			No comprehensive spatial layers available in New Zealand.

3 Spatial decision support tools

Section 3: Key messages

- The two most common decision support tools, Zonation and Marxan, perform similar types of analyses using different algorithms. Each analysis is based on the value of 'cells' relative to other cells within the study area.
- Zonation produces hierarchical prioritisations of the landscape based on the value of each cell relative to pre-defined objectives. Model algorithms allow for inclusion of different options that represent balancing of multiple objectives, inclusion of connectivity, differential weighting of features, and other options that allow for inclusion of ecological and socio-economic criteria
- The primary output of Zonation is a spatial map that demonstrates the ranking of cells from highest to lowest priority. Additional data outputs can be used to assess the protection afforded to any single biodiversity feature or group of biodiversity features under a given proportion of the landscape protected. Boxplots and tables are also regularly used to summarise the performance of a Zonation scenario at protecting biodiversity values across various proportions of the landscape protected.

3.1 Inside the black box of conservation planning decision-support tools

Many different decision-support tools have been developed to support spatial conservation planning in marine and terrestrial ecosystems (Leslie et al. 2003, Center for Ocean Solutions 2011). The two most common tools are Zonation and Marxan (Moilanen et al. 2009, 2014, Ball et al. 2014), with Zonation being the most commonly applied tool in Aotearoa New Zealand's marine environment. As previously discussed in section 1, the tools provide transparent, repeatable scenario analyses to support decisions. The tools themselves have detailed information on algorithms available in their training manuals (Moilanen et al. 2014) or on the project website (https://marxansolutions.org/).

Marxan is designed to solve the 'minimum set problem' where the goal is to achieve some minimum representation of biodiversity features for the least possible cost. It uses simulated annealing to calculate alternative sets of priority areas for achieving conservation targets, i.e., both a 'best' solution and a range of potential solutions that achieve similar biodiversity targets (Ball et al. 2014). Marxan variations include the ability to weight species or habitat types, the ability to pre-select or pre-exclude areas from protection, and aggregation options that allow for clumping of protected cells that are more suitable for management. Marxan outputs include maps of multiple solutions that provide similar levels of biodiversity protection. Marxan is well-suited to stakeholder meetings, facilitating discussion of different options and how they interact with existing uses within a region.

Zonation uses a reverse stepwise heuristic algorithm to identify solutions that have both high value for conservation, and low cost in terms of resource use, but also are balanced with respect to representation of different species or habitats, and connectivity between protected areas (Moilanen et al. 2009, 2014). Zonation produces a hierarchical prioritisation of the landscape based on the conservation value of the site (cells), iteratively removing the least valuable cell from the landscape until no cells remain.

When actually implementing a conservation planning process, a number of common steps occur where best practice guidance would be useful. Here, we provide a suite of common options available within the Zonation software.

3.2 Zonation application to New Zealand marine biodiversity datasets

Procedurally, Zonation starts with a full set of grid cells (e.g., of a particular area), and sequentially removes cells of the lowest 'value'. Cell value is calculated based on a combination of the value of the cell with respect to, for example, all taxa distributions, and cells are allocated higher value if they represent high biodiversity value for multiple taxa. However, representativeness of all taxa is also included in the solution, i.e., when taxa have disjunct or non-overlapping distributions, the solution will include cells that may be of value to only one or a few taxa. For example, if a taxon is only found in a small number of cells, these cells are more likely to be chosen as high priority to ensure protection for that particular taxon. Ideally, those cells are also of value to other taxa, but if not, the Zonation algorithm strives to represent all taxa in priority solutions.

Zonation includes many options for cell removal rules (Moilanen 2007). Core Area Zonation is the most commonly-used option, where highest values are given to the most important locations within each species' distribution, maximizing representativeness across species. The Additive Benefit Function is similar but with more focus on protecting areas of high overlap of many species, such as hotspots of species richness. Zonation has a Target Based Algorithm that can match the Marxan approach of requiring specification of target representation levels of individual features, though a target is not required for other cell removal rules. A Random cell removal rule allows comparison to a non-structured solution to determine how much better scenarios are for biodiversity protection than ad-hoc locations.

Model variations also include the ability to weight species, the ability to pre-exclude or pre-include particular areas, and the ability to aggregate cells. Various options are available to differentially weight taxa so that particular taxa are given higher (or lower) levels of protection. For example, endemic species or particular endangered or threatened species can be given a higher weighting to make their level of protection higher than non-endemic species. Or, as in the earlier example, taxa with particularly disjunct distributions could be down-weighted, so that the solution is less dependent on one or a few taxa. Zonation allows 'silent' layers to have zero weighting, i.e., such that they have no contribution to priorities within a scenario. The inclusion of 'silent' or zero weighted layers allows their performance under different scenarios to be evaluated. The use of silent layers is suitable for layers with significant gaps in spatial coverage that would otherwise result in selection of areas with spatial coverage, and avoidance of areas with limited knowledge of their biodiversity features.

Zonation can be run with or without cost layers, i.e., trade-offs that conflict with biodiversity protection. When cost trade-offs are included, Zonation attempts to optimise biodiversity but avoid high cost areas. For example, cost areas can be those that are of value to a fishery (i.e., where fishing takes place and high catches have been historically returned).

Generally, Zonation will attempt to find cells with similar biodiversity values, but that have low cost (i.e., relatively lower fish catch). Often, alternative cells can be found, although the solution may require a larger number of total cells to achieve the same value for biodiversity when optimising for both biodiversity and a cost layer. An alternative to using this 'cost' trade-off feature is to provide a negative weighting on layers that are incompatible with biodiversity protection.

Another feature of Zonation is the ability to incorporate declines in biodiversity value due to the effects of different stressors that may vary in their impact within a region. Zonation uses a discounting algorithm, where a 'condition' layer (e.g., a sediment stressor map) is added, and used to reduce the biodiversity value relative to this stressor layer. A weight is applied to this layer and can be varied to determine an appropriate relative effect of the decline in condition.

Zonation is also able to add uncertainty in understanding of biodiversity features, for example those uncertainty layers associated with predictive models of species distributions (Moilanen and Wintle 2006). Zonation can include an uncertainty layer of the same grid as the predictive models, and the relative impact of this uncertainty layer can be increased or decreased through a weighting parameter that determines how much the value of the modelled layer decreases due to uncertainty.

Mask options are another tool within Zonation, allowing two types of integration. First, Zonation can input a 'model area', allowing the user to change the area that is being modelled, for example to do a focused run on a particular sub-region without having to clip all layers to this new sub-regional area. These options in comparing how scenarios differ between broad scale (e.g., national) and regional or locally-driven priorities. A second mask option can be used to force inclusion or exclusion of areas as priorities for biodiversity protection. For example, Aotearoa New Zealand's 44 marine reserves can be pre-selected as priorities to automatically select them in the top solution; this approach allows consideration of other areas based on their complementarity with areas that have provisions for biodiversity protection. Exclusion could include areas that are not compatible with biodiversity protection, or could not be selected as marine protected areas such as shipping lanes.

Zonation also includes a number of aggregation options to maximise network connectivity of protected areas (Moilanen and Hanski 2001), with a default option including 'edge removal' to maximise processing speed of each scenario; in this case, cells with fewer neighbours (i.e., edges) are preferentially removed, assuming that they are of lower value than cells within a larger group of cells that are occupied by biodiversity features. Other aggregation algorithms include boundary penalties which penalise solutions with high perimeter to area ratios (similar to the algorithm used in Marxan to increase network connectivity), the mechanistic boundary quality penalty, which uses species-specific neighbourhoods and dispersal curves to maximise network connectivity across all species in a scenario, and a directed connectivity algorithm that allows for directional dispersal such as that of currents or other hydrodynamic features that influence larval dispersal patterns (e.g., Grantham et al. 2003). The primary challenge of most of these connectivity or aggregation algorithms is that typically empirical information does not exist to parameterise these algorithms for most marine species.

Zonation also includes options that allow for balancing across different regions, called administrative units. Here, a model area can be separated into different units, for example, the Territorial Sea and the broader EEZ, to result in equal prioritisation within each administrative region.

This option has been used for example to examine differences in priority between national and regional priorities (Geange et al. 2017), and the relative balancing (global versus regional) can be dialed up or down corresponding to fully global or fully regional balancing, or somewhere in between.

3.3 Introduction to Zonation outputs

To those unfamiliar with Zonation software, we illustrate typical types of Zonation outputs that will be used throughout this report. First, the most common visual output from Zonation is a spatial prioritisation map which provides a visual output for each scenario showing the priority value for each cell to assist in identifying areas of high value for biodiversity conservation. This output is typically provided as a *.tif or a *.asc raster file that can be input into geospatial software packages. The Zonation Graphic User Interface (GUI) also provides a *.jpg of this graphical solution, which illustrates the hierarchical prioritisation provided by Zonation, with highest priority areas selected by the scenario illustrated in red, through to lowest priority areas for biodiversity conservation in blue and black (Figure 3-1). Merged maps allow visual assessment of the differences in priority between two scenarios, allowing the user to evaluate implications of different options or datasets of prioritisation of different locations.

Another output from Zonation is a set of performance curves that describes the level of protection for each biodiversity feature as the proportion of the model area in protected areas is progressively increased (Figure 3-2, Figure 3-3). Outputs include the proportion of each taxon range protected across the full range (i.e., 0–100% of total area protected) of area put into biodiversity protection, such that solutions can identify combined metrics such as average, minimum and maximum levels of protection. Different species or groups of species can be averaged to determine how protection changes with increasing area allocated to higher priority solutions for biodiversity. This feature is useful in demonstrating the required area to achieve conservation targets. Zonation provides these curves in the GUI with an x-axis that is sometimes difficult to interpret, as it is presented with respect to the process by which cells are 'removed' within the algorithm (Figure 3-2). Rather, it is often easier to interpret these analyses using a reversed x-axis as shown here (Figure 3-3).

Finally, information in these curves can be extracted for individual species or individual area in the top priority solutions, allowing direct comparison of the relative protection provided by each scenario for a particular biodiversity feature (Table 3-1). To illustrate how protection varies within a group, box plots can be used to show the median and range of protection for all features within a group for a particular priority solution (Figure 3-3).

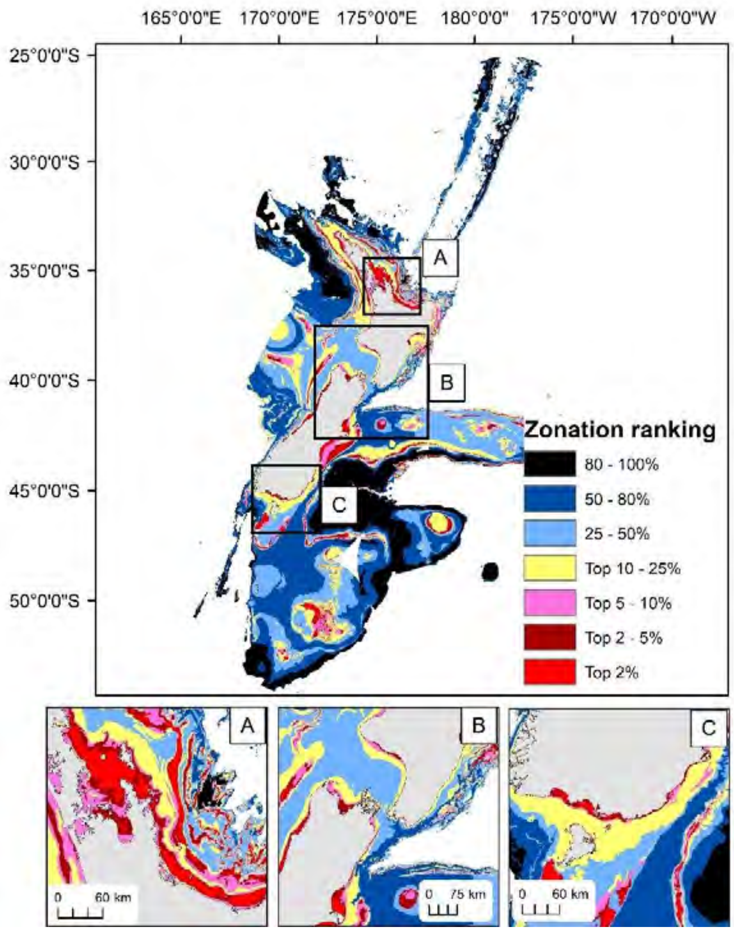

Figure 3-1: Zonation spatial prioritisation. An example of a typical spatial representation of a Zonation prioritisation. This example is for the demersal fish species group.

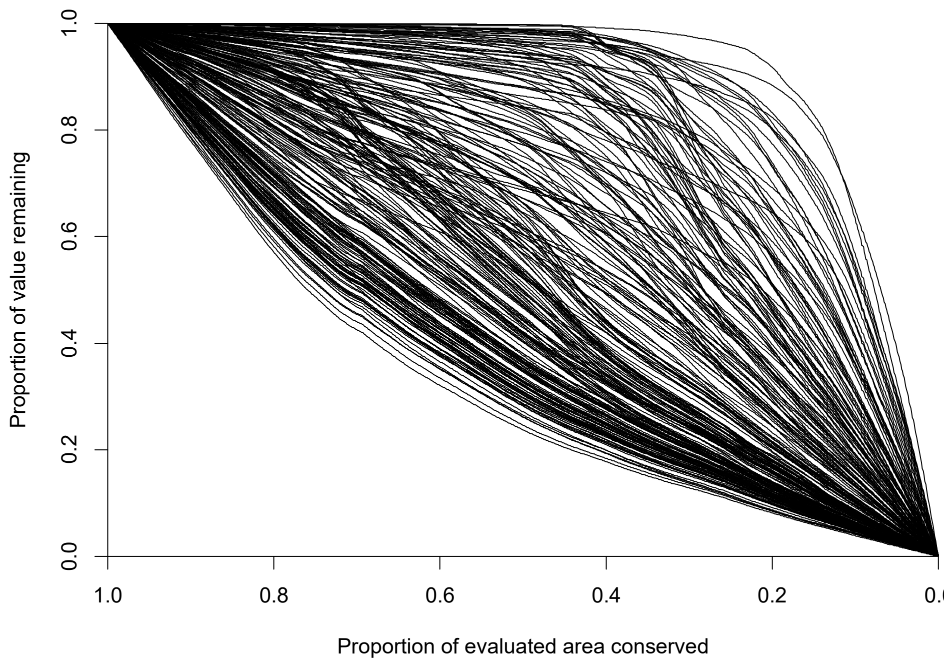

Figure 3-2: Feature conservation curves. An example of feature conservation curves for the demersal fish scenario. Each curve represents a separate demersal fish species.

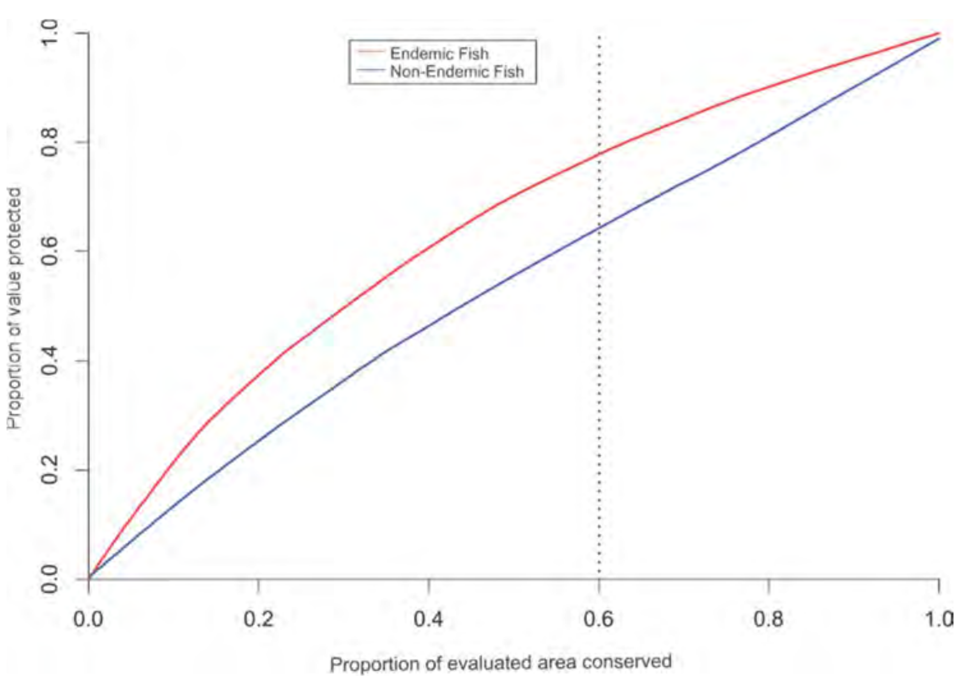

Figure 3-3: Feature conservation curves by groups. Example of conservation curves grouped by endemic and non-endemic species of demersal fish. Note this curve has a reversed x-axis from the standard curve provided by the Zonation software. The dotted line indicates relative protection of fish provided by the area identified in the top 60% of the model area.

Table 3-1: Zonation output summary table. An example of a typical summary table from a Zonation output used to assess the performance of a prioritisation at protecting biodiversity values associated with certain species/groups/features. Values represent the proportion of biodiversity value within a certain priority area (e.g., top 10% solution as identified within a Zonation scenario).

	Snapper ***Chrysophrys auratus***	**Blue cod** ***Parapercis colias***	**Rig** ***Mustelus lenticulatus***
Top 10 % priority area	0.289	0.281	0.263
Top 20 % priority area	0.557	0.507	0.477
Top 30 % priority area	0.813	0.664	0.677

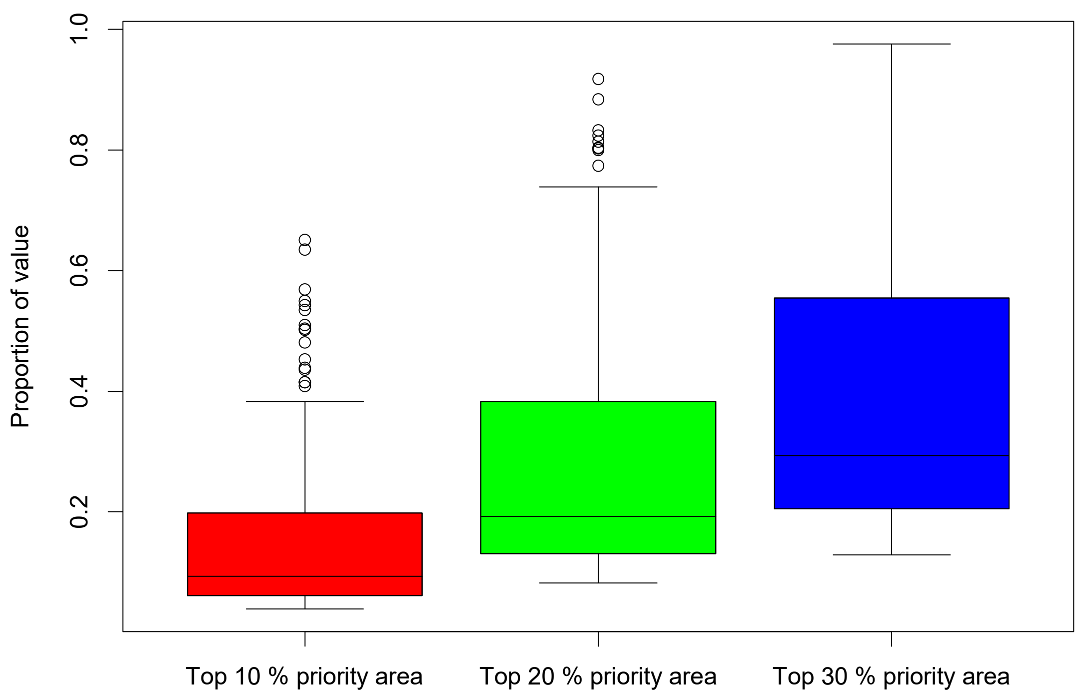

Figure 3-4: Boxplot of Zonation scenario performance. An example of a box plot used to illustrate the performance of a Zonation prioritisation at protecting the biodiversity value of the input features. This plot shows the range of protection across all features in the prioritisation under the 10, 20 and 30% top priority areas, for the demersal fish prioritisation.

4 Pātaka Tohutao – the ‘Cookbook’ of steps and decision points

In te reo Māori, pātaka is a storehouse of food, a pantry, a larder, and tohutao refers to the recipes, the best recipes, the valuable recipes. Thus together these terms mean cook book, “a storehouse of best practice and recipes.“ Here, we illustrate the series of steps, and provide guidance on the decisions that need to be made at each step, for a typical spatial conservation planning process.

4.1 Step 1: Knowledge gaps

Section 4.1: Key messages

- Knowledge gaps are common in spatial planning processes, particularly in data poor areas.
- The analysis extent can be clipped to areas where stakeholders have confidence there is sufficient data for an unbiased analysis; this may include clipping based on environmental characteristics (e.g., depth).
- Environmental coverage is a spatial and statistical representation of how well the environmental characteristics of the study area have been sampled for a certain biodiversity grouping. The study area can be clipped to areas of ‘good environmental coverage’ to minimise the influence of data poor areas on prioritisations. The level of environmental coverage considered ‘good’ is a decision point that requires stakeholder input.

An important first step is considering what to do with missing ingredients. Typically, with most spatial planning processes there are gaps in available knowledge and datasets that represent biodiversity and/or human use components. We have developed with several options for addressing these gaps that are transferable among different prioritisation exercises. While often sampling effort is poorest in deep, offshore waters, there are also gaps in our knowledge of some poorly sampled inshore regions of New Zealand, such as the South Island west coast.

A simple method for accounting for knowledge gaps is to clip the input data to an area where stakeholders are comfortable with the level of sampling that has occurred, and thus higher confidence can be held in the occurrence of biodiversity features. In many cases, the distribution of sampling may follow environmental gradients (e.g., depth) where the impracticalities of sampling at extreme values result in a paucity of information. In these cases, it may be appropriate to clip input data to values where limited sampling has occurred (e.g., a depth cut-off). The species distribution models used in this study are clipped to a depth cut-off of 2500 m for all taxa except cetaceans, due to a lack of sampling beyond this depth. Thus, all Zonation scenarios that utilise these biodiversity features are limited to depths shallower than 2500 m. This intervention limits the inclusion of areas we know are data poor and can be used in addition to the masks of environmental coverage discussed below, which establish a more quantitative cut-off for sampling distribution.

Environmental coverage

A commonly encountered knowledge gap originates from a lack of or uneven distribution of sampling effort across the prioritisation area. Clearly, areas that are better sampled have a better representation of their biodiversity values while areas that are poorly sampled are often represented as having limited or unknown value for biodiversity. One option to account for these data gaps within spatial prioritisations is to generate a spatial layer that represents 'environmental coverage'. Environmental coverage is a spatial representation of the probability of the environmental characteristics of a cell being sampled given the distribution of sampling effort for a given taxa/biodiversity value (Lundquist et al. 2020a, Stephenson et al. 2020a,b). This environmental coverage layer can then be utilised by clipping all data layers to areas of higher environmental coverage (e.g., using a 10% threshold for environmental coverage) and developing prioritisations only for adequately sampled areas, with alternative proxies for biodiversity such as habitat classification groups (see section 4.5) used to inform prioritisation of poorly sampled areas (Figure 4-1).

An example of uneven sampling biases resulting in spatial differences in environmental coverage is the distribution of sampling effort for demersal fish and benthic invertebrates at the scale of the New Zealand EEZ. This coverage has a strong bias to fishable depths (typically <1600 m) and to locations where fisheries surveys are regular carried out (e.g., the Chatham Rise), although there are also some inshore environmental coverage gaps in estuaries and coastal zones (Figure 4-2).

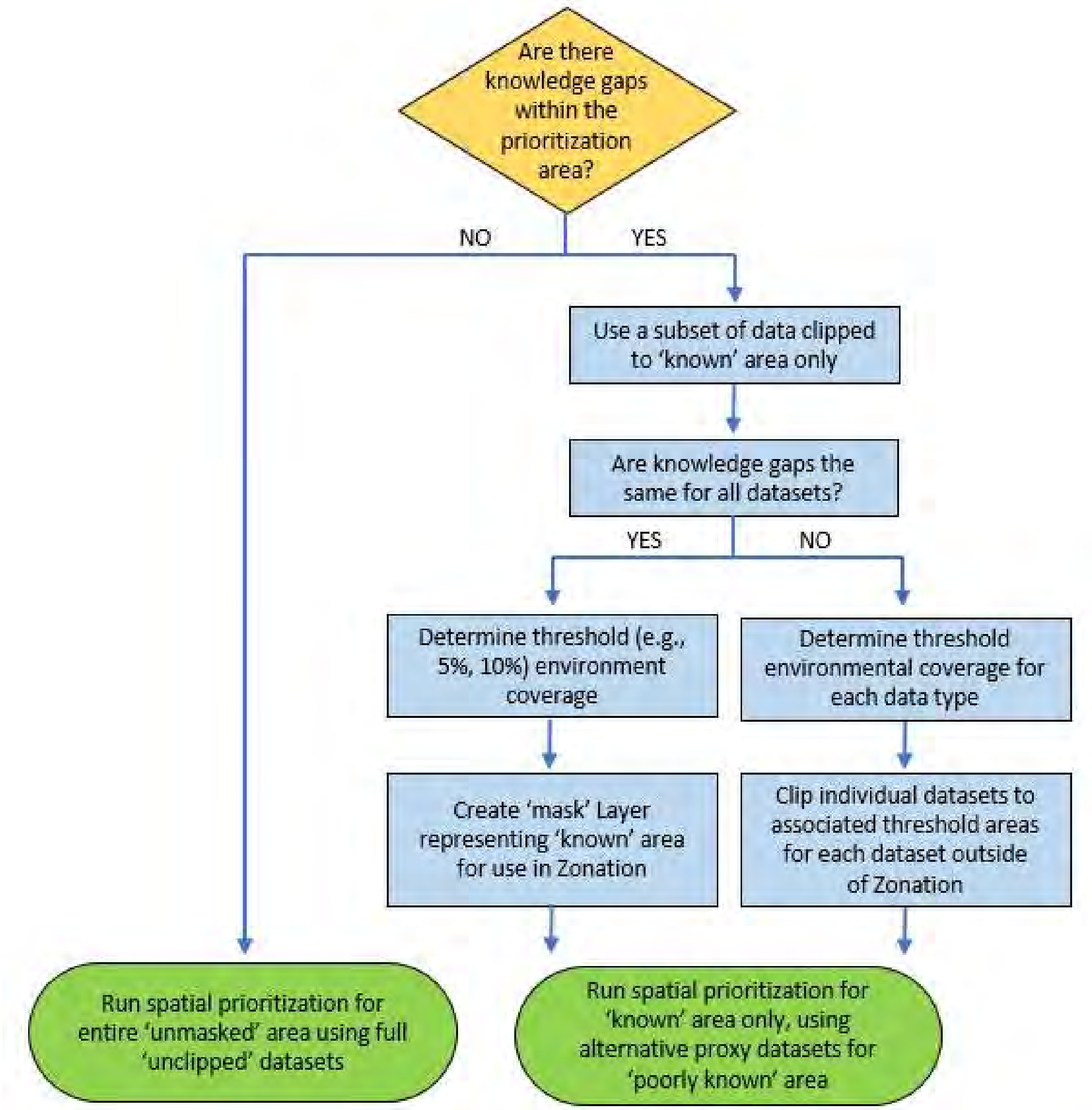

Figure 4-1: Flow chart of decision points with respect to areas of poor environmental coverage.

Depth is also correlated with sampling effort, and thus, marine biodiversity knowledge, due to logistics and expense of sampling at extreme depths. As such, depth could also be used as a proxy for environmental coverage, excluding depths with limited sampling beyond a depth threshold. Typically, species distribution models are clipped to depths based on available sampling effort, such as demersal fish and benthic invertebrates, both of which were clipped to 2500 m during model development (e.g., Figure 4-3)

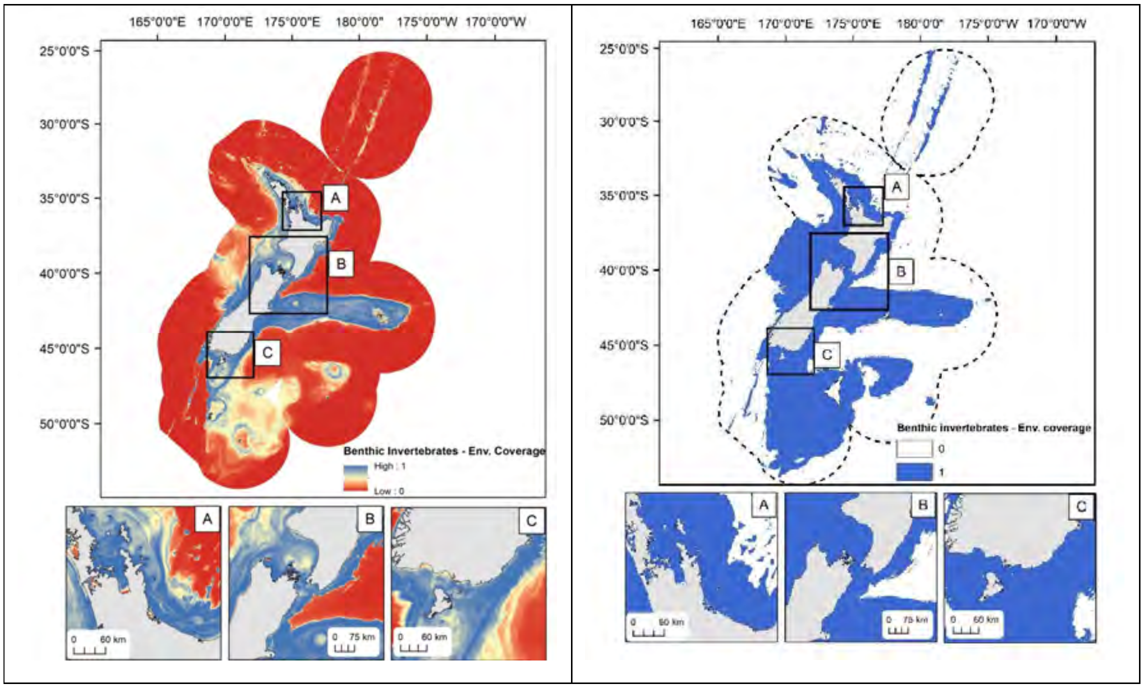

Figure 4-2: Environmental coverage in the New Zealand EEZ. LEFT: Example using datasets available to develop species occurrence models for benthic invertebrates (from Lundquist et al. 2020a). RIGHT: Clipping mask based on 0.05 threshold of environmental coverage.

Environmental coverage can be calculated following methods described in Stephenson et al. (2020a,b) and may be produced for any spatial layer that has known presence and absence locations. Values for environmental coverage range from 0 (highly unlikely a cell's environmental characteristics have been sampled) to 1 (highly likely a cell's environmental characteristics have been sampled). Environmental coverage can be applied to the prioritisation within Zonation using the 'mask' function, which reduces the prioritisation area to areas of adequate environmental coverage. Only a single mask layer can be incorporated within this function within Zonation, thus it is important the environmental coverage layer represents the sampling distribution of all taxa groups used within the prioritisation (e.g., see demersal fish example below). If multiple taxa groups with different sampling methodology are used within a prioritisation, an alternative approach is to clip the biodiversity layers to adequate environmental coverage outside of Zonation (Figure 4-1, Figure 4-2). In this way, multiple taxon-specific environmental coverage layers can be used to minimise prioritisations in poorly sampled space.

Whether environmental coverage is incorporated as a mask, or outside Zonation, an important stakeholder decision must be made as to what reflects 'adequate' environmental coverage (Figure 4-1, Figure 4-2). Presently, there are no systematic methods to calculate a cut-off value for adequate environmental coverage. Thus, best practice would be to socialise different options and their implications for the prioritisation through a stakeholder process, with stakeholders selecting a value that best represents their expectations for minimising the influence of poorly sampled space while maximising the extent of the prioritisation area. For example, Stephenson et al. (2020a) used a value of 0.05 based on input from the MSAG members, above which environmental coverage was deemed adequate.

To illustrate the influence of different values for adequate environmental coverage, we present three different prioritisation scenarios below, based on demersal fish (EEZ wide SDMs for demersal fish species, Lundquist et al. 2020a; Stephenson et al. 2018a,b, Leathwick et al. 2008). The first scenario is a Zonation analysis without using a mask for environmental coverage (Figure 4-3). The second and third scenarios apply a mask for environmental coverage at either 0.05 (Figure 4-4) or 0.10 (Figure 4-5) cut-offs. The major difference between Figure 4-3 and Figure 4-4 is a substantial decrease in the extent of the prioritisation area under 0.05, following the removal of areas with poor environmental coverage (Figure 4-4). Areas of poor environmental coverage removed from the analysis in Figure 4-4 are typically located in offshore, deep-water regions such as the Bounty Trough, parts of the Challenger Plateau, east of Campbell Island and off the west coast of the Northland Peninsula. With the removal of some high-medium priority cells that were in areas of poor environmental coverage (e.g., centre Challenger Plateau, Figure 4-4), we see some alteration in the distribution of some areas identified as high priority for conservation in the 0.05 scenario (Figure 4-3, Figure 4-4), namely on the south Chatham Rise and on the Campbell Plateau. This comparison shows how changing the prioritisation area extent can influence the distribution of priority areas that are retained in both scenarios. Under a scenario with higher environmental coverage cut-off (0.10), there is a further decrease in the prioritisation area, again in offshore areas (e.g., Challenger Plateau), but very limited change in the distribution of high priority cells (Figure 4-5).

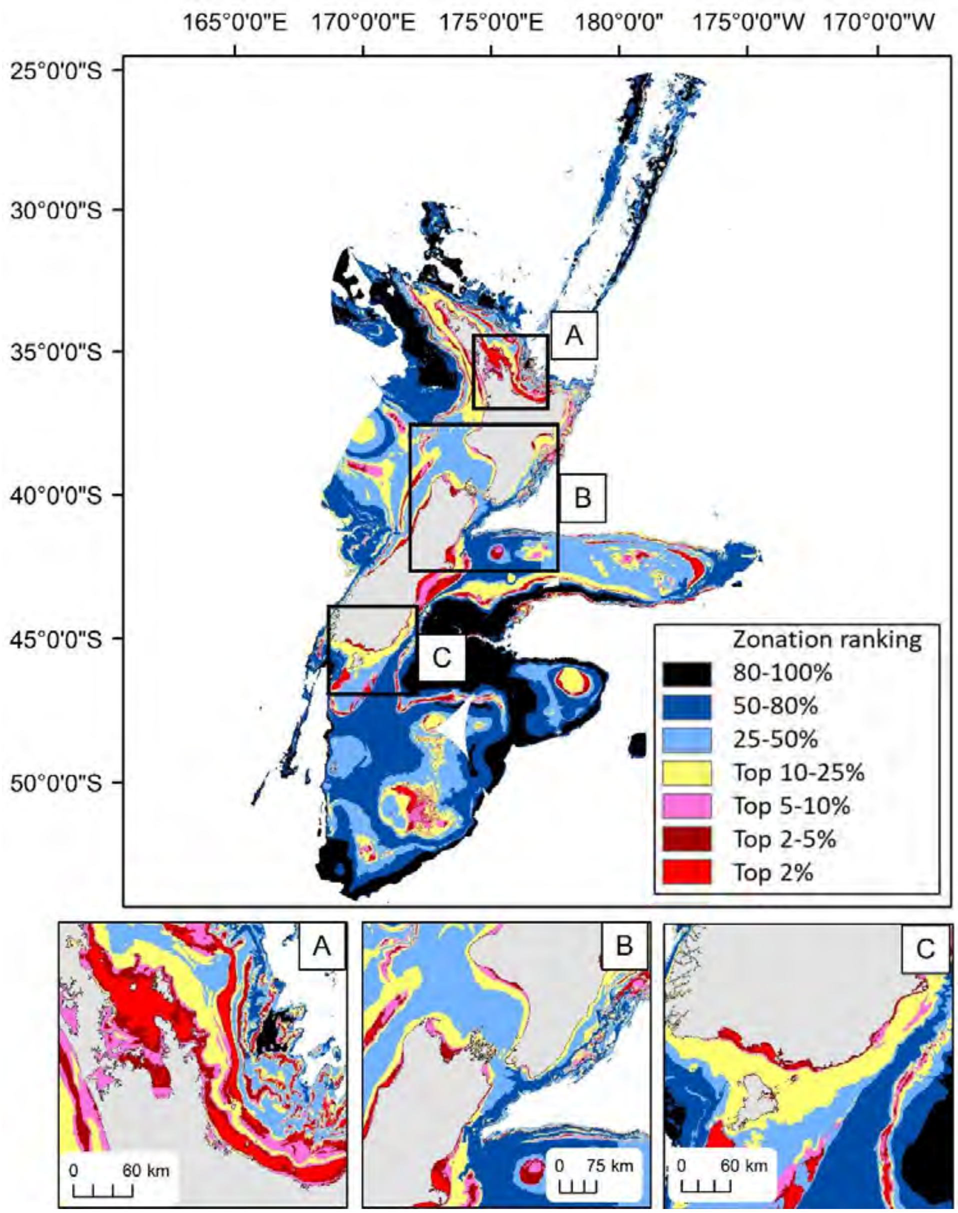

Figure 4-3: Spatial prioritisation based on demersal fish species occurrence models, developed for depths to 2500 m, with no additional clipping to environmental coverage thresholds. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

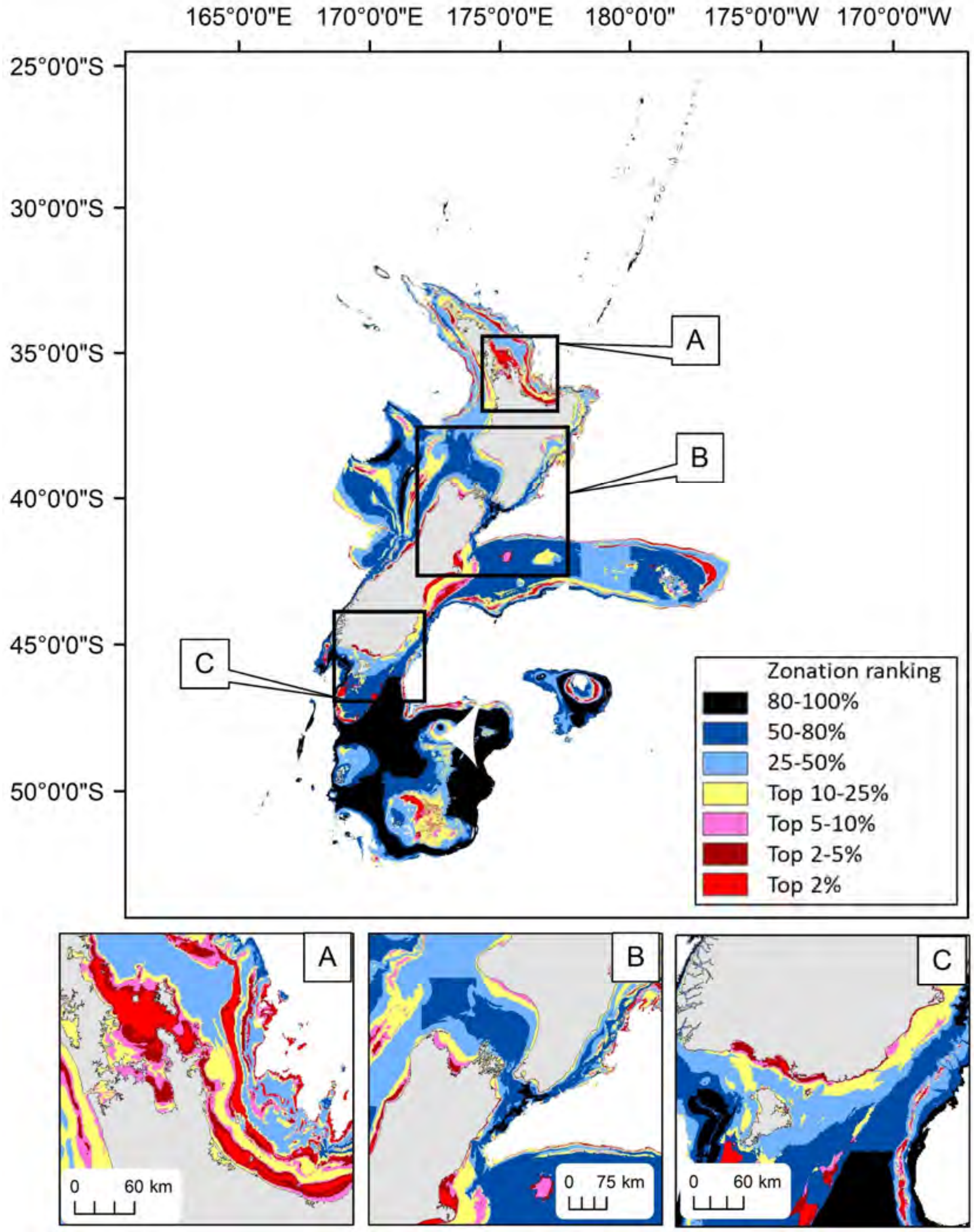

Figure 4-4: Spatial prioritisation of demersal fish clipped to environmental coverage at a threshold of 0.05. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

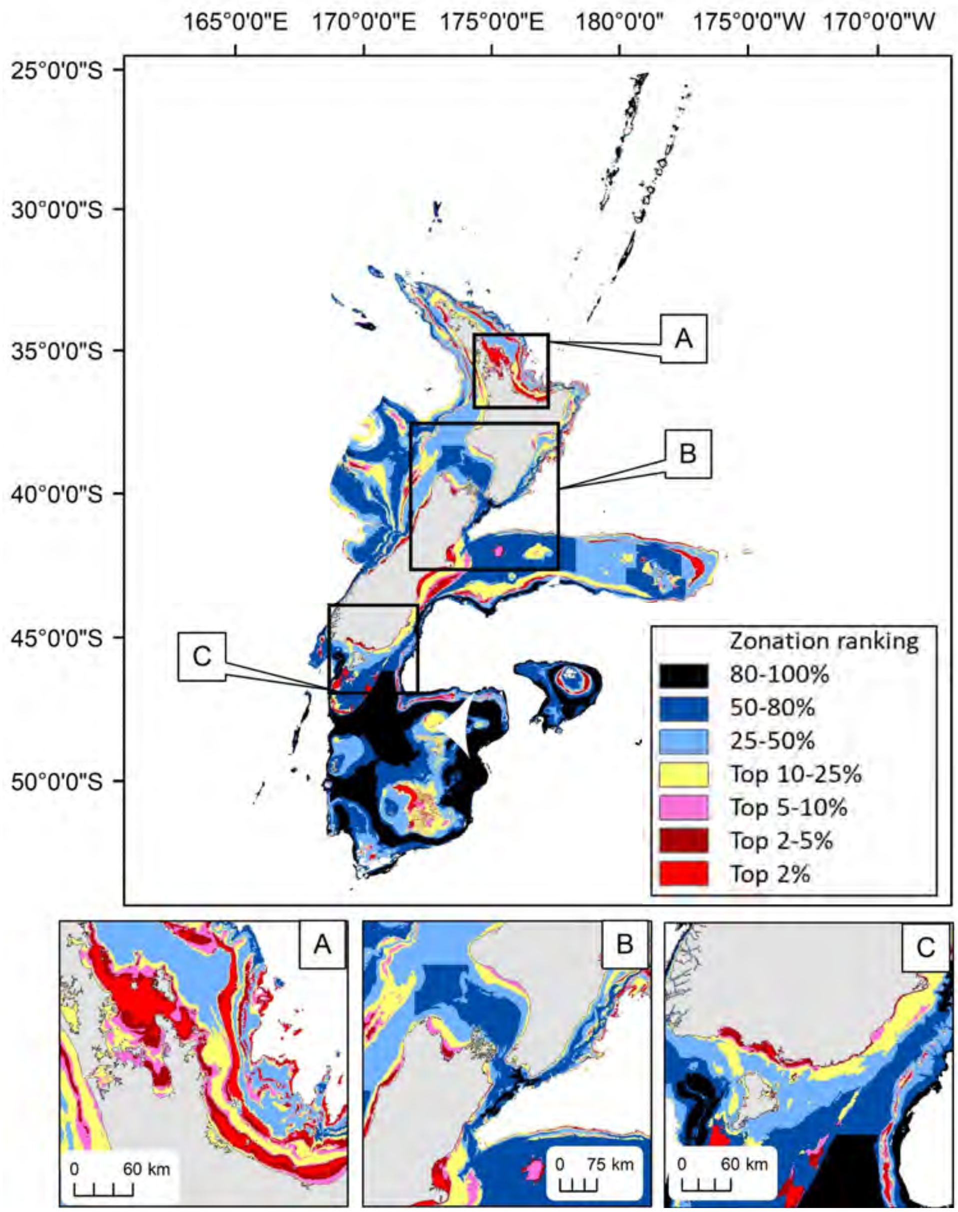

Figure 4-5: Spatial prioritisation of demersal fish clipped to environmental coverage at a threshold of 0.10. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

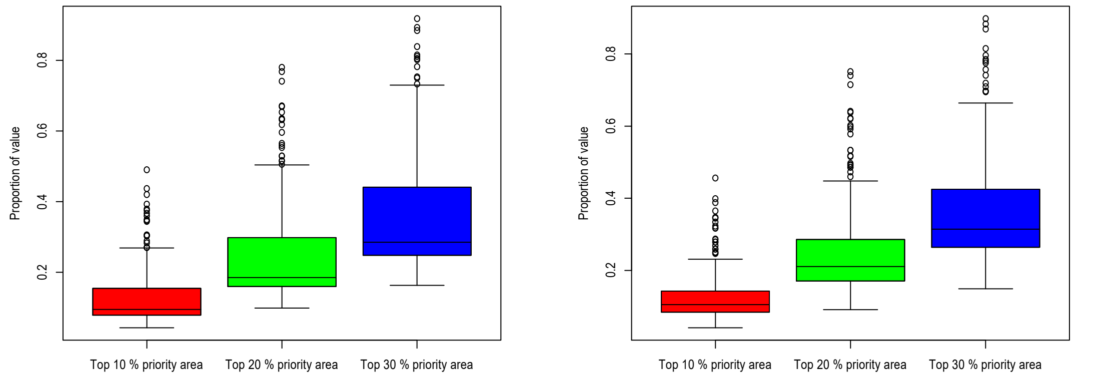

Figure 4-6: Performance of scenarios used to remove knowledge gaps by clipping the analysis extent to areas of adequate environmental coverage. The figure on the left used an environmental coverage cut-off of 0.05 and the figure on the right used an environmental coverage of 0.1.

In this comparison, there was very little difference in the performance of the Zonation prioritisation between the two scenarios with different environmental coverage cut-offs (Figure 4-6). This result is likely due to areas with poor environmental coverage having low predicted habitat suitability for demersal fish. However, it is important to appraise how decisions on the environmental coverage cut-off can impact on prioritisation performance as in some cases, areas with poor environmental coverage can have high predicted habitat suitability (e.g., the cetacean scenario).

4.2 Step 2: Regional vs national prioritisation balancing

Section 4.2: Key messages

- The scale of the analysis can influence the performance of prioritisations. Users may wish to explore several scales of analysis to determine the scale most appropriate for a given planning process.
- Zonation model options allow for balancing representation within subregions, e.g., to include both national and regional targets for representation of biodiversity features.
- The administrative unit (ADMU) function in Zonation sets geographic boundaries for management or administration units, allowing for targets for representation of different features to be achieved within these units, as well across the full area.
- The function 'mask missing areas' can be used to perform regional analyses for localised areas to determine high priority areas within a certain region.

A second major decision point for spatial prioritisations is the scale at which the prioritisation analyses are carried out. This decision point is strongly linked to the objectives of the project and the scales used for reporting protection metrics. For example, in a New Zealand context, spatial planning processes may be carried out for the entire New Zealand marine realm for which New Zealand has an obligation to report protection metrics under the Convention for Biological Diversity (https://www.cbd.int/). In contrast, unitary authorities responsible for protection of biodiversity with defined jurisdictions within the territorial sea are likely to require prioritisations on regional scales (e.g., 10s to 100s of km^2).

Zonation has several options for setting different scales of prioritisation. The first option is the use of the 'administrative unit' (ADMU) function. This function uses a raster layer that sets geographic boundaries for management or administration units by assignment of different values to each unit. Zonation can then perform prioritisations within each of these different units separately, while still allowing the reporting of protection statistics for the entire prioritisation area. Further, the ADMU weighting option allows a user to specify the degree to which the prioritisation is focussed within individual administrative units with options for a scenario to be fully local (coded by 0), fully global (coded by 1), or anywhere in between.

To illustrate the influence of using the ADMU function to balance regional and national prioritisations, we have provided several examples below. The first example shows the use of the ADMU function to perform prioritisations within the boundaries of the Territorial Sea (<12 nm of coast) and the EEZ (>12 nm of coast to 200 nm) separately (Figure 4-7). In this scenario, the ADMU weighting value is set to 0 – full local prioritisation. This ADMU scenario is undertaken for the demersal fish taxonomic group and includes SDMs for 239 fish species. When compared with the outputs from the baseline demersal fish scenario (Figure 4-3), there is an increased prioritisation of deeper areas within the Territorial Sea to be more inclusive of taxa associated with deeper habitats found on the edges of the Territorial Sea. The changes in priority include deep areas around all the major offshore island groups (particularly the Kermadec Islands, Auckland Islands) and inshore areas such as Kaikoura Canyon. Offshore (EEZ) prioritisation values remain similar, other than some changes around the Challenger Plateau (Figure 4-7).

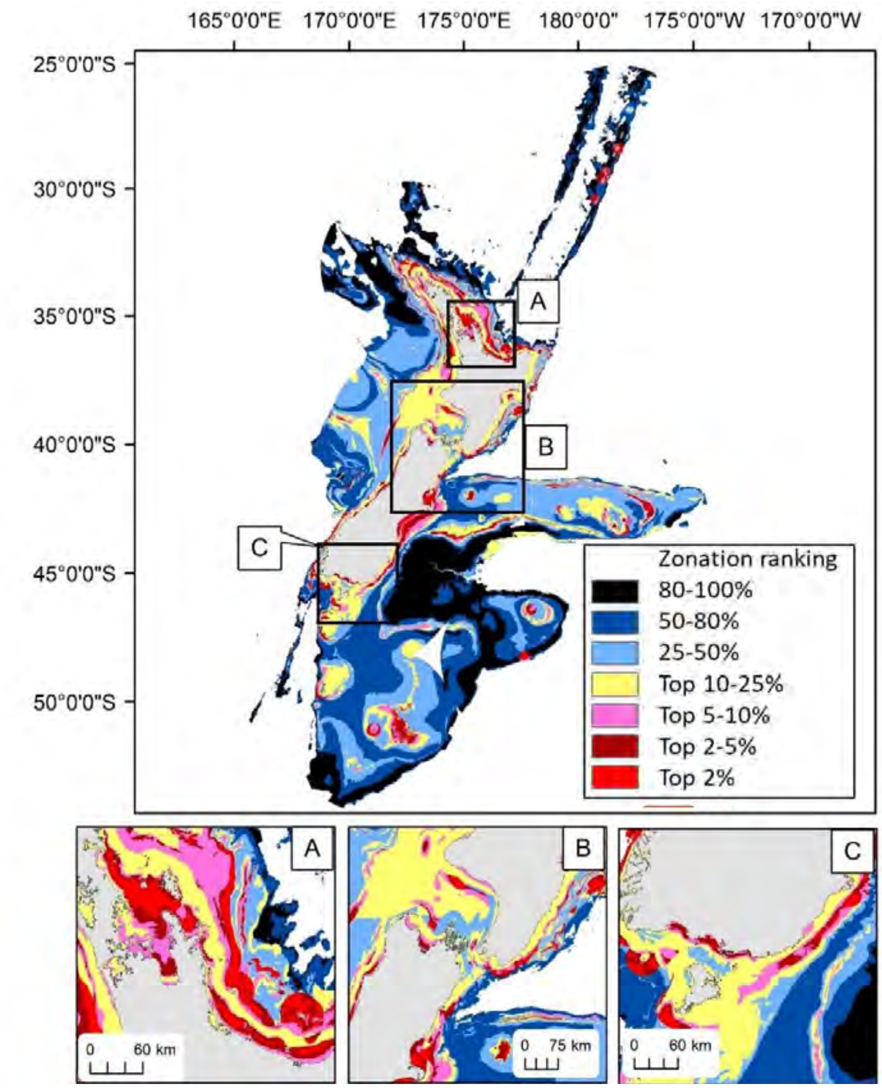

Figure 4-7: Spatial prioritisation based on demersal fish, using an ADMU option to balance priorities between the Territorial Sea and the broader EEZ. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

Using an ADMU to partition the demersal fish prioritisation into Territorial Sea and EEZ strata results in a small decrease in the average performance of the prioritisation when compared to the baseline demersal fish scenario (Figure 4-8). This result is likely due to forcing an unnatural boundary across an area that constitutes an important part of the range of many demersal fish species. Such fragmentation of habitat is an important consideration when setting ADMU settings.

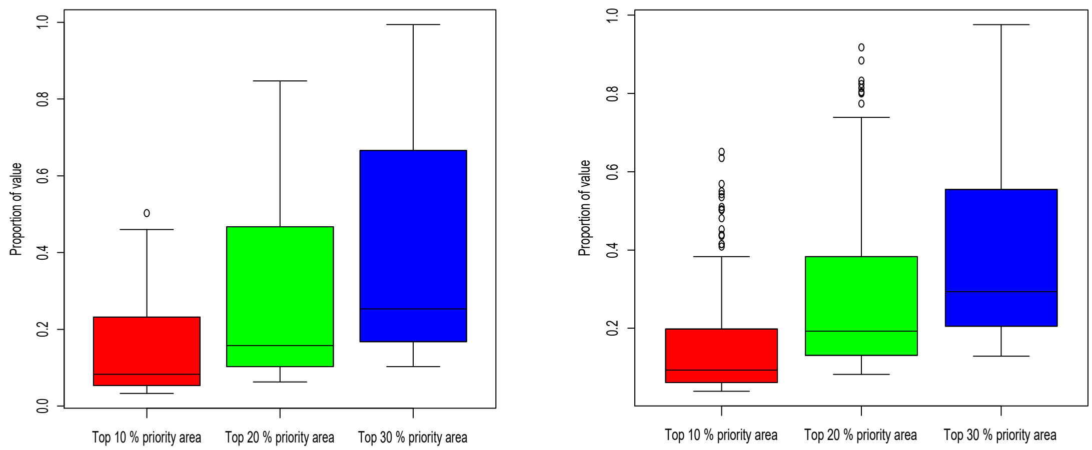

Figure 4-8: Performance of scenario for the spatial prioritisation of demersal fish using an ADMU function for the territorial sea and the EEZ (left), compared with the performance of the baseline demersal fish scenario (right).

Another example of using the ADMU function to alter the scale of the prioritisation is the use of bioregions. While not necessarily reflecting boundaries for the management of different jurisdictions, setting bioregions as administration units ensures prioritisations provide appropriate representation for areas of different environmental character (at broad scales). In this scenario, we have used a 7-group classification from the SCC to categorise the New Zealand marine environment into 7 bioregions (Figure 4-9). This bioregional layer was used as an ADMU layer with the ADMU weight set to 0 (full local scale prioritisation within each bioregion). Again, the demersal fish taxonomic group was used for an example in this scenario. Under this bioregional prioritisation, there are some marked differences in the distribution of prioritisation values compared to the baseline demersal fish scenario (Figure 4-10). A greater area on the Chatham Rise is categorised as medium priority area, and there are substantial differences in prioritisation around the shelves of the sub-Antarctic Islands.

Prioritisation patterns in coastal areas remain broadly similar, apart from the locations where narrow bands of key bioregions exist, e.g., Pegasus Bay and the Kaikoura coast, the Marlborough Sounds, and around Solander Island off Southland (Figure 4-10). Similar to the Territorial Sea-EEZ ADMU scenario (Figure 4-7), deeper parts of more coastal bioregions tend to be favoured, likely due to sampling bias favouring similar depths throughout the EEZ. Often, the distribution of priority bands reflects the shape of the bioregions themselves, which can result in some sharp transitions between priority areas (e.g., the Chatham Rise).

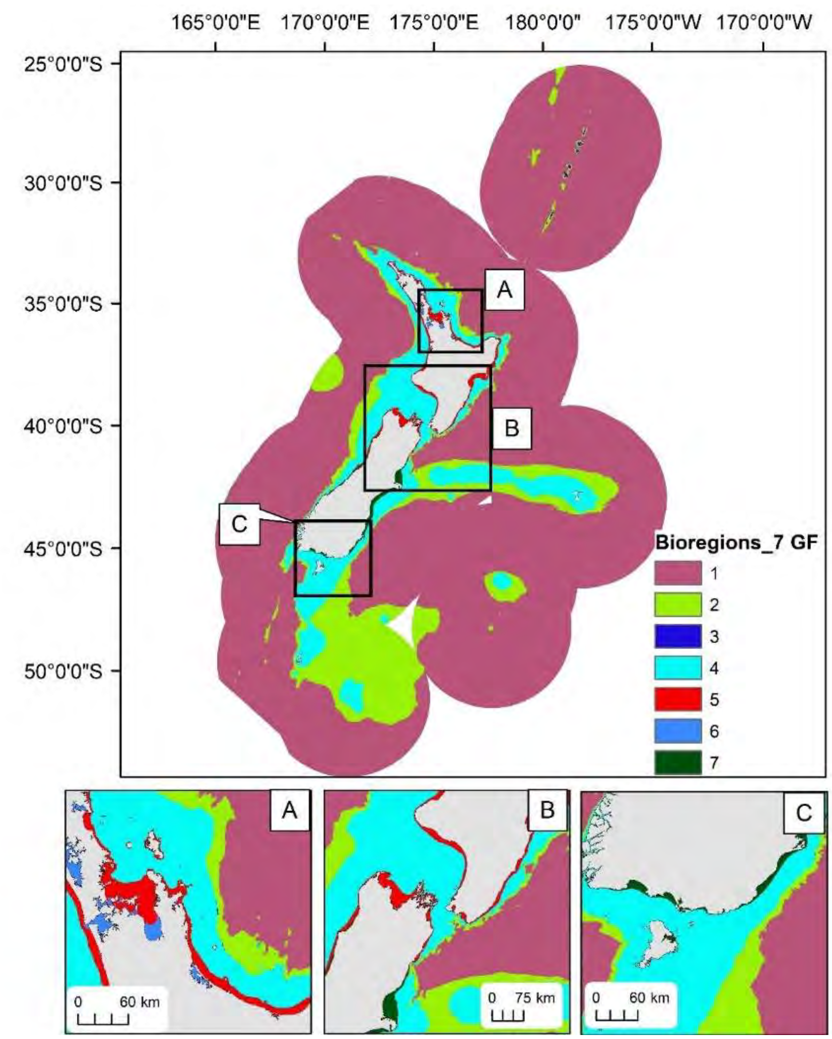

Figure 4-9: An example of using the Seafloor Community Classification to categorise the New Zealand marine environment into 7 bioregions for use as Administrative Units in Zonation.

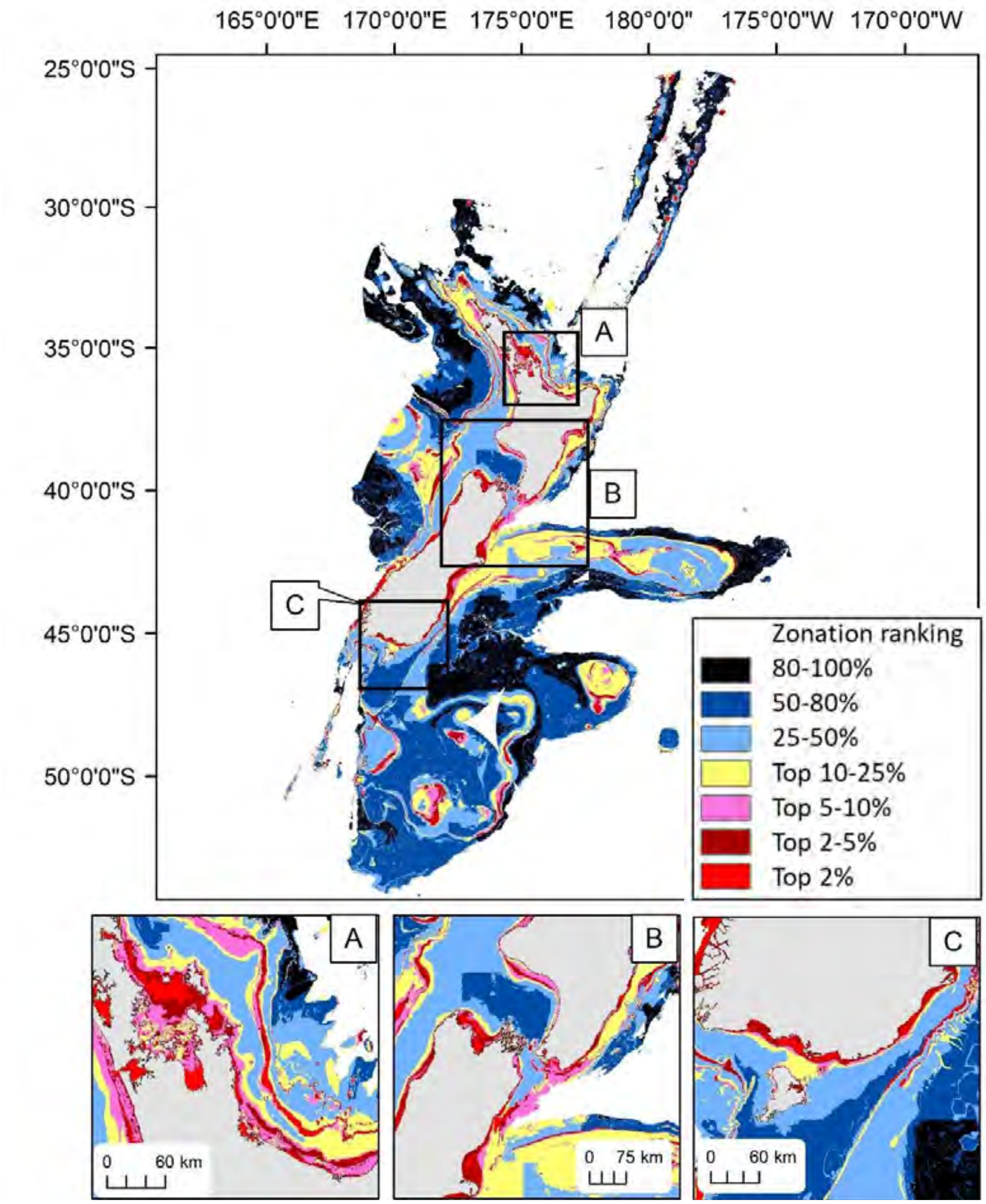

Figure 4-10: Spatial prioritisation based on demersal fish, using an ADMU option (weighting 100% regional) to balance priorities between across 7 bioregions identified using the Seafloor Community Classification. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

The performance of the demersal fish bioregional analysis shows a slight increase in proportion of value protected across the top 10, 20 and 30% priority areas when compared with the baseline demersal fish scenario (Figure 4-11). This result illustrates how protection can be increased when the representativeness of distinct communities is incorporated into the spatial prioritisation and contrasts with the decrease in protection observed under the Territorial Sea-EEZ scenario.

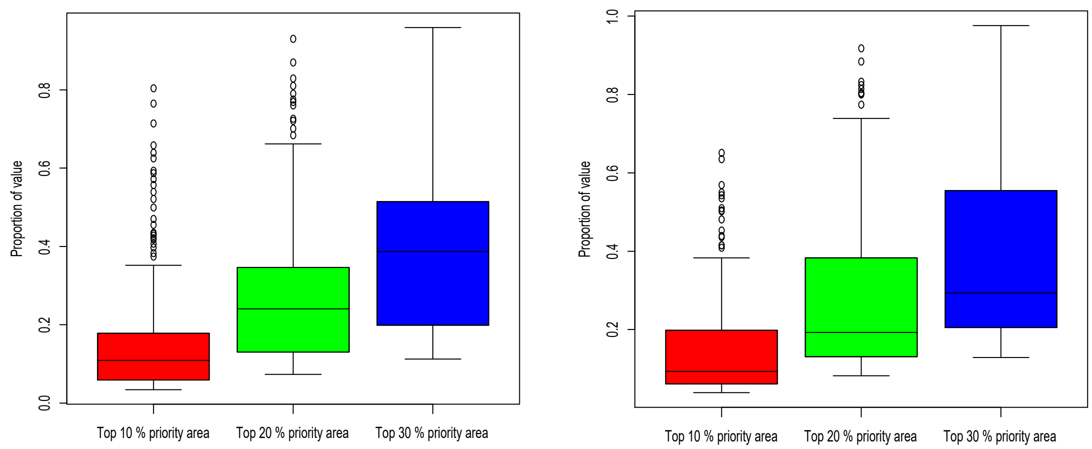

Figure 4-11: The performance of a scenario that uses a 7-class bioregional layer as an ADMU in order to force representation of different bioregions in a demersal fish prioritisation (left), compared with the performance of the baseline demersal fish scenario (right).

To demonstrate how varying the ADMU weight settings affects the spatial prioritisation, we also generated a scenario where we perform the same bioregional analysis detailed above, under higher (or lower) weightings of regional versus global priorities (ADMU weight settings of 0.3 and 0.7, respectively, Figure 4-12, Figure 4-13). In essence, the distribution of prioritisation values in these two scenarios illustrate transitions between the fully local ADMU scenario (Figure 4-10) and the fully global scenario (baseline demersal fish iteration; Figure 4-3). For example, the notable changes in prioritisation around the sub-Antarctic Islands under the fully local scenario are more gradual under the intermediate ADMU weighting scenarios. Further, the broad establishment of medium priority cells across much of the western Chatham Rise under the fully local scenario was not indicated in the intermediate weighting runs, where the distribution of priority cells more closely resembled the fully global scenario.

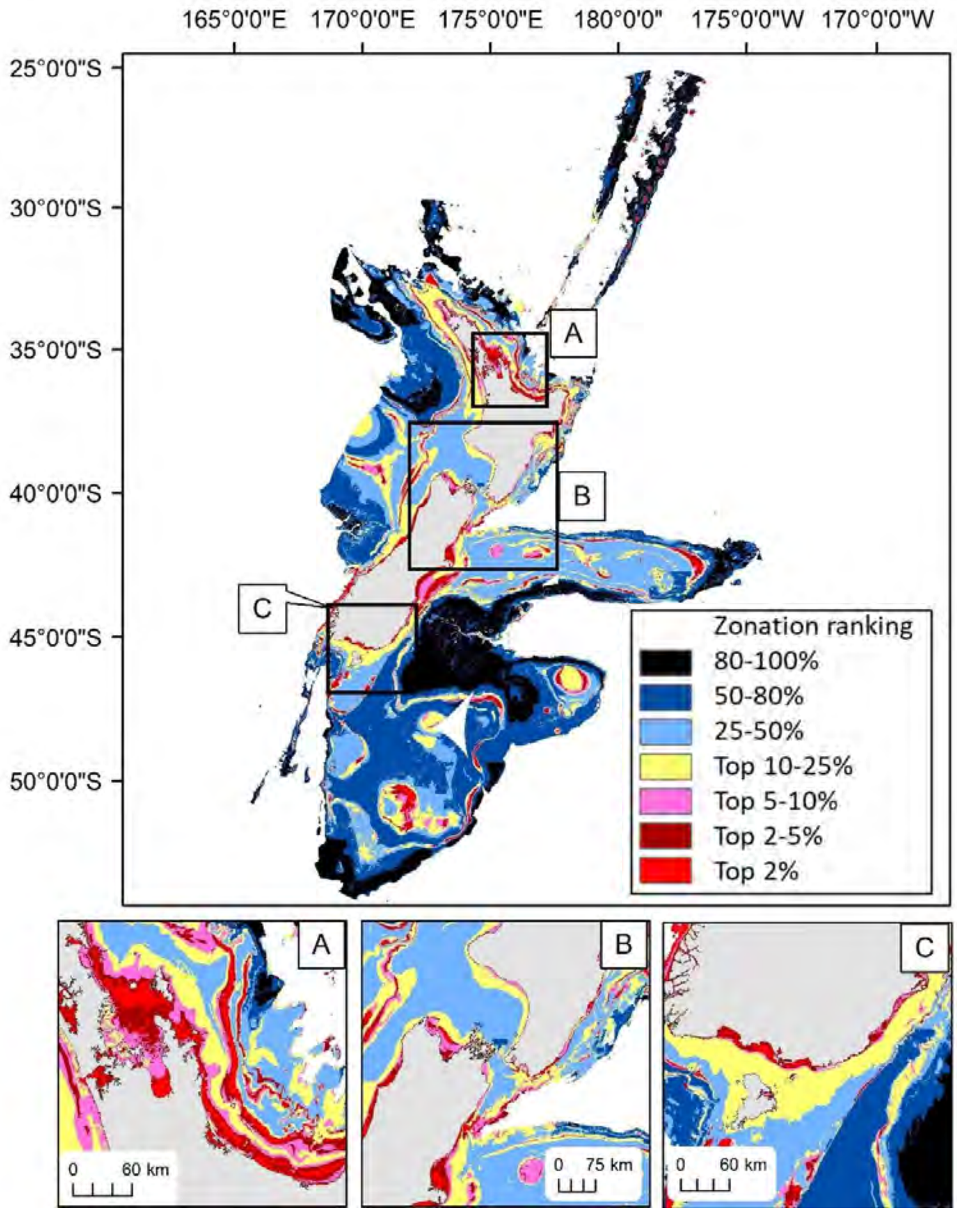

Figure 4-12: Spatial prioritisation based on demersal fish, using an ADMU option (weighting 0.3) to balance priorities between across 7 bioregions identified using the Seafloor Community Classification. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

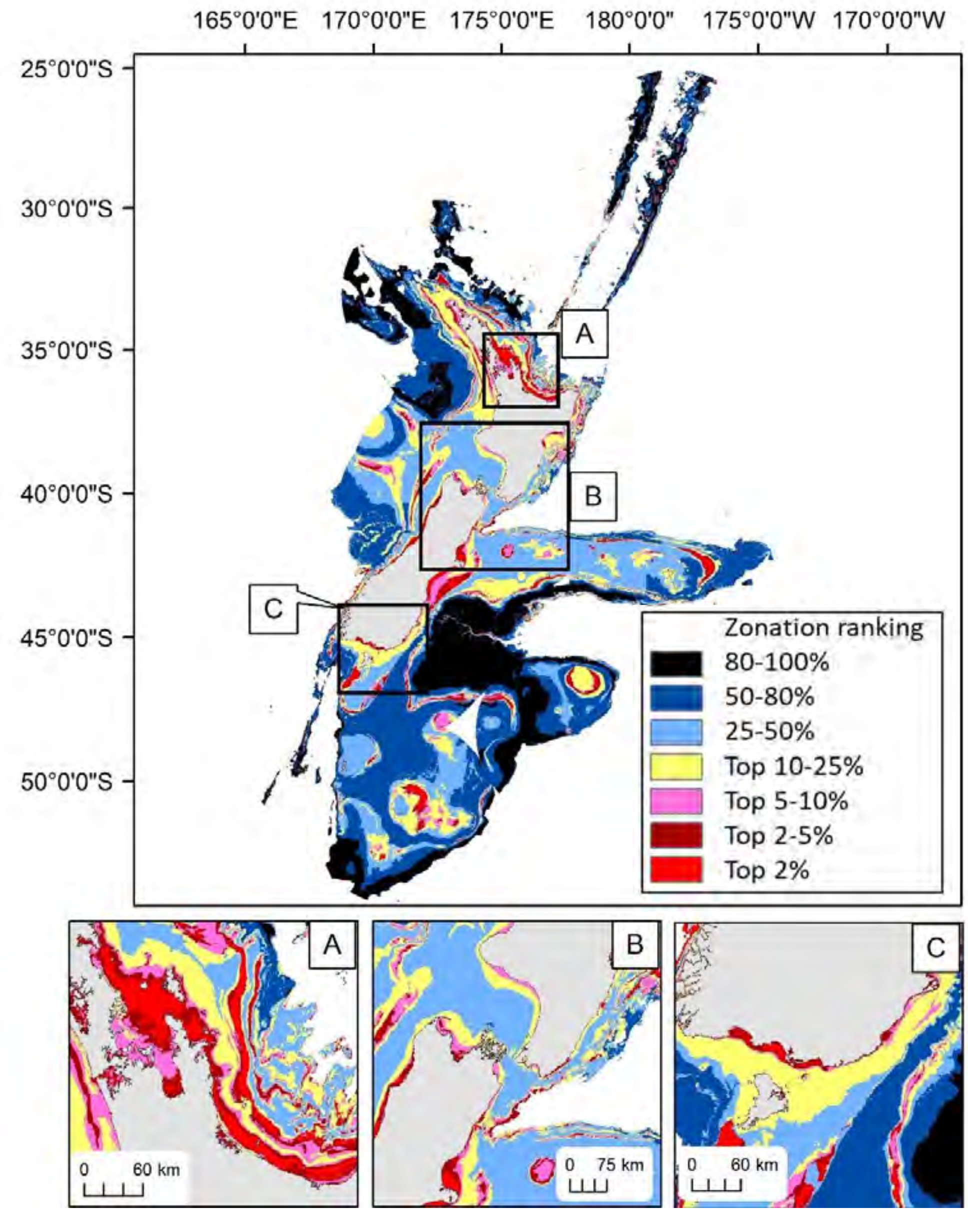

Figure 4-13: Spatial prioritisation based on demersal fish, using an ADMU option (weighting 0.3) to balance priorities between across 7 bioregions identified using the Seafloor Community Classification. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

If a particular location is the target of spatial planning, another option is to use the Zonation function 'mask-missing-areas' to remove all spatial data outside of the area of interest. A gridded spatial layer detailing the extent of the regional area of interest is provided within this option, which Zonation uses to clip the prioritisation extent. All further analyses are done within this area only.

This option allows users to determine the high priority areas within a certain region, without reference to the distribution of biodiversity values elsewhere and can be useful for setting regional-based planning targets. Further, it allows an appraisal of how well national prioritisation scenarios determine locally important areas.

To illustrate this example, we conducted a suite of prioritisation scenarios for the Cook Strait region, with the extent of this regional analysis determined via consultation with the MSAG. We performed the regional scale prioritisation for a range of taxa groups and KEA criteria but give the results for two taxa groups, demersal fish and cetaceans. In order to compare how prioritisation outputs can differ depending on the scale of analysis, we also provide the national scale prioritisation outputs clipped to the area of interest for these two taxa groups (Figure 4-14, Figure 4-15, Figure 4-16, Figure 4-17).

There are considerable differences in the distribution of prioritisation values between the regional and national demersal fish scenarios. The national scenario shows broad bands of prioritisation cells that run adjacent to the coastline in the north and south coasts of Cook Strait (Figure 4-15), while the regional scenario has much more fine scale variability in the distribution of high priority areas with clear regional hotspots (Figure 4-14). Under the national scenario, the Marlborough Sounds is categorised as medium to high value while it is low value in the regional example. The main similarities between the two scales are high value areas in Golden Bay and in Cloudy/Clifford Bays, suggesting these are important locations for demersal fish at both regional and national scales.

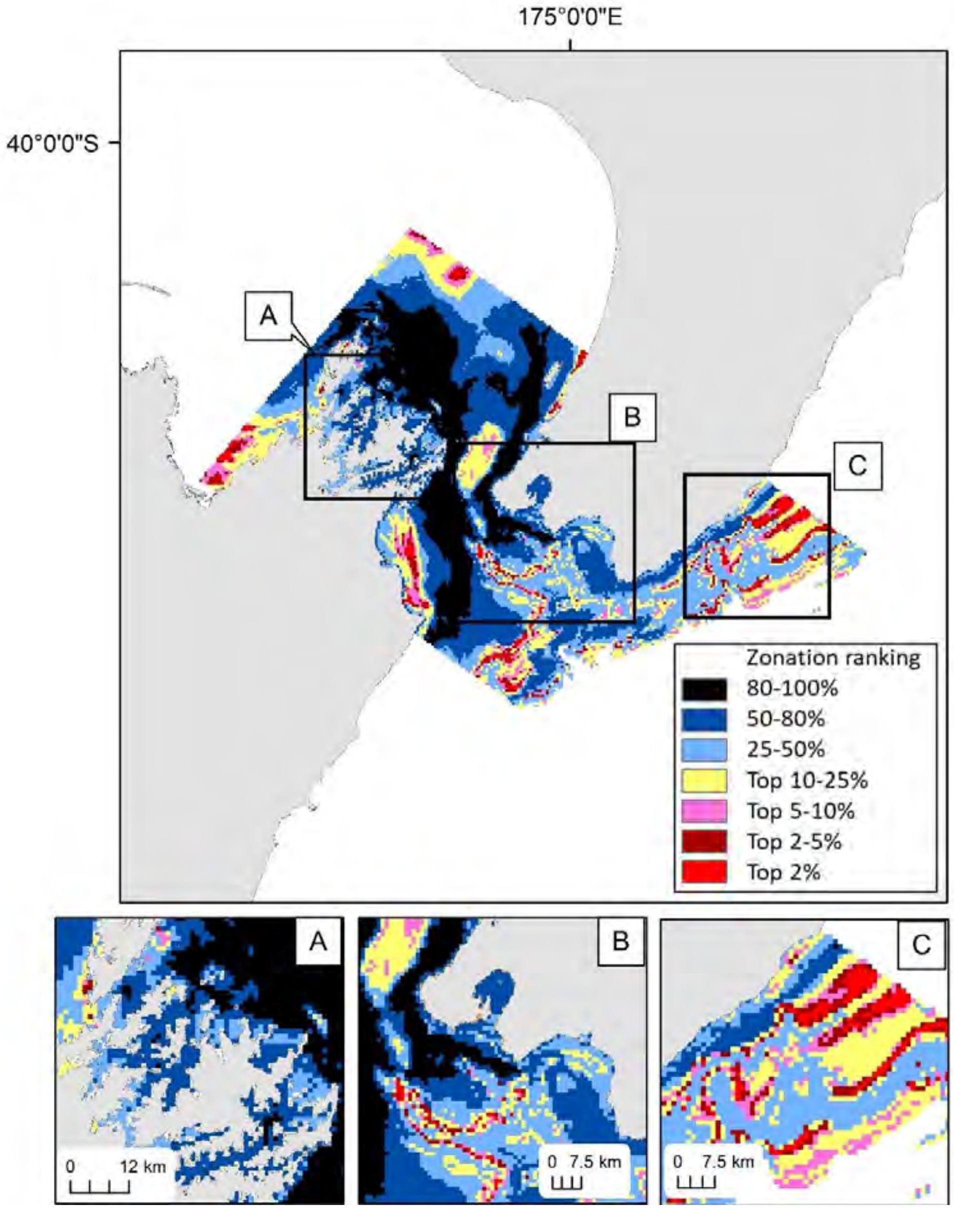

Figure 4-14: Spatial prioritisation based on demersal fish, using a mask layer to analyse datasets within only the Cook Strait region. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

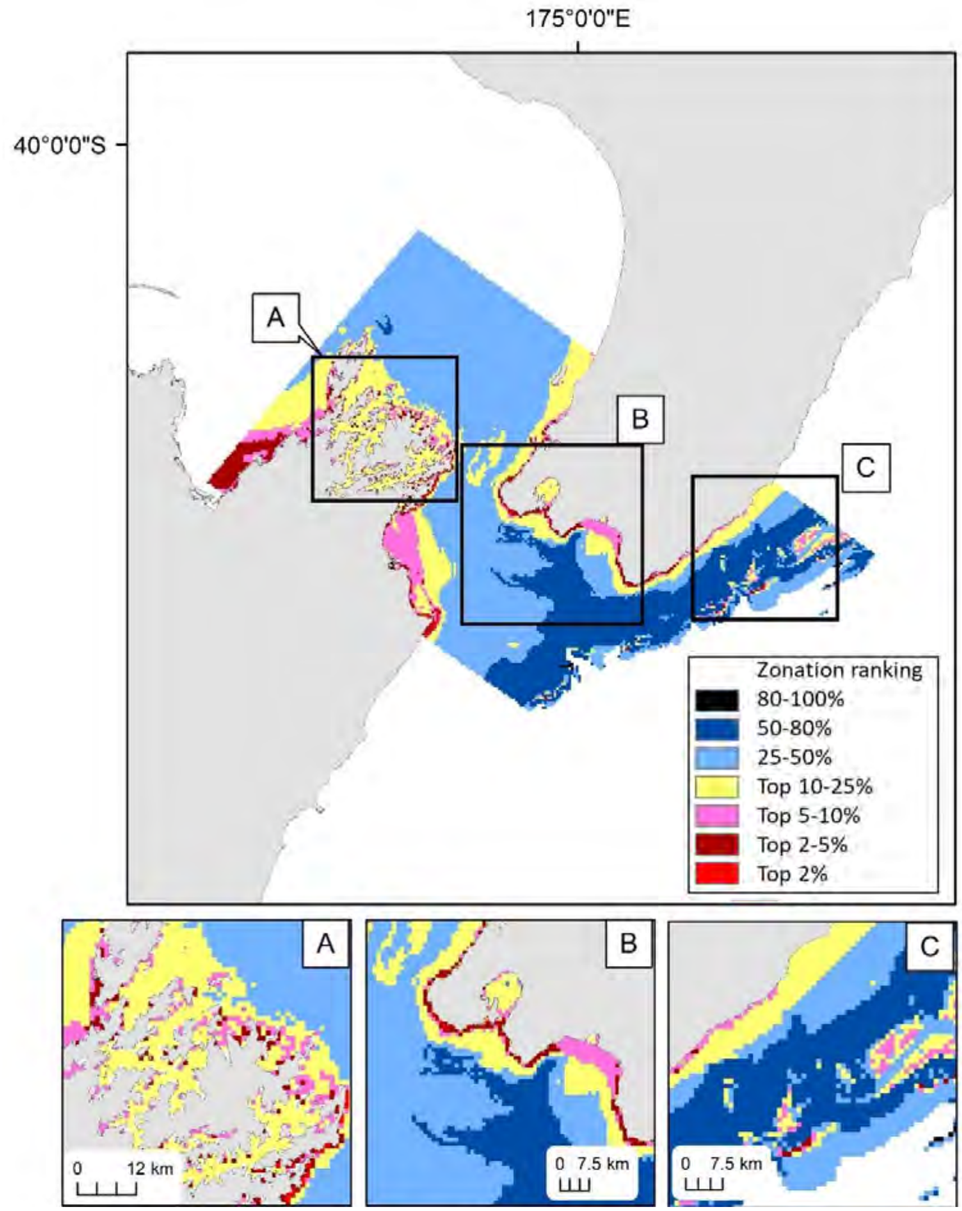

Figure 4-15: Spatial prioritisation based on demersal fish using national layers to depths of 2500 m, but showing only Cook Strait regional area. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

Similar to the demersal fish comparison, high value areas for cetaceans under the national scale prioritisation are reflected as coastal bands, while the regional analyses show more fine scale hotspots in some areas. Under the national scenario, the majority of the Marlborough Sounds is classified as high value (Figure 4-17) compared to small localised hotspots within the sound under the regional scenario (Figure 4-16). Areas in Cloudy Bay and the South Taranaki Bight are high value areas under both the regional and national scenario. A notable feature of the regional scenario is the band of medium-high prioritisation in the southeast of the study area. This spatial pattern is due to a large number of cetacean modelled distributions being driven largely by depth, and thus deeper-offshore habitats are determined as high value by Zonation due to the overlap of a large proportion of these cetacean distributions.

However, a large number of the depth-driven models are less accurate relative to environmental suitability models and are based on a limited number of cetacean sighting records (see section 4.3) and thus caution must be exercised when interpreting these depth related prioritisation bands. Such a feature was not evident in the national scale cetacean scenario, likely because the depths within the regional study area are comparatively shallow with respect to the depth distribution of habitat throughout the EEZ.

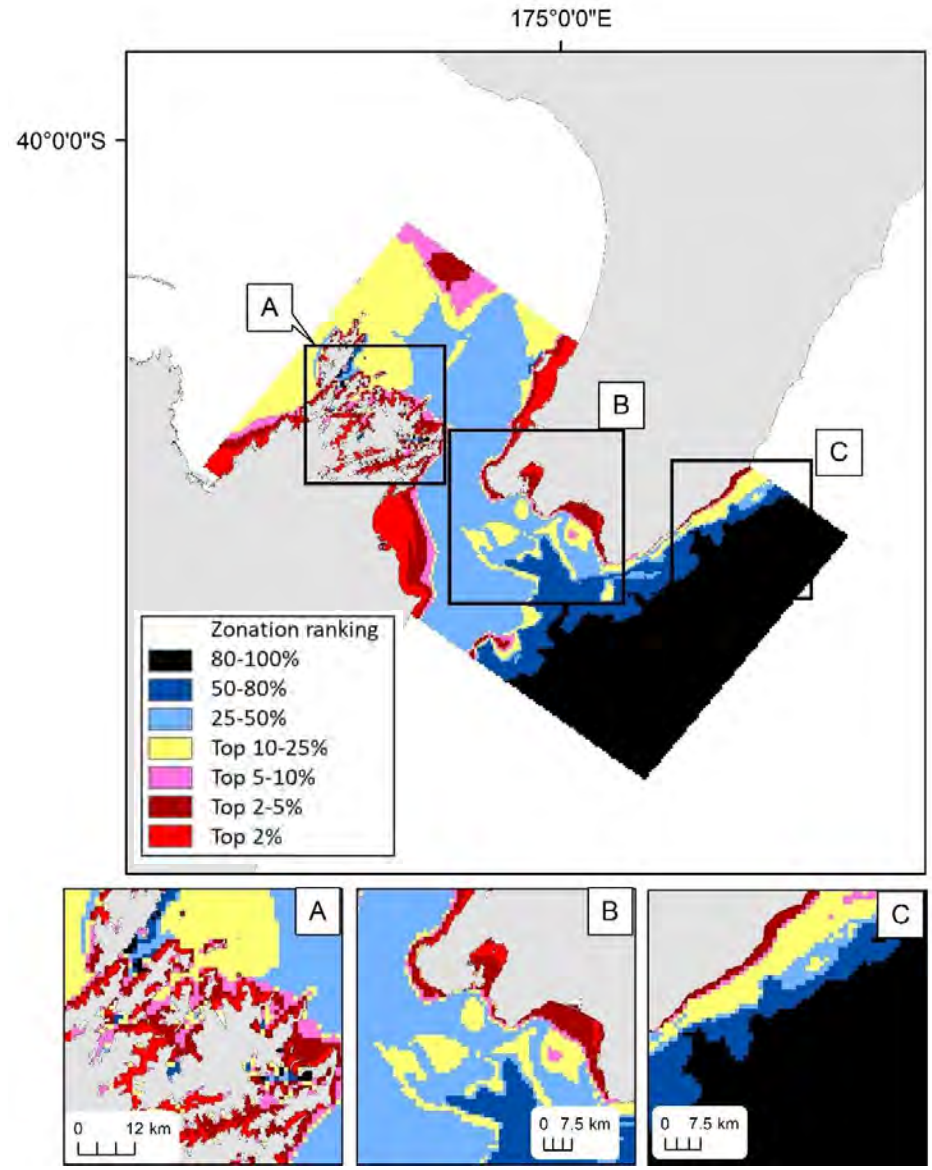

Figure 4-16: Spatial prioritisation based on modelled cetacean distributions masked such that analysis includes only Cook Strait regional area. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

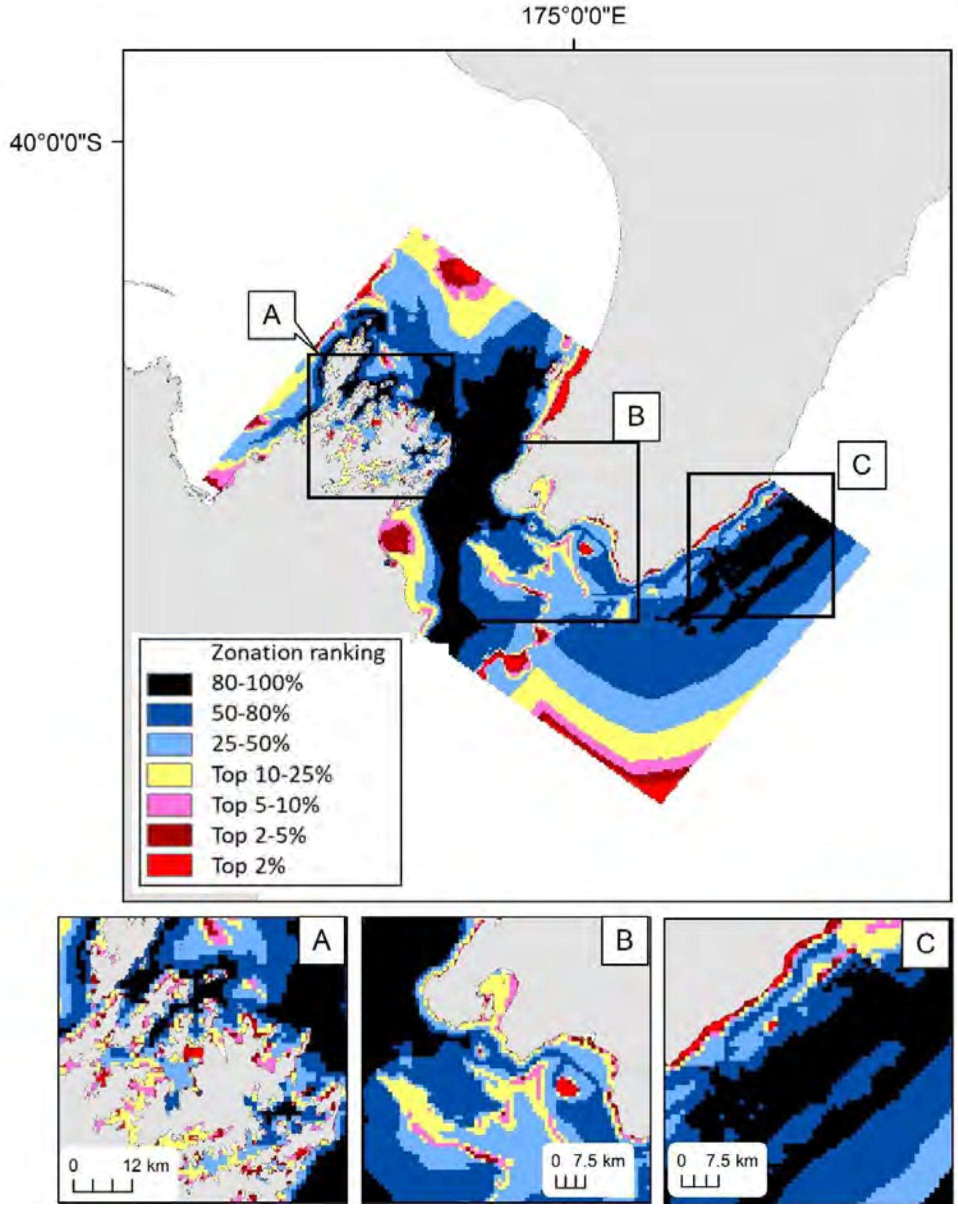

Figure 4-17: Spatial prioritisation based on modelled cetacean distributions using national layers, but showing only Cook Strait regional area. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

When deciding whether a regional or national prioritisation may be appropriate for a certain location, it is important to consider the protection metrics afforded by analyses at either scale. To assess which scale is most appropriate, metrics need to be calculated for the proportion of biodiversity protected across different taxa or KEA criteria layers. These calculations sum the cell values (e.g., species occurrence/abundance) inside and outside 'protection' areas, with the boundaries of these areas being various Zonation priority cell cut-offs (e.g., the top 10, 20 or 30% priority areas). Such calculations give an objective measure of the performance of various Zonation prioritisations across different biodiversity values and scales of prioritisation. We have provided an illustration of such calculations for key taxonomic and KEA criteria layers, under 10, 20 and 30%

prioritisation areas for the regional and national scale demersal fish and cetacean taxa scenarios (Figure 4-18).

The performance of the demersal fish prioritisation was higher across each of the three priority zones (10, 20, 30%) when undertaken at a regional scale, compared with the national scale analysis (Figure 4-18). The prioritisation was particularly more efficient under the top 30% priority area at the regional scale. Such increases in performance in regional analyses is likely related to the ability of Zonation to discern biodiversity hotspots at much finer scales, due to comparatively fewer constraints around the minimum size of such features. The trade-off with such fine scale characterisation is increased complexity in the distribution of high priority areas, which may be more difficult to socialise with stakeholders (Moilanen et al. 2013). An additional trade-off results from the likelihood that high priority areas may not align across regional boundaries. Jurisdictional boundaries may not reflect any meaningful segregation of biodiversity values, and may compromise the performance of prioritisations at regional scales when compared to broad national scales (e.g., Moilanen et al. 2014).

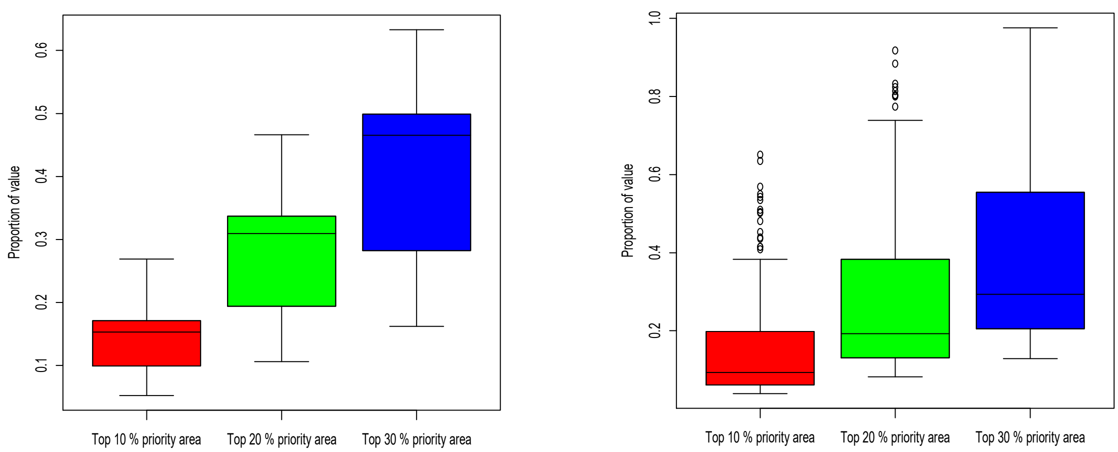

Figure 4-18: Box and whisker plots of relative protection given to demersal fish in the national (right) and regional (left) prioritisations.

A key advantage of performing prioritisations at regional scales is the possibility of incorporating additional, fine-scale data that may be incomplete at broader scales. This process may include the use of gridded environmental data or predictive models of species distributions that are higher resolution (e.g., 250 m vs 1 km), or new data sets that are only available within a regional area of interest. Currently, there is a lack of accurate fine-scale data on substrate characteristics (e.g., reef, mud, sand habitat types) for most locations at a national scale. These data are an important component for predictive models for a range of taxa, and there may be reasons to ensure prioritisation is representative of certain habitat types (e.g., reef habitat with important biodiversity, productivity and rarity values in some areas). Accurate substrate datasets exist in some regional locations and thus prioritisations in these areas would benefit from their inclusion; a national layer is available from Bostock et al. (2019).

One possible use for substrate type datasets is to perform a prioritisation using substrate type as an ADMU – whereby a prioritisation would select the high value locations for protection within different substrate classes (i.e., the best locations for reef or sand habitat protection). In this scenario, a spatial layer denoting the extent of each substrate type would be supplied as the ADMU layer, coded by different numbers. However, this intervention may not be appropriate if the underlying species distribution models do not include substrate type as an environmental predictor. Without information on the relationship between substrate and species occurrence, Zonation prioritisation values may incorporate erroneous predictions of habitat suitability that is inherently unsuitable for species that are substrate obligate.

An illustration of how a substrate type layer may be used as an ADMU in a regional prioritisation showcases how this could be used to prioritise 'best' areas for particular sediment types such as rocky reef areas (Figure 4-19). In this scenario, we use a spatial layer that illustrates different sediment types, established by Bostock et al. (2019), and a reef substrate layer provided by the Department of Conservation. While these layers have some recognised inaccuracies (Stephenson et al. 2020b), for the purposes of an example prioritisation it is useful to illustrate how new data could be included within a regional scale prioritisation if available. The input biodiversity layers for this scenario are SDMs for demersal fish, benthic invertebrates, reef fish and macroalgae (Figure 4-19).

The incorporation of an ADMU for substrate type causes some fragmentation of the Zonation priority bands that reflect areas of different substrate types (Figure 4-19). Small, high-priority areas that consist of a small number of cells are typically the location of valuable reef habitat – such patchiness reflects the nature of this habitat type compared to broader spatial coverage of soft sediment habitats. Clusters of high priority reef habitat are seen in the Marlborough Sounds, on the Wellington South Coast and along the Wairarapa Coast.

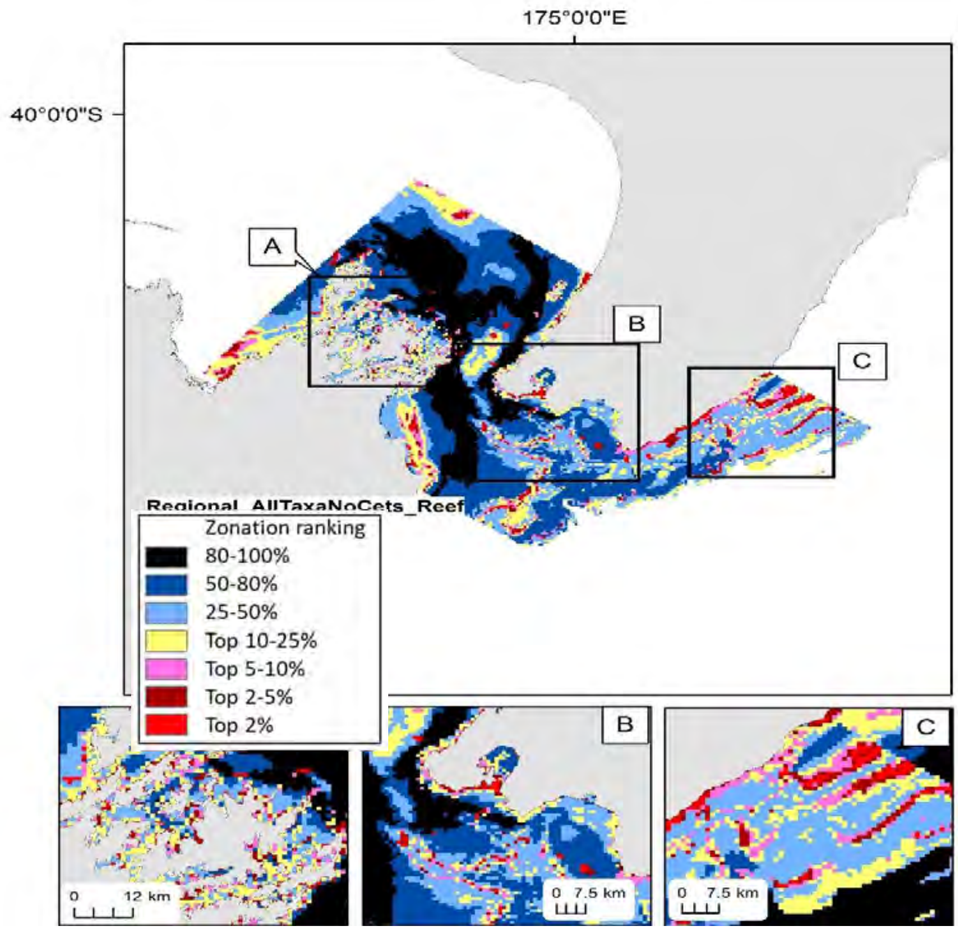

Figure 4-19: Spatial prioritisation utilising sediment layers as Administrative Units for balancing priorities across sediment type. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

4.3 Step 3: Utilising predictive models of taxa groups

Section 4.3: Key messages

- Predictive models are based on the relationship between the characteristics of the environment (e.g., depth, temperature) and the presence or abundance of taxa or habitats. This relationship allows the prediction of presence/abundance to cells with known environmental characteristics.
- Currently, 613 marine species distribution models are available at a national extent for taxa which include demersal fish, benthic invertebrates, cetaceans, macroalgae and reef fish.
- The distribution of different taxa groups is driven by different environmental characteristics. To understand how different taxa groups influence a prioritisation, Zonation scenarios can assess the influence of each taxa group independently before combining taxa groups into a single scenario.

Predictive models of taxa are often available as input layers into biodiversity prioritisation scenarios. Often only a subset of total biodiversity is represented in species distribution models, and models are often biased to particular taxonomic groups of economic or societal interest, for example, prior national scale layers were until recently limited to demersal fish models (Leathwick et al. 2008). Recent predictive models (reviewed in Lundquist et al. 2020a) include a total of 613 species occurrence models, with EEZ scale models for 30 cetacean taxa (including species, subspecies and species complexes), models to 2500 m depth for 239 demersal fish species, and models for 207 benthic invertebrate genera. Species occurrence models available for only reef habitats in shallower waters are available for 51 rocky reef associated fish species and 86 macroalgal species.

Because distributions of different species, genera and broader taxa groups are likely to be driven by different environmental features, it is important to consider how each suite of taxa models influences spatial prioritisations prior to including all distributions in a combined model. Completing a series of scenarios for each taxa group allows interpretation of broader patterns within taxa groups that may have strong influence within combined models. Different taxa model layers may also have different extents, due to available point records to inform distributions or known environmental features that are key drivers of patterns in distribution for these taxa (e.g., macroalgal associations with hard substrates).

Not surprisingly, different taxa groups show differences in priority areas across the New Zealand EEZ (demersal fish: Figure 4-3, benthic invertebrates: Figure 4-20, rocky reef fish: Figure 4-21, macroalgae: Figure 4-22, cetaceans: Figure 4-23). Differences are most notable between different extents (e.g., reef substrate models versus models to 2500 m versus models of the full EEZ for cetaceans). Priority areas also show differences in locations of priority given to inshore versus offshore locations. Understanding how these taxa model layers influence prioritisations is useful in determining how to weight groups of layers in combined analyses (see combined taxa group runs in this section, and all-inclusive analysis in section 4.7).

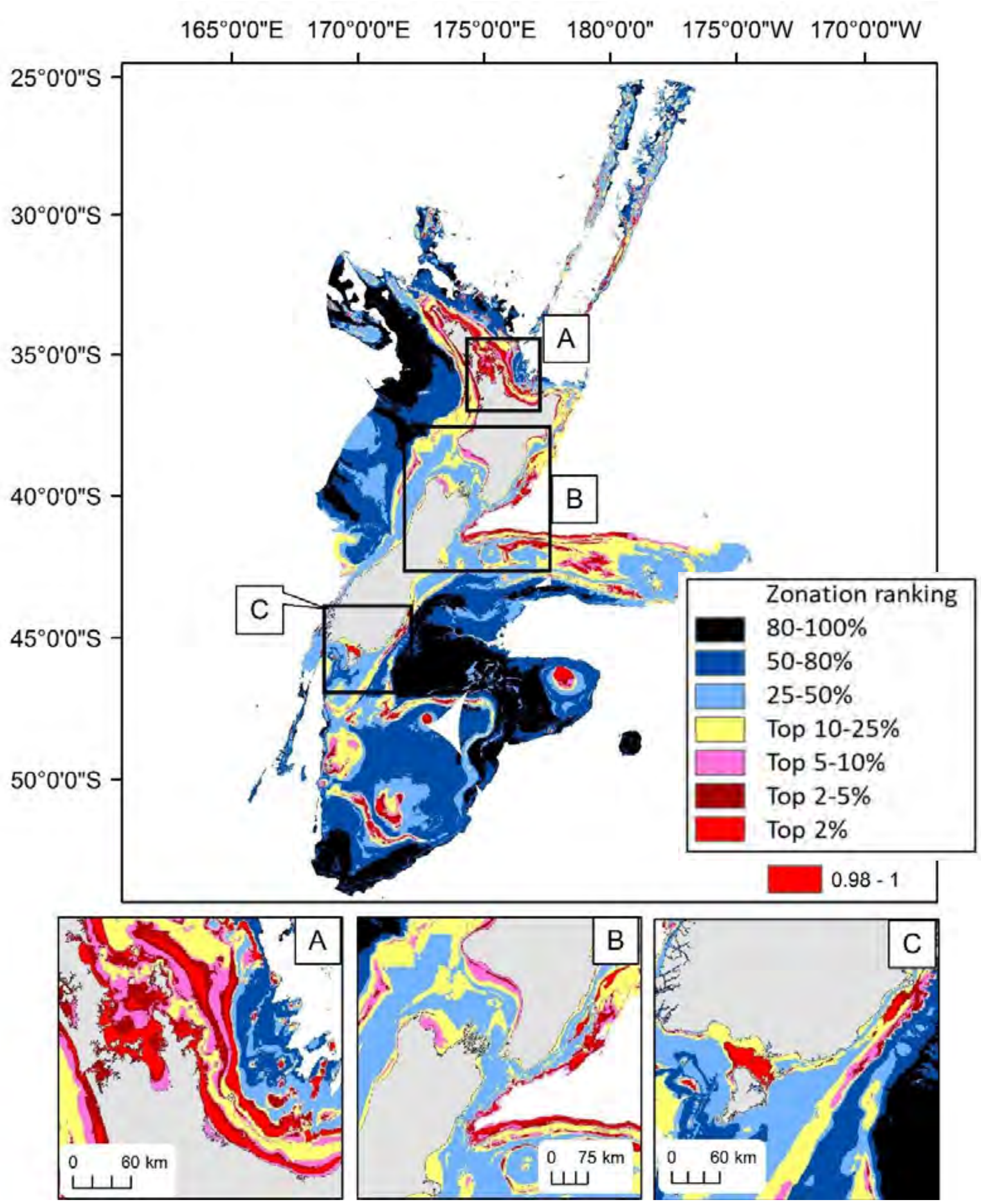

Figure 4-20: Spatial prioritisation based on benthic invertebrate occurrence models. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

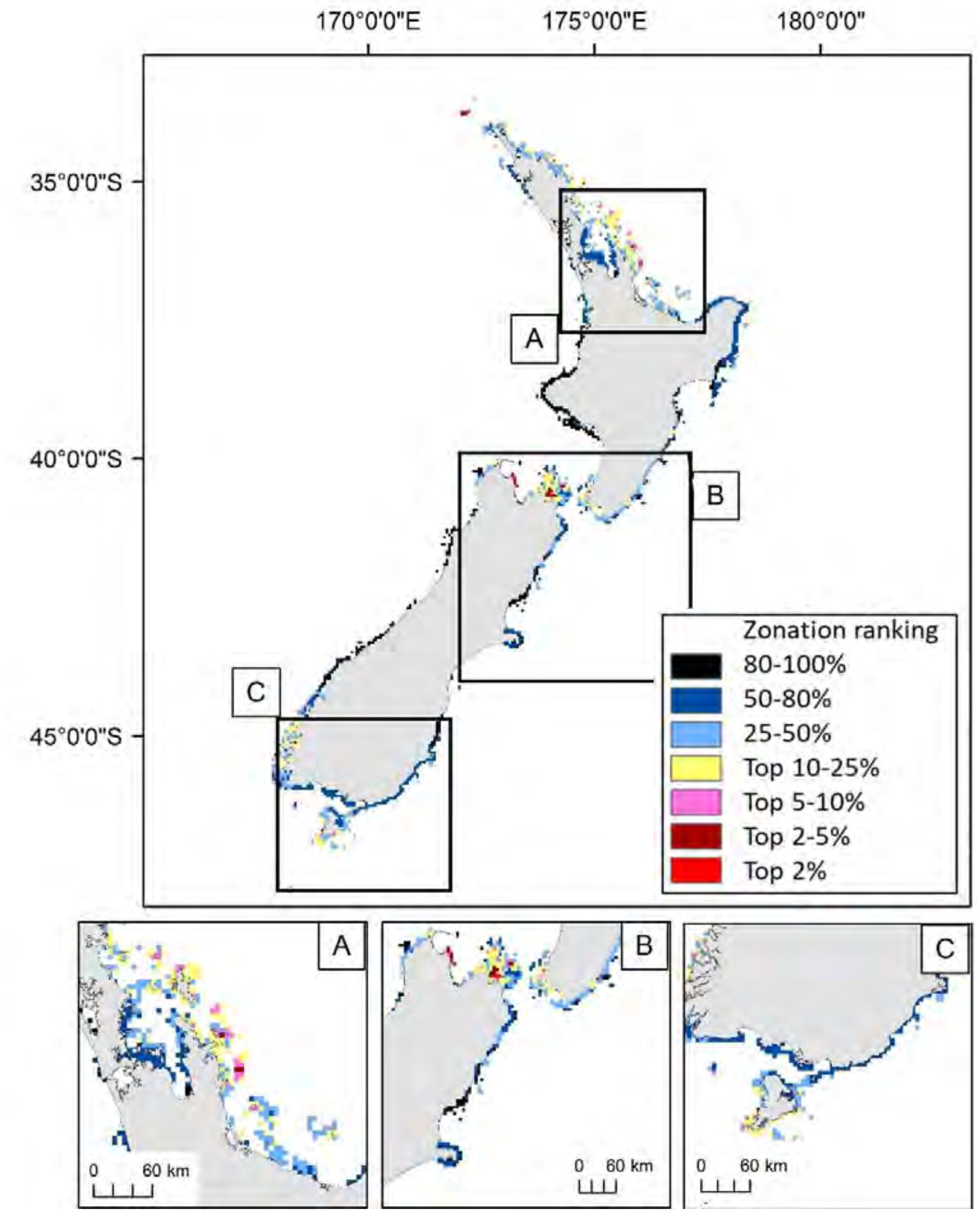

Figure 4-21: Spatial prioritisation based on rocky reef fish species occurrence models. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

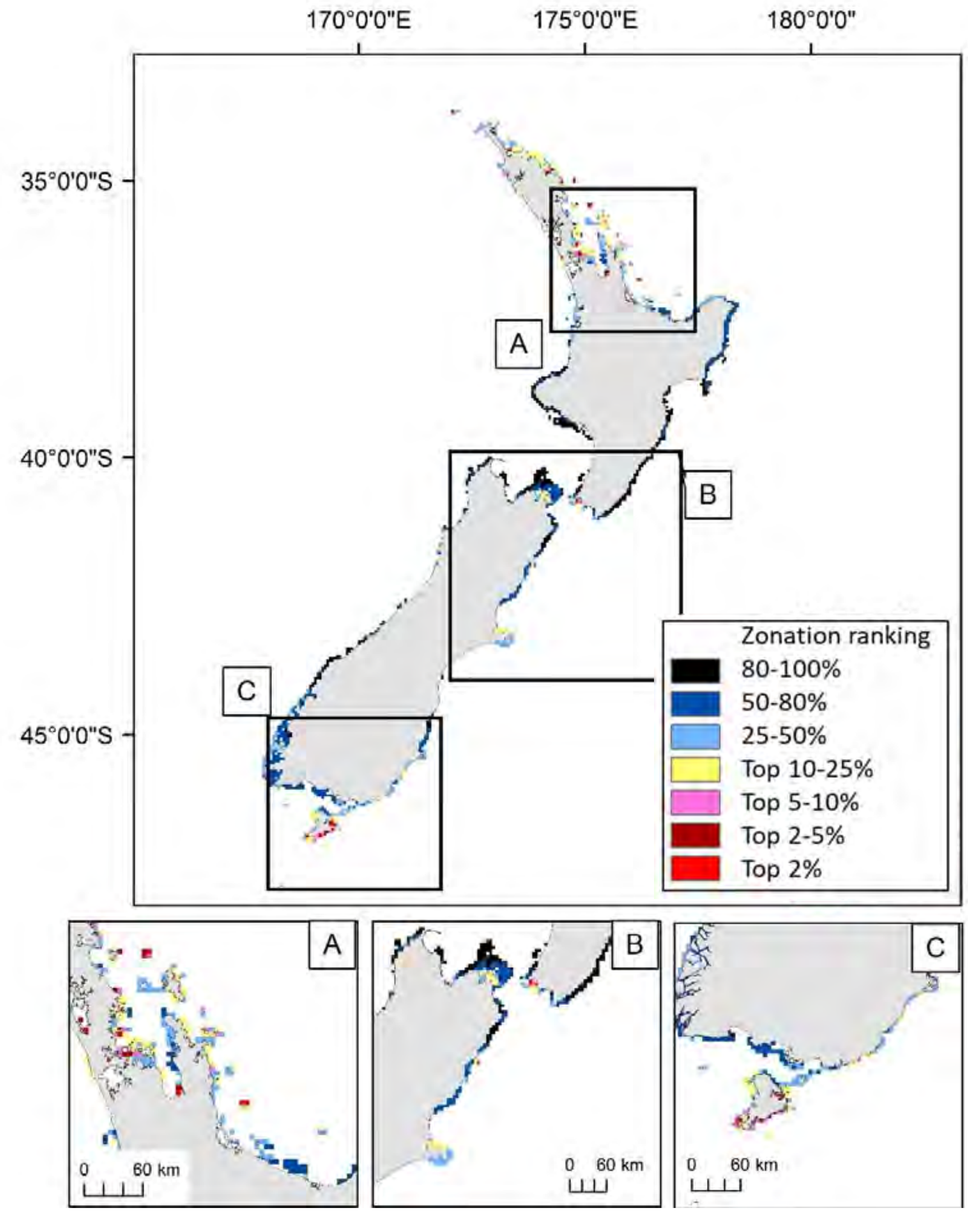

Figure 4-22: Spatial prioritisation based on macroalgal occurrence models. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

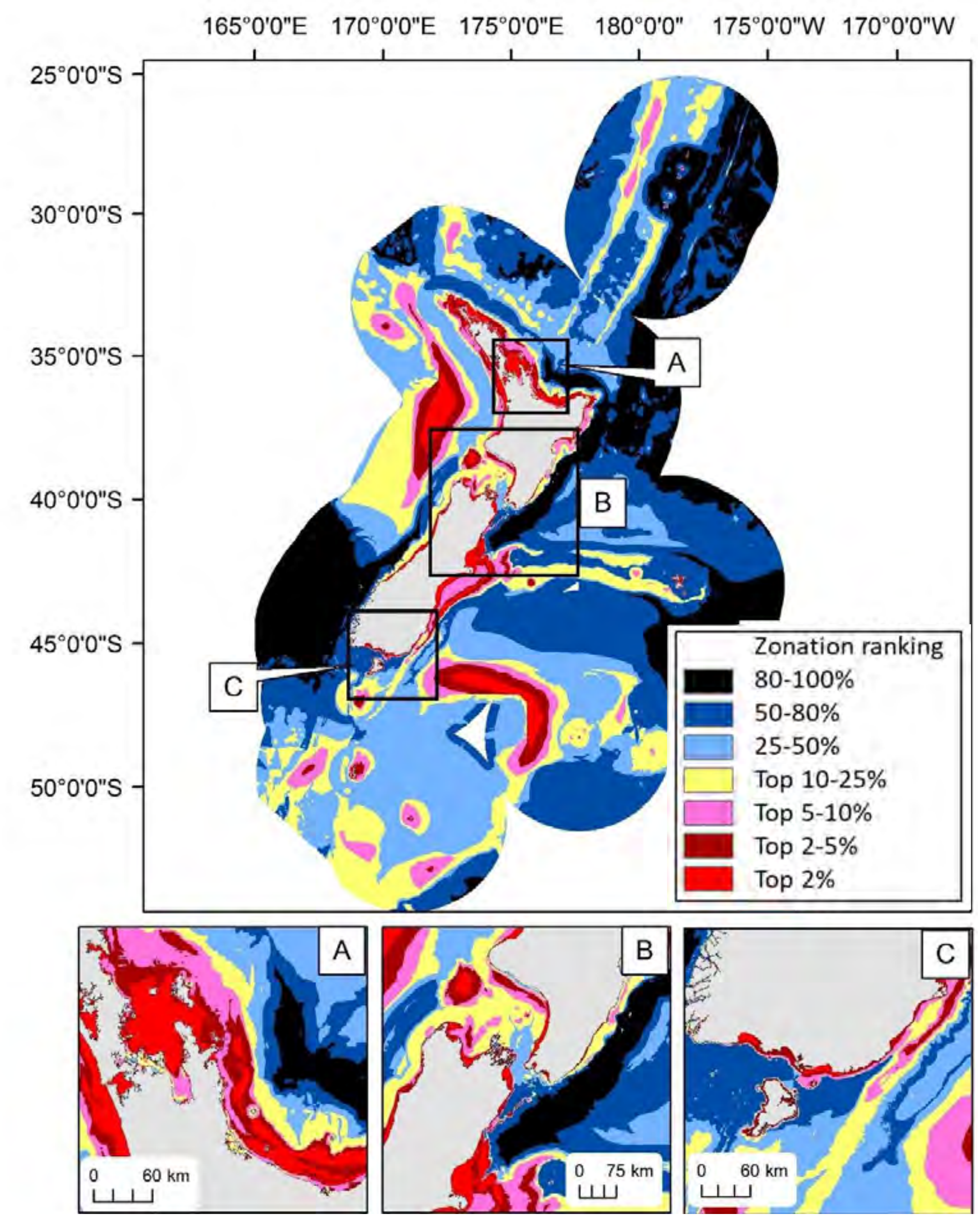

Figure 4-23: Spatial prioritisation based on cetacean habitat suitability models. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

The performance of the spatial prioritisation for cetaceans (Figure 4-27) was lower across the three priority areas relative to the other taxa (Figure 4-8, Figure 4-24, Figure 4-25, Figure 4-26). For each relative proportion of priority area in protection, there was a similar corresponding value of proportion of the cetaceans protected, suggesting the performance of the Zonation scenarios is low for these taxa. Such a result is in keeping with the broad distribution patterns illustrated by Stephenson et al. (2020a) for cetacean taxa in New Zealand waters, where the high habitat suitability areas for many species were broadly distributed across offshore habitats. Zonation has a 'random cell removal rule', that allows users to test whether the performance of a scenario is any better than a random allocation of prioritisation values – the cetacean scenario discussed here may be an appropriate candidate for such a test.

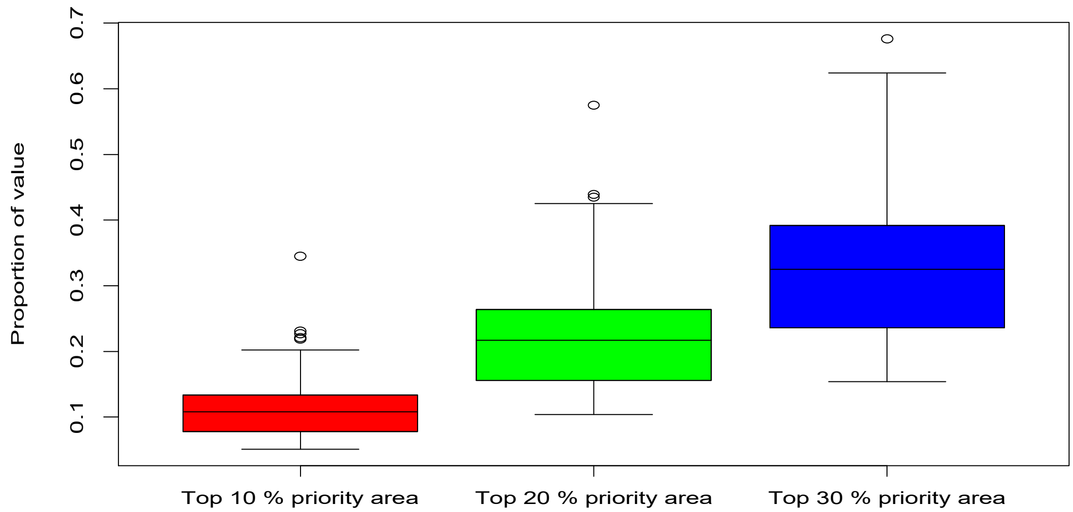

Figure 4-24: Performance of a spatial prioritisation for benthic invertebrate taxa across 10, 20 and 30% of the top priority areas. Performance is measured by the proportion of biodiversity value retained within top priority areas.

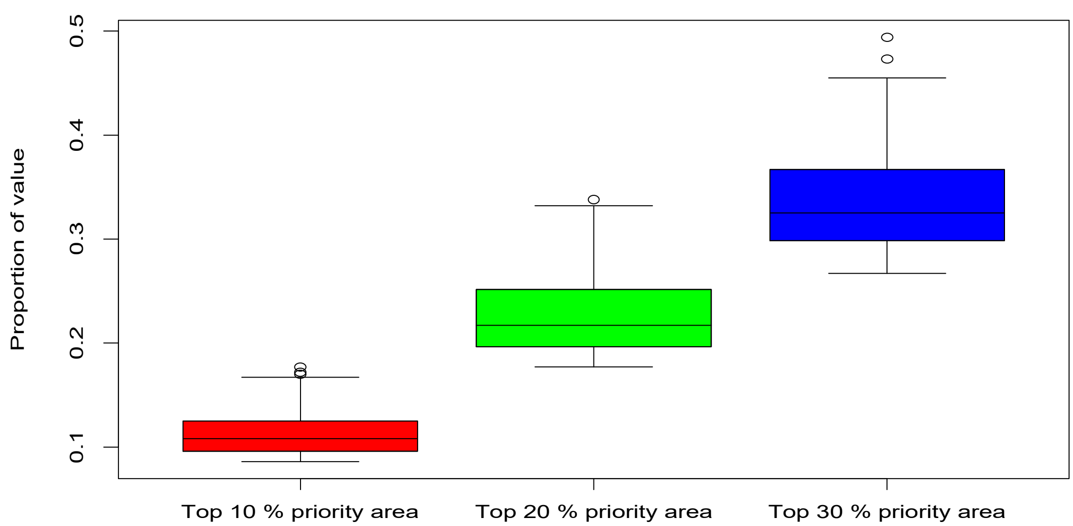

Figure 4-25: Performance of a spatial prioritisation for reef fish taxa across 10, 20 and 30% of the top priority areas. Performance is measured by the proportion of biodiversity value retained**.**

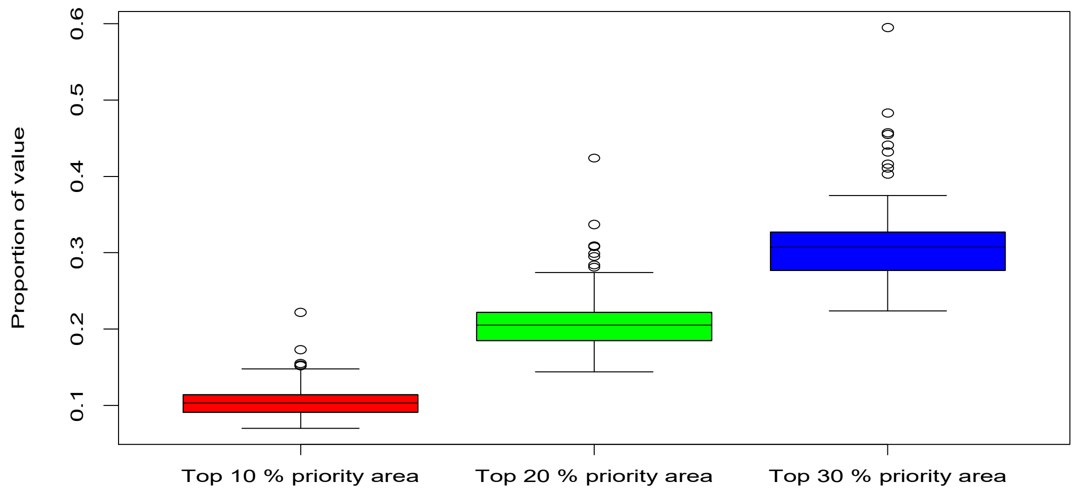

Figure 4-26: Performance of a spatial prioritisation for macroalgae taxa across 10, 20 and 30% of the top priority areas. Performance is measured by the proportion of biodiversity value retained within top priority areas.

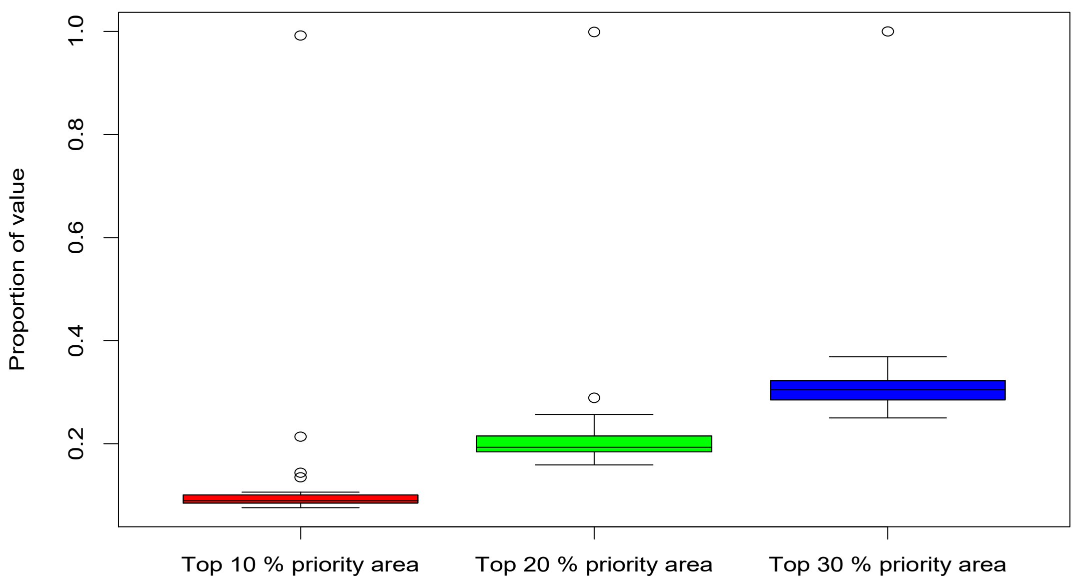

Figure 4-27: Performance of a spatial prioritisation for cetacean taxa across 10, 20 and 30% of the top priority areas. Performance is measured by the proportion of biodiversity value retained.

Models within a taxa group can also be of different types, for example cetacean predictive models include both Boosted Regression Trees for taxa with at least 50 sightings records, and less robust RES models for taxa with limited sightings (Stephenson et al. 2020a), the latter requiring less data on species presence and utilising only three environmental predictors. The RES models typically are for less common taxa that are found offshore, thus their inclusion is likely to bias prioritisations toward offshore locations where there is limited information for validation. Thus, the performance of the cetacean scenario may have been influenced by the RES models, which were used for cetacean taxa with limited sightings data (15 species). Therefore, prioritisations that pool several model 'types' for a single taxa may wish to explore separate prioritisations for different models, or weighting species layers according to the confidence in their model predictions (e.g., Figure 4-23). For example, one decision may be to provide a higher weighting in Zonation to those taxa for which predictive models are expected to be more robust, in this case the BRT models. Not surprisingly, this decision results in a shift in prioritisation toward locations where these 15 taxa are more likely to be observed (Figure 4-28).

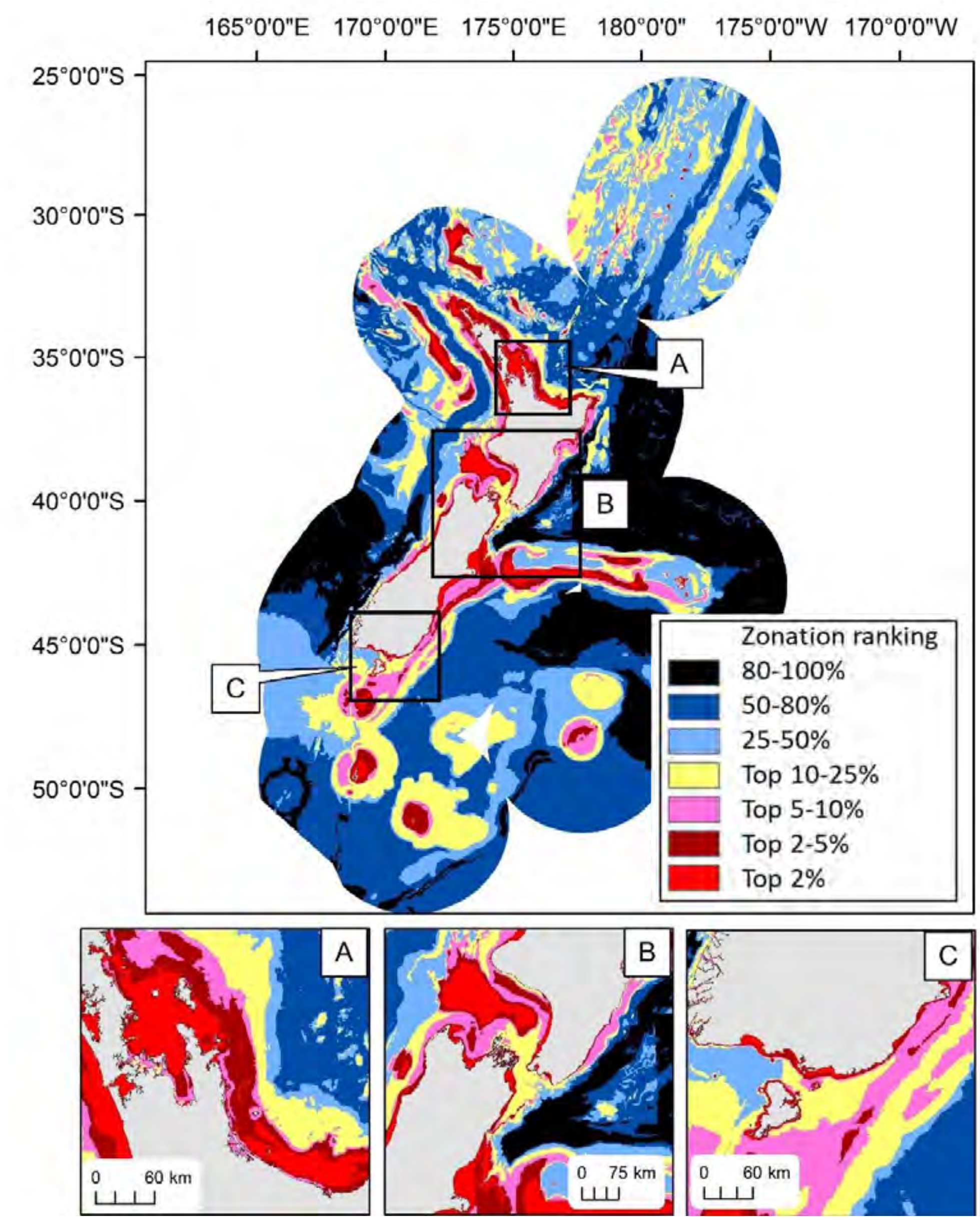

Figure 4-28: Spatial prioritisation based on cetacean species occurrence models, with upweighting of BRT models of 5 times weighting given to RES models. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

Spatially explicit uncertainty

A further aspect of the use of predictive models of taxa' habitat suitability, occurrence or abundance in Zonation prioritisations is whether to include uncertainty in these layers in prioritisations, and if so, how much to discount or down-weight layers by their associated uncertainty. With all modelled datasets, there are generally some associated measures of spatially explicit model uncertainty. Depending on the model approach used to generate layers, uncertainty layers may represent standard deviation (SD), coefficient of variation (CV) or standard error (SE).

The uncertainty layers represent the confidence of the model in predicting the value of a particular grid cell. In many modelling approaches, the uncertainty values are generated via bootstrapping – where model fitting, validation and prediction is performed with randomly selected subsets of training data and repeated for a set number of iterations (often 100 or 1000). The variability in the spatial predictions for each cell among model iterations provides a measure of uncertainty that represents stability in model fit and parameter estimation. For example, mean values of uncertainty for demersal fish layers demonstrate expected patterns with respect to limited data in deeper offshore areas, but also showcase differences in model uncertainty between regional coastal areas (Figure 4-29).

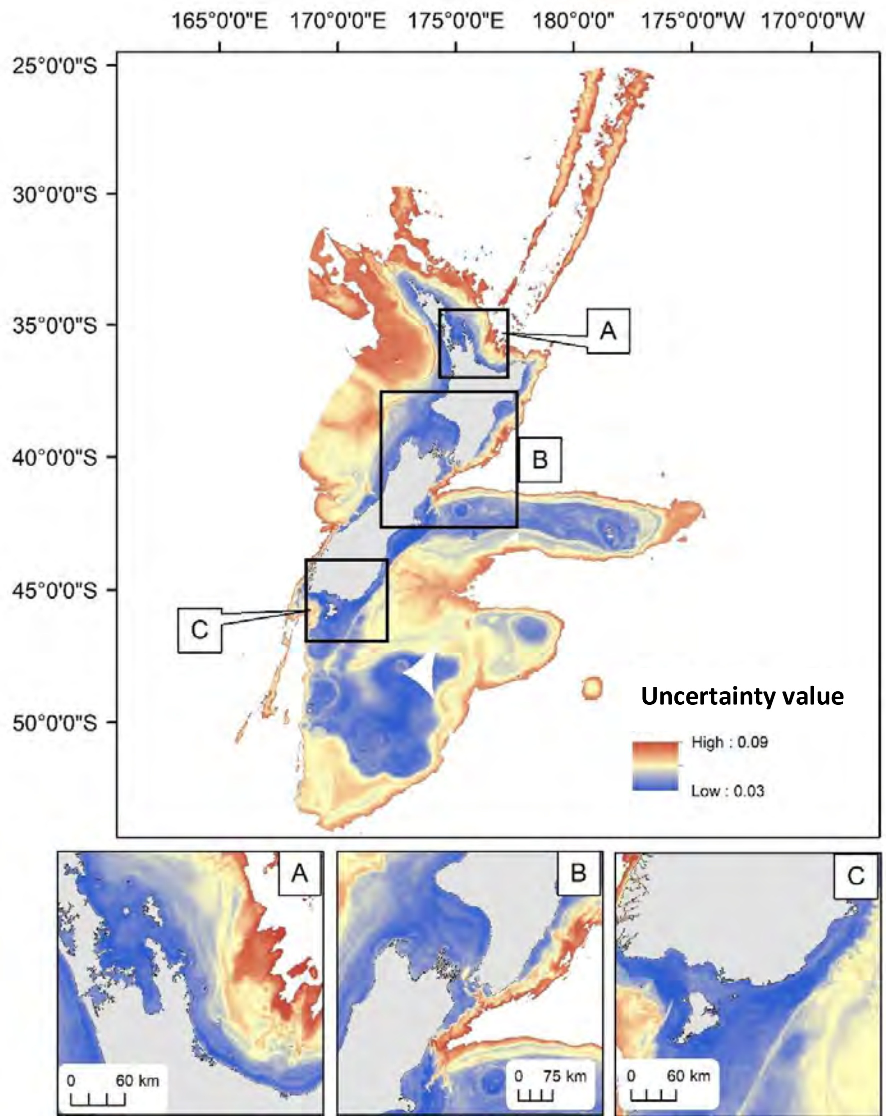

Figure 4-29: Mean demersal fish uncertainty values, averaged across 239 demersal fish species occurrence models. Colour legend indicates higher uncertainty in red, and lowest in blue.

Within Zonation, uncertainty layers are incorporated into the spatial prioritisation via the 'info-gap analyses' functionality. This function reduces the magnitude of cell values within biodiversity layers by subtracting the uncertainty for a given biodiversity feature. For example, if an individual cell for blue cod habitat suitability has a value of 0.9 and the same cell has a standard deviation of 0.05, the final value for that cell when discounted by uncertainty will be 0.85. There is further adaptability in the application of uncertainty via the specification of an alpha value, that allows users to alter the degree to which uncertainty reduces biodiversity values. In the above blue cod example, the adjusted HSI value of 0.85 would occur using an alpha value of 1. If this value was set at 0.6, the uncertainty value applied to the original HSI value would become 0.03 and the uncertainty -adjusted HSI value would be 0.87. The alpha functionality can be particularly useful when standardising the influence of different uncertainty metrics that may be provided with different biodiversity layers. Further, the functionality allows direct stakeholder input into the degree to which uncertainty should influence the final prioritisation output.

Illustrating the use of uncertainty in Zonation prioritisations, the demersal fish prioritisation with uncertainty showcases how inclusion and weighting of uncertainty modifies priority areas to reduce selection of areas with high uncertainty (Figure 4-30). A further illustration (lower figure in Figure 4-30) demonstrates change in relative priority values between the two scenarios. These uncertainty scenarios can be a useful tool to showcase what locations are being given higher or lower priority when uncertainty in modelled taxa distributions is included in the prioritisation process.

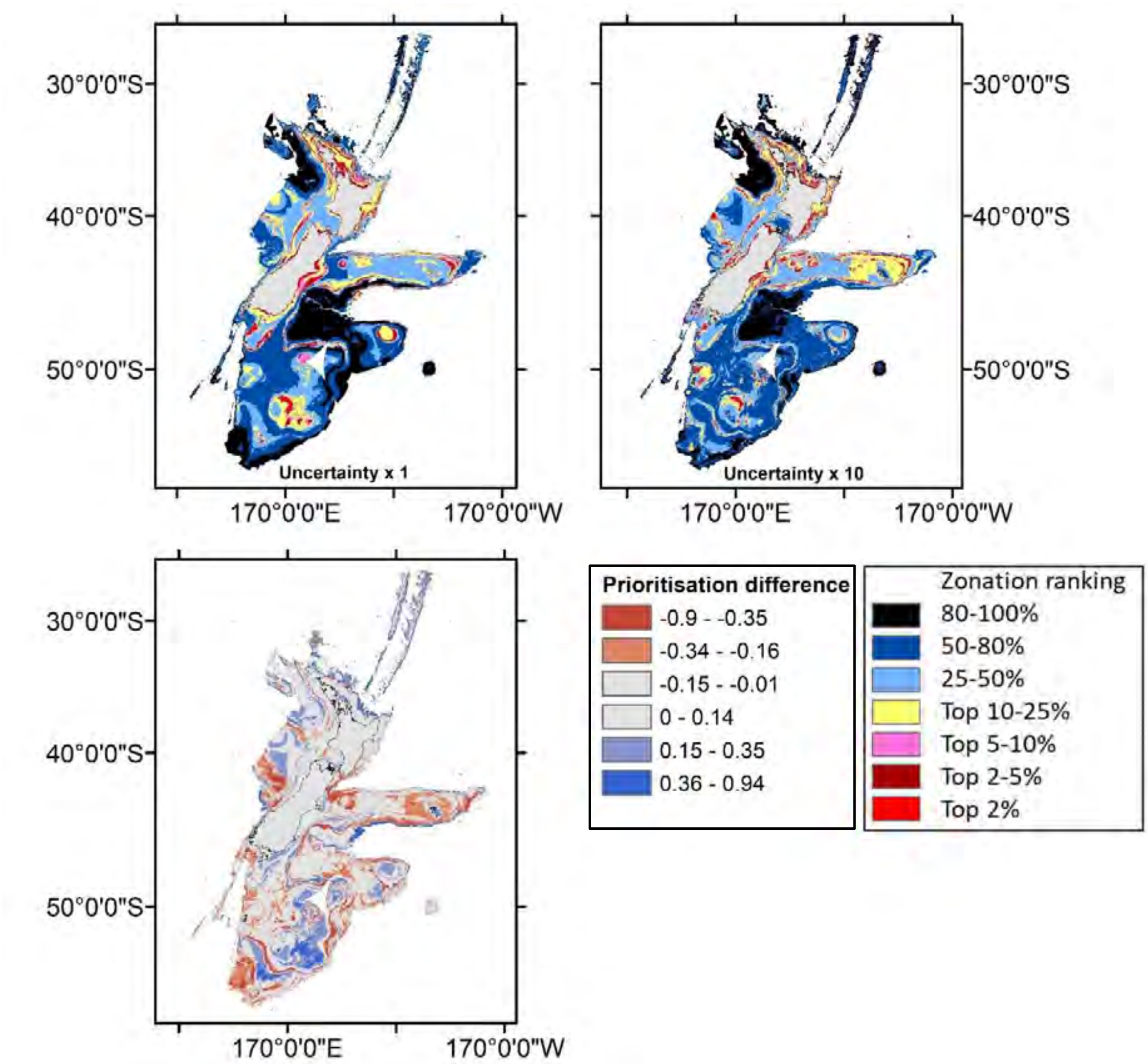

Figure 4-30: Comparison of uncertainty in spatial prioritisations based on demersal fish species occurrence models. TOP LEFT: inclusion of uncertainty with weighting of 1.0; TOP RIGHT: inclusion of uncertainty with weighting of 10. BOTTOM LEFT: illustrates relative differences in prioritisation values between the two scenarios, with red indicating lower prioritisations with higher uncertainty weighting, and blue indicating higher prioritisation with higher uncertainty weighting. Zonation ranking legend indicates higher priority areas for conservation in red, and lowest in black.

Combining across distributions

Combining multiple taxa group distributions should be informed by a suite of taxon-specific scenarios, as per illustrative scenarios presented earlier in this section. These scenarios allow for interpretations of how each taxon might influence priority solutions, as well as understanding of how the extent of each taxa group's distributions influences prioritisations. For example, reef areas are a very limited proportion of the total EEZ, compared to cetacean distributions which cover the full extent of the EEZ. Thus, priority areas for reef taxa are likely to highlight particular inshore reefs at much smaller scales, whereas cetacean priorities in inshore regions are likely to include extensive coastal areas.

Similarly, the difference in high priority area extents may be substantial, such that the top 10% priority areas for cetaceans covers at least an order of magnitude larger area than the top priority area for demersal fish and benthic invertebrates (Figure 4-31, Figure 4-32).

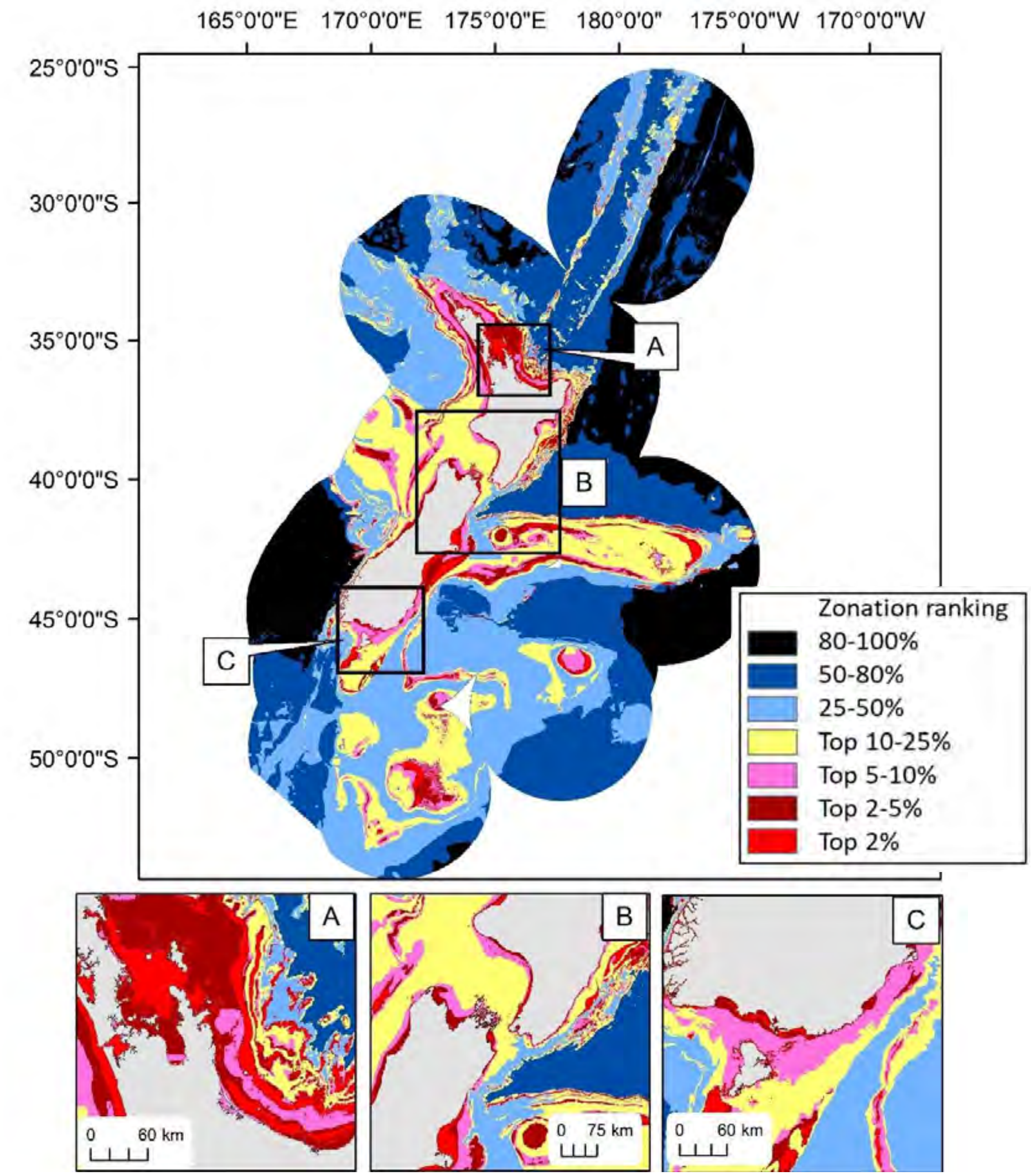

Figure 4-31: Spatial prioritisation based on combined scenario including species occurrence models for five taxonomic groups (cetaceans, demersal fish, reef fish, benthic invertebrates, macroalgae). Colour legend indicates higher priority areas for conservation in red, and lowest in black.

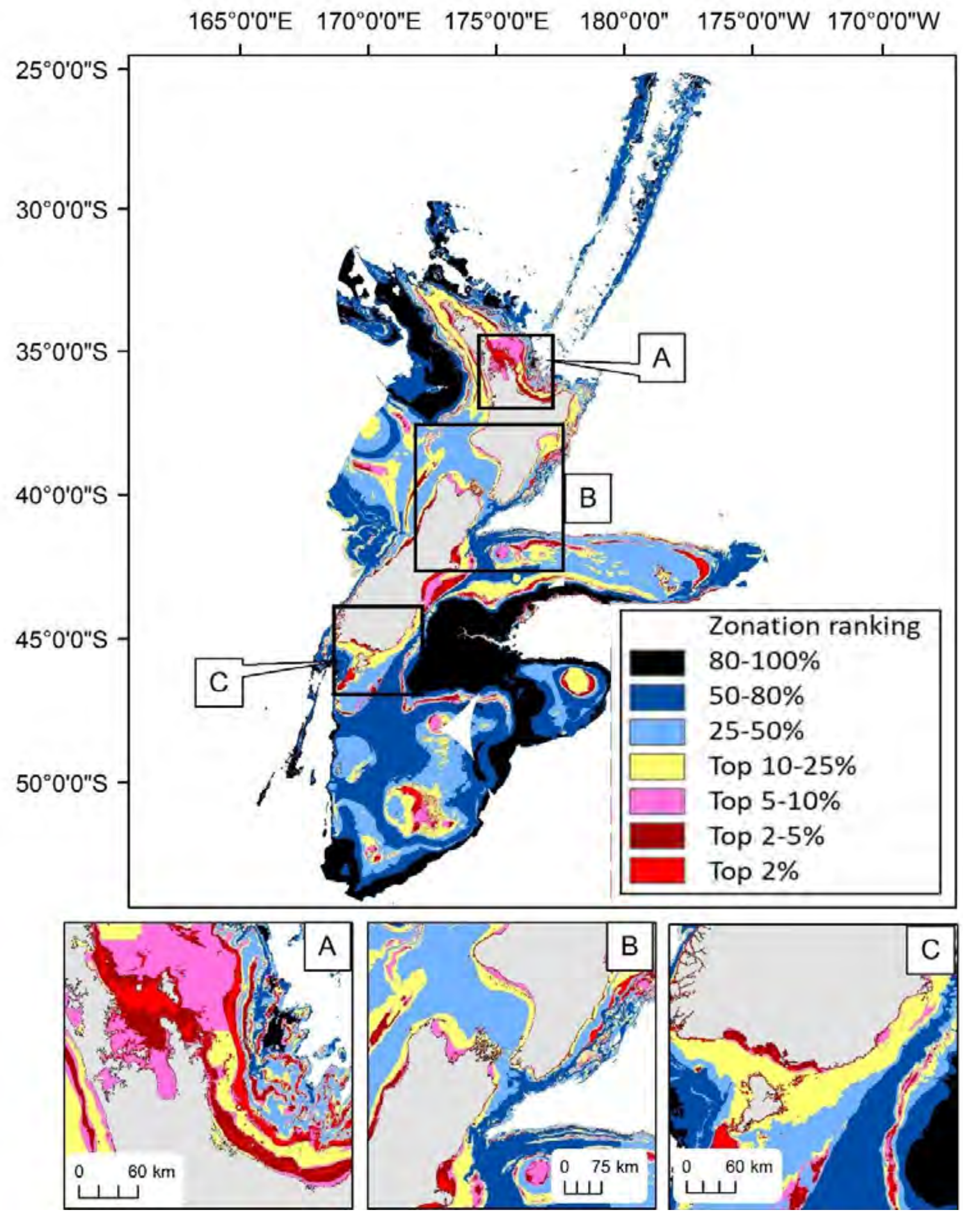

Figure 4-32: Spatial prioritisation based on combined scenario including species occurrence models for four taxonomic groups (demersal fish, reef fish, benthic invertebrates, macroalgae) but excluding cetacean species occurrence models. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

The extent covered by taxa groups also influences relative performance in the combined scenario. Taxa with restricted distributions (e.g., reef fish, macroalgae) can have their full distributions selected in a small proportion of the total area. In contrast, taxa groups with broader distributions (e.g., cetaceans, benthic invertebrates, demersal fish) have lower average performance, as a much larger proportion of the EEZ is required in protection to cover large proportions of their distributions (Figure 4-33).

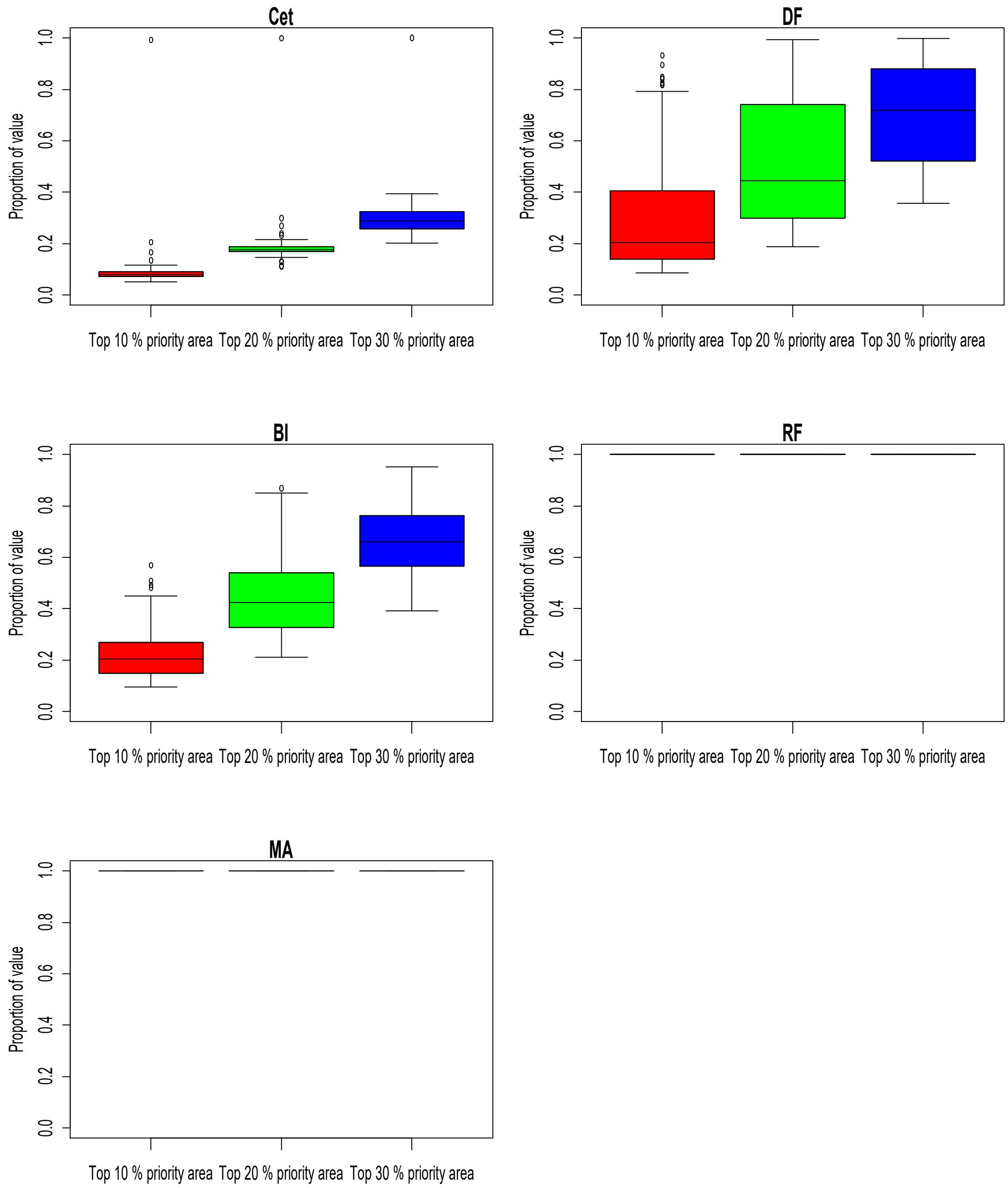

Figure 4-33: Performance of a spatial prioritisation for all taxa across 10, 20 and 30% of the top priority areas. Performance is measured by the proportion of biodiversity value retained within top priority areas. Cet: cetaceans; DF: demersal fish; BI: benthic invertebrates; RF: reef fish; MA: macroalgae.

4.4 Step 4: Representing KEA criterion layers

Section 4.4: Key messages

- KEA datasets may contribute to more than one KEA criterion and thus 'double counting' (i.e., the same dataset being utilised multiple times) could occur in Zonation scenarios, meaning that dataset will have a larger influence on the final prioritisation. This outcome may not be undesirable for important taxa/habitats, but the effects should be discussed with stakeholders.
- If double counting is to be avoided, users may choose to retain datasets in the highest priority criterion based on the objectives of the spatial planning process while removing them from criteria that are a lower priority.
- There may be considerable overlap among the datasets used to perform KEA scenarios and those used to populate taxa specific scenarios. If scenarios are required to be independent, users can remove taxa that occur in KEA scenarios from their respective taxa prioritisations. Alternatively, users may choose to omit a KEA criterion scenario in favour of a taxa-specific prioritisation with increased weight for species that have a particular importance (e.g., threatened species).
- Due to spatial biases, the KEA datasets that are represented by points and polygon features may be best included within Zonation analysis as 'silent layers'. This option allows the performance of prioritisation to be assessed for a point/polygon feature dataset without the spatial biases inherent in these layers contributing to the prioritisation outcome.
- Layers that inform the KEA criterion 'naturalness' are unlikely to be used as biodiversity features, however, they may be employed as threat, cost or condition layers depending on how stakeholders perceive their relationship with biodiversity values.

In most spatial planning projects, it is common to pool datasets available from a range of different studies that report on various biodiversity, cost or naturalness values. In such cases, it is important to have a transparent decision-making process around which datasets are progressed into Zonation scenarios and an acknowledgment of differences in priority that may arise from such decisions. In the present study, datasets were available from several government-funded projects that were running concurrently. These include the MSAG projects for the development of the SCC (Stephenson et al. 2020b), mapping key ecological areas (Lundquist et al. 2020a) and projects to develop SDMs for vulnerable marine ecosystem indicator taxa (Anderson et al. 2020). These projects, along with advances made in the development of SDMs in the present study, have resulted in a database of several 100 spatial layers that may be used for spatial prioritisation investigations at various scales.

In particular, the Key Ecological Areas (KEA) projects (Stephenson et al. 2018b; Lundquist et al. 2020a), have generated a significant number of spatial layers for investigating the distribution of important ecological areas within New Zealand's marine environment. Spatial datasets are grouped under nine KEA 'criteria' that have been developed by the MSAG (see Freeman et al. 2017, based primarily on criteria identified in Clark et al. 2014). While representing different attributes of KEAs, there is nonetheless some overlap in the datasets among the various criteria. For example, an individual SDM for a species of deep sea coral may contribute to several criteria: 1) vulnerability/fragility, sensitivity of slowly recovering species/habitats, 2) importance for threatened/declining species or habitat if the species is threatened and 3) ecological function due to having functional traits (i.e., upwards structure forming) that support ecosystem function. There is overlap among datasets from each KEA criteria and spatial layers that may be used to perform prioritisation involving different taxa groups (see sections 4.3), habitat classifications (section 4.2) and threats (section 4.6).

'Double counting' may occur both within a single prioritisation (i.e., layers may occur more than once in a single prioritisation), or between multiple scenarios (e.g., layers may contribute to more than one scenario). In the latter case, caution must be taken when combining scenarios with overlapping layers into a single inclusive prioritisation (e.g., the all-inclusive analysis, see 4.7). Conceivably, if a layer contributes to many component scenarios that are then amalgamated into an 'all-inclusive' scenario – they may occur many times in the final analysis. Including layers more than once within a single scenario causes them to contribute more weight to the prioritisation results. If a certain species is particularly important and meets several criteria, there may be good reasons for it to contribute disproportionately to the final prioritisation. However, this decision is an important point to discuss with stakeholders.

In this section we provide guidance around minimising 'double counting' among comparative Zonation scenarios. Depending on the aims of the prioritisation project, representing individual spatial layers across a range of scenarios may not undermine prioritisation results, as long as care is taken to double-check input layers should individual scenarios be amalgamated.

Due to the existing categorisation of spatial layers and degree of overlap (e.g., Figure 4-34), we summarise the decisions with respect to example KEA criteria, however the same discussions would be needed for the integration of datasets from a range of different sources.

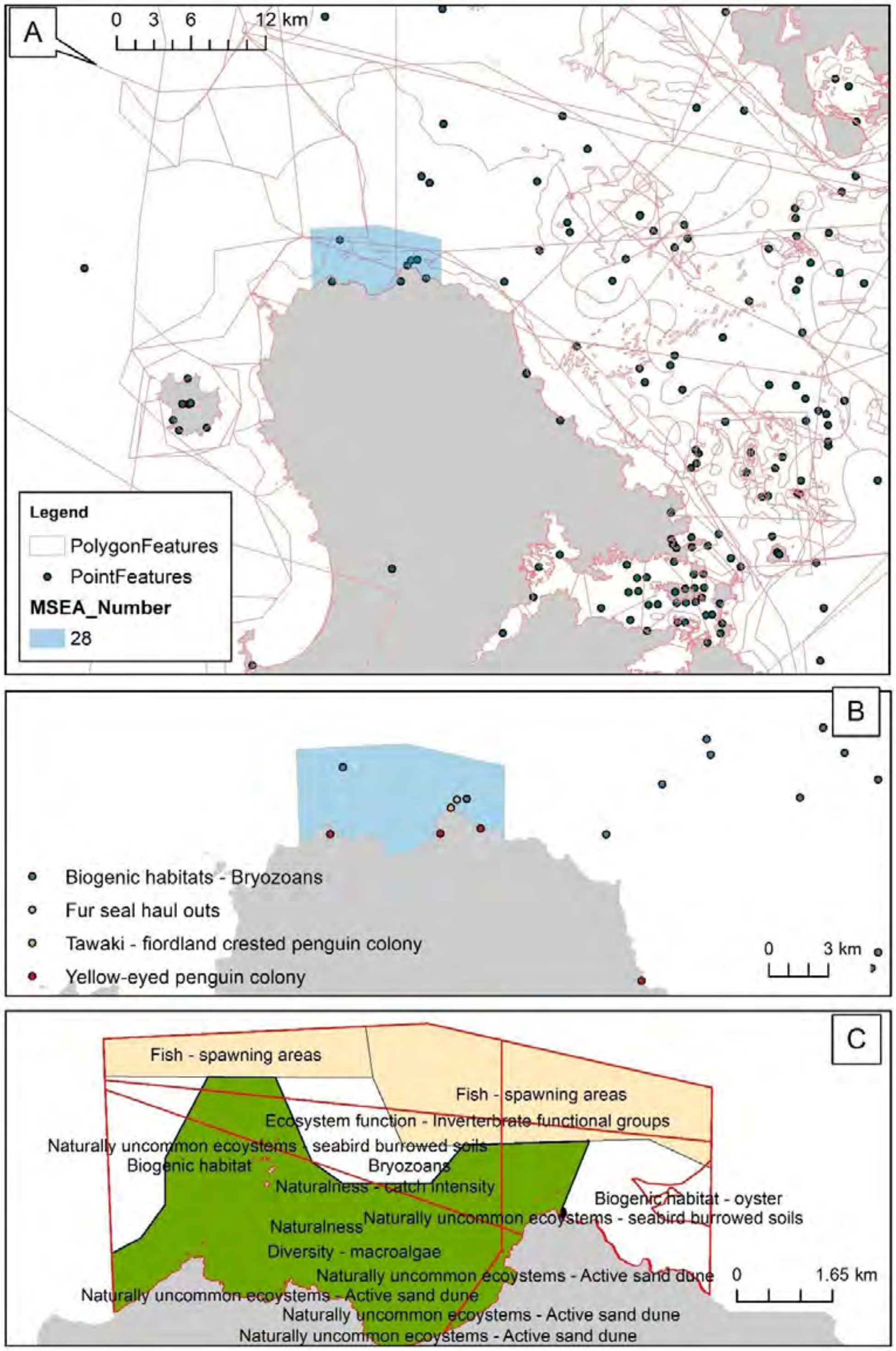

Figure 4-34: Example of suite of potentially overlapping features that satisfy multiple KEA criteria. A. All point and polygon features near Stewart Island. B. A subset of point record features. C. A subset of polygon features.

4.4.1 Vulnerability, Fragility, Sensitivity or Slow Recovery

This criterion is defined as “areas that contain a relatively high proportion of sensitive habitats, biotopes or species that are functionally fragile (highly susceptible to degradation or depletion by human activity or by natural events) or with slow recovery” (Lundquist et al. 2020a). Examples of spatial layers that could be used to inform this criterion include datasets on biogenic habitats (e.g., bivalve beds, bryozoan thickets, algal meadows), and individual predictive models for species with low fecundity/high longevity (e.g., coldwater corals, baleen whales). Clearly, a range of these datasets overlap analyses for various taxa prioritisations. Many of the biogenic layers will feature in the benthic invertebrate prioritisations and there will also be overlap between low fecundity species and those that are represented in the ‘threatened species’ KEA criteria (see below). Additionally, large brown macroalgae (e.g., *Durvillaea antarctica*, *Ecklonia radiata*, *Macrocystis pyrifera*) fit within the ‘vulnerable’ category due to their susceptibility to anthropogenic impacts and slow/lack of recovery in some areas. These macroalgal species also contribute to the ‘productivity’ KEA criterion scenario due to their contribution to coastal primary production.

Spatial management projects often place a high priority on protecting habitat or species that are vulnerable. As such, if double-counting is to be minimised among comparative scenarios, it is likely layers representing these species/habitats would be removed from individual taxa or habitat scenarios and retained in a scenario that best represents vulnerable biodiversity features. To compare across scenarios, particular KEA layers such as vulnerability layers can be included as silent layers (i.e., included in scenarios but without weighting such that overlap within priority solutions is easily calculated for comparative purposes). In this way, the relative effectiveness of competing prioritisations can be appraised, even if particular KEA layers do not contribute directly to the prioritisation.

An alternative approach for a KEA-specific prioritisation, such as vulnerability, is to retain layers from this criterion within their respective taxa/habitat scenarios, but give these layers increased weighting in the prioritisation scenario. In this case, a specific ‘vulnerability’ scenario would not be run, with the assumption that the high weight of the vulnerability layers within component scenarios would ensure these features are adequately protected. As always, it would be important to appraise the proportion of biodiversity protected under both approaches to be sure how either decision would influence the performance of the spatial prioritisation for these important taxa/habitats.

4.4.2 Uniqueness / Rarity / Endemism

Inclusion of unique, rare and endemic species in a KEA prioritisation scenario is possible by a number of methods. First, species occurrence models are available for both endemic and non-endemic species (noting that models are typically not available for rare or unique species). These modelled layers can be either included as separate scenarios that consider only endemic species, or scenarios can be run which give higher weighting for endemic species.

Point records are also available for rare and unique species, compiled from extracts of point records on national and international databases. Point record layers can be converted into rasterised grid layers with the number of points per cell available as an input into a scenario either as a direct input layer, or as an silent or unweighted layer. The available New Zealand rare and unique species KEA layers do show spatial patterns of point records that reflect spatial patterns of sampling effort, such that high records are typically most common in depths >200 m. Because these point record databases are not comprehensive, it is recommended that these are used as ‘silent’ layers, rather than contributing directly to Zonation scenario prioritisations.

4.4.3 Special Importance for Life History Stages

This criterion describes "areas that are required for a population to survive and thrive" (Lundquist et al. 2020a). Examples of spatial layers that contribute to this criterion include spawning layers for individual, commercially important fish species, nursery habitats, pinniped breeding colonies and foraging range, seabird colonies and breeding distribution, migratory corridors, and foraging hotspots. Spawning layers and nursery habitat for fish species are only likely to overlap to a very limited extent with predictive models that describe the full extent of a species distribution, thereby minimising overlap with Zonation scenarios for demersal/reef fish taxa. The location of breeding colonies for pinnipeds and seabirds are similarly specific to the life history criteria, however their foraging range may also be included in taxon-specific scenarios. Further, there is likely to be overlap between this scenario and the prioritisations for threatened taxa for certain threatened species (e.g., New Zealand sea lion, elephant seal, black petrels, yellow-eyed penguin). In some cases, important areas for species life history stage may be associated with certain habitat types (e.g., subtidal seagrass meadows as fish nursery grounds). If there is strong evidence for these species-habitat associations, a layer representing the extent of such habitats may be used as a proxy layer for life history importance. In these cases, overlap may be introduced with scenarios that perform habitat-specific prioritisations such as the vulnerability and productivity criteria (see sections 4.4.1 and 4.4.5).

We performed a prioritisation analysis for the 'life history stages criterion' as an illustration of the challenges discussed above. We made a decision to include spatial layers that represented species-specific extent of important areas for certain life history characteristics, excluding proxy spatial layers (e.g., seagrass). Thus, we included spawning areas for 39 commercially important finfish species, breeding distribution layers for 70 seabird species, a layer denoting the location of important bird areas (IBAs) and the number of species present, and the location of pinniped rookeries with an associated buffer reflecting approximate foraging range (Figure 4-35). The input biodiversity features received an equal rating, with no feature specific weightings for threatened taxa. A number of these features are represented in additional protection measures such as Marine Mammal Sanctuaries, and that many of these features are located on terrestrial coastlines or offshore islands, resulting in additional land-based protections in place for protection of these important life history sites.

The life history prioritisation illustrates a range of areas throughout NZ's marine environment that are important for certain life history processes (Figure 4-35). The coastal and shallow continental shelf zones of the east coast of the North Island, around the Marlborough Sounds, North Canterbury and the Southland coast have all been determined as high priority in this scenario. These locations are likely included due to their importance for commercial fish spawning habitat, as well as supporting the breeding distribution of several coastal birds. There are also hotspots for high priority areas around all of the major offshore islands groups which will be related to the hotspots of these locations for bird colonies and subsequent breeding distribution, as well as the foraging range for NZ sea lions and fur seals.

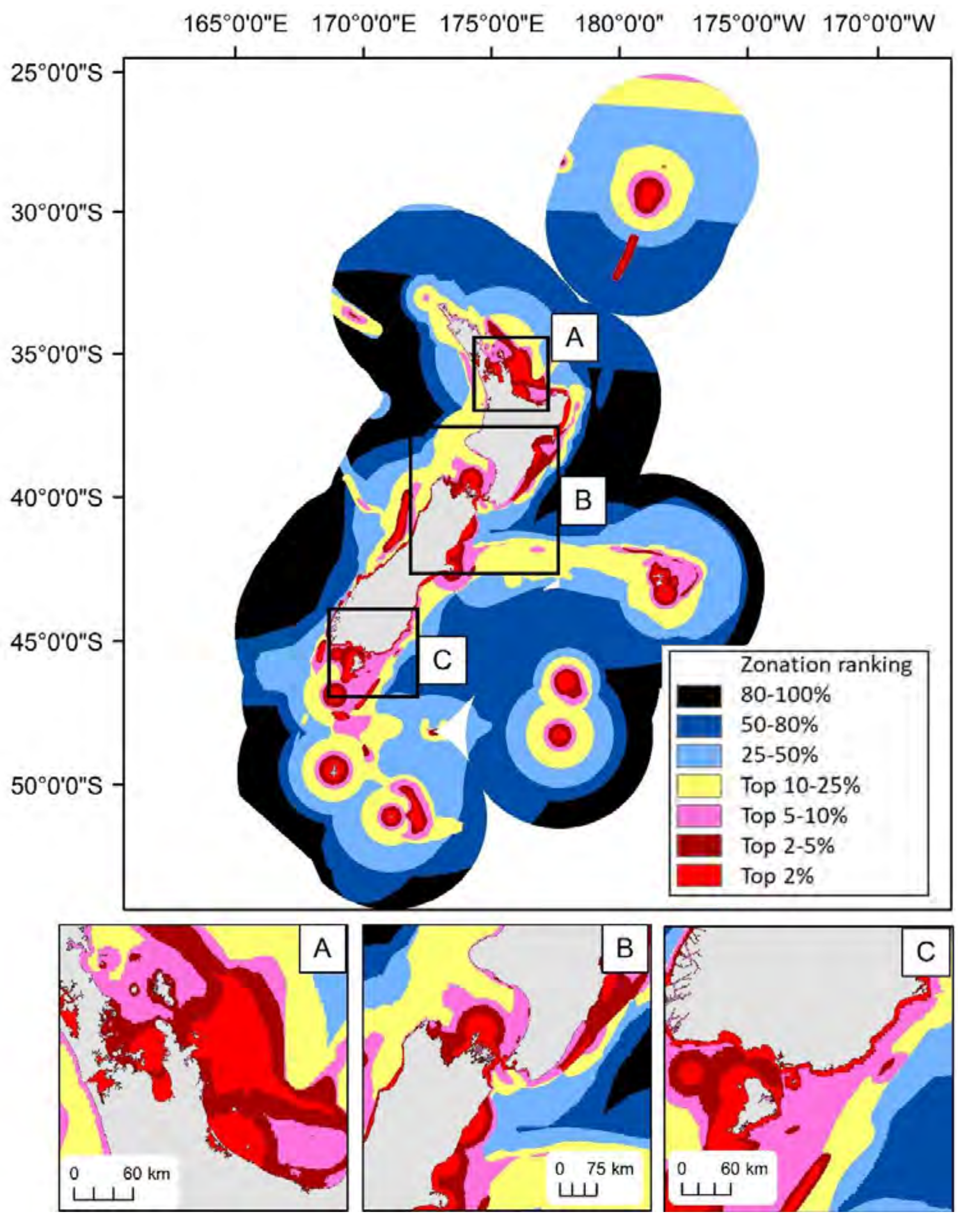

Figure 4-35: Spatial prioritisation based on KEA layers associated with special importance for life history stages, including layers for marine mammal, seabird, and fish. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

4.4.4 Importance for Threatened / Declining Species and Habitats

The KEA criteria 'Importance for Threatened/Decline Species and Habitats' criterion is defined as "Area containing habitat for the survival and recovery of endangered, threatened, declining species or area with significant assemblages of such species" (Lundquist et al. 2020a). This KEA criterion is often a key priority for spatial management projects. Layers that represent this criterion are guided by various threat classification systems including the IUCN Red List and New Zealand Threat Classification System (NZTCS). Any species or habitat with a spatial representation of distribution or presence may be included under this criterion.

Layers from the KEA projects include estuarine area with populations of threatened shorebirds, foraging areas for marine mammals and seabirds, species distribution models of threatened marine mammals, and point records for threatened seabirds, fish, and macroalgae. Habitat themselves are also often considered threatened and so may be represented by this criterion. For example, the UNGA has passed resolutions establishing criteria for vulnerable marine ecosystems (VME) in the deep ocean, and taxa that represent them (Rowden et al. 2019), and equivalent taxa have been identified for the oceans within and surrounding the New Zealand marine environment (Anderson et al. 2020). Some of these VME indicator taxa, i.e., corals, are protected species under the Wildlife Act, and are also indicators of Sensitive Environments under the EEZ Act.

As the ‘threatened’ criterion typically refers to individual species or indicator taxa, there is clearly overlap between layers that contribute to this scenario and analysis for individual taxa groupings. Threatened marine mammals, seabirds, fish and macroalgae will all occur in the scenarios for their respective taxa groups. Similarly, predictive models for several of the benthic protected species (i.e., VME indicator taxa) are included within taxon-specific scenarios for benthic invertebrates. It should be noted that the benthic invertebrate models are all based on genera level records and draw on some different data sources than those for the protected and VME indicator taxa models (Anderson et al. 2020). Thus, there may be some differences in layers denoting the distribution for the same protected species/taxa due to different data providence.

A number of point records layers are also available to inform this KEA criterion, for examples, records from the citizen science databases iNaturalist illustrating seabird records. As with point records for rare and unique species, these point record layers can be converted into rasterised grid layers with the number of points per cell available as an input into a scenario either as a direct input layer, or as a silent or unweighted layer. In the case of seabird and shorebird records, these layers illustrate hotspots around population centres, and with regularly monitored locations of high bird priority such as Ramsar sites. As these point record databases are not comprehensive, it is recommended that these are used as silent layers and not contribute Zonation scenario prioritisations.

Due to the high importance held by this (or similar) criteria in many spatial management projects, it is unlikely that prioritisation practitioners wish to favour individual taxa scenarios above a targeted threatened species run. In this case, it may be appropriate to remove threatened species, or to set them as silent layers, in the component taxa scenarios. Similar to double-counting options with other KEA scenarios, the alternative is to retain threatened species layers within component taxa scenarios and weight them higher than non-threatened taxa. An additional option (in either a component taxa scenario, or a KEA scenario) is to weight input features according to threatened status, where the most threatened taxa (e.g., nationally critical under the NZTCS) have a stronger influence on the prioritisation.

To illustrate potential challenges in the use of this KEA criterion in prioritisations, we ran an analysis using predictive models for threatened marine mammals, fish, and benthic invertebrates (including some VME indicator genera and bryozoans). The non-breeding distributions of threatened seabird species were also included, but not the breeding distribution (to minimise overlap with the scenario for the ‘life history’ criterion). We conducted an analysis with all input features weighted equally, and one where nationally critical species (or IUCN equivalent) were upweighted by a factor of 3 (Figure 4-36, Figure 4-38).

The prioritisation for threatened taxa/habitats identified several hotspots for these features throughout the NZ marine environment (Figure 4-36). These include the north-east coast of the

North Island, Cook Strait around Banks Peninsula and around the sub-Antarctic and Chatham Islands. These locations all feature strongly in the distribution of endangered marine mammals and seabirds, while offshore high priority areas (e.g., Challenger Plateau, areas on the Chatham Rise) are likely driven by high habitat suitability for protected benthic species (e.g., cold-water corals). The prioritisation performed well, with a high proportion protected across three high priority classes (Figure 4-37).

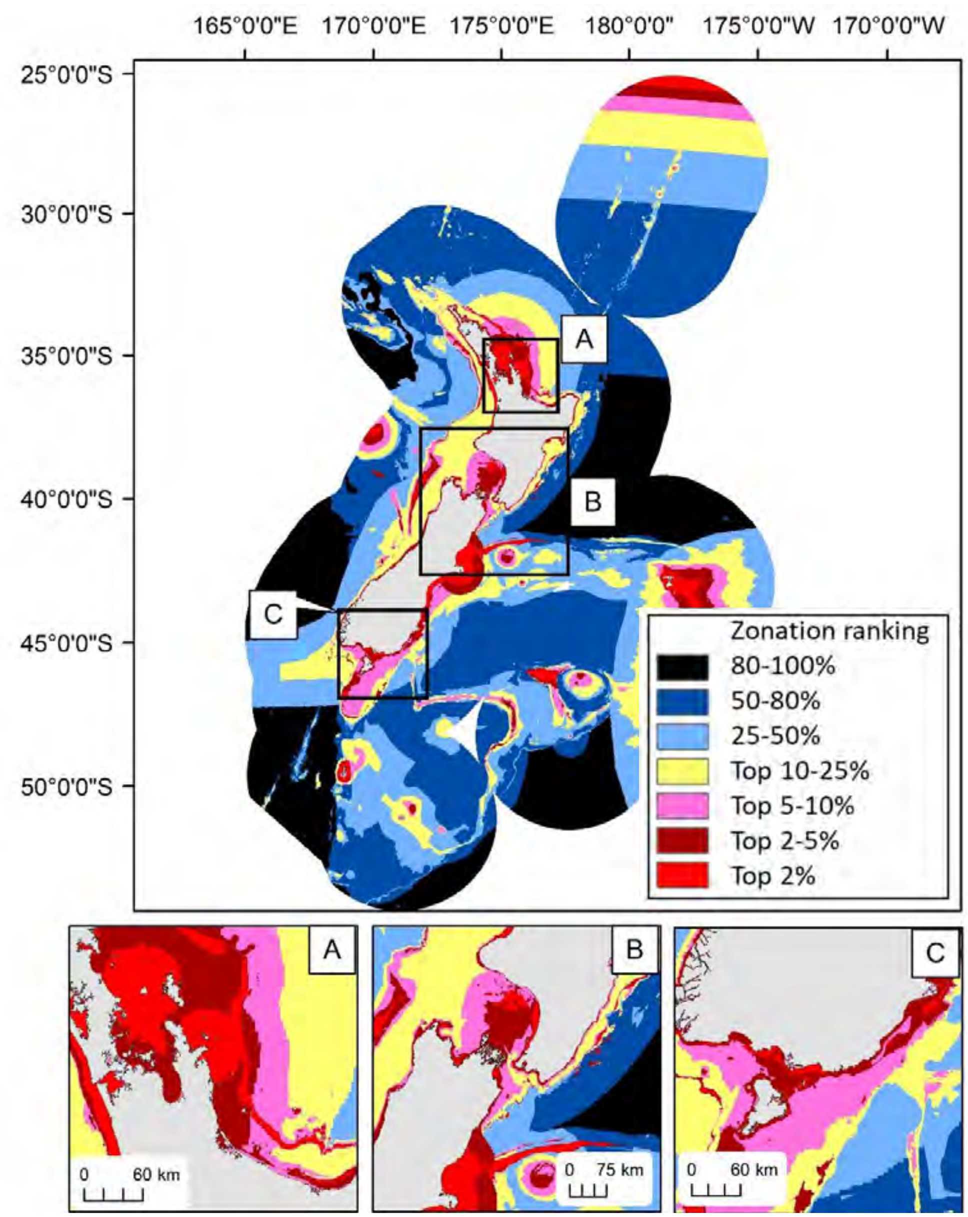

Figure 4-36: Spatial prioritisation based on KEA layers associated with threatened taxa, with equal weighting given to all layers; insets highlight priorities in inshore regions. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

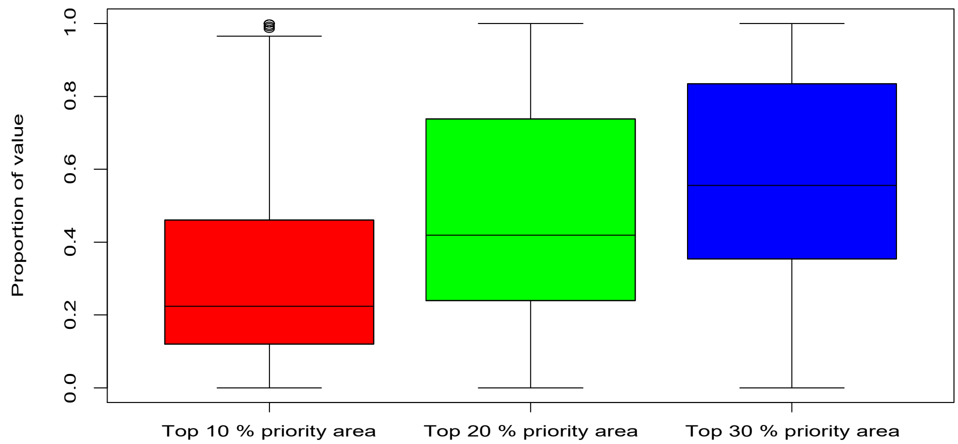

Figure 4-37: Performance of a spatial prioritisation for threatened criteria taxa across 10, 20 and 30% of the top priority areas. Performance is measured by the proportion of biodiversity value retained within top priority areas.

There was considerable variation between the threatened taxa/habitat scenario that had all features weighted equally and that which had a higher weighting for critically endangered species (Figure 4-38). The weighted scenario showed an expansion of the high priority area around the Chatham Islands – a location that is important habitat for several endangered seabirds. Further, the majority of the Northland region was incorporated into the high priority area under the weighted scenario, reflecting the presence of critically endangered marine mammals (Maui dolphin, Bryde's whale and bottlenose dolphin). The effects of the weighting is also illustrated in plots of the feature conservation curves. Under the unweighted scenario, non-critically endangered taxa receive a higher proportion of value protected across most of the prioritisation area. In contrast, the critically endangered taxa achieve higher value protected in the weighted scenario (Figure 4-39).

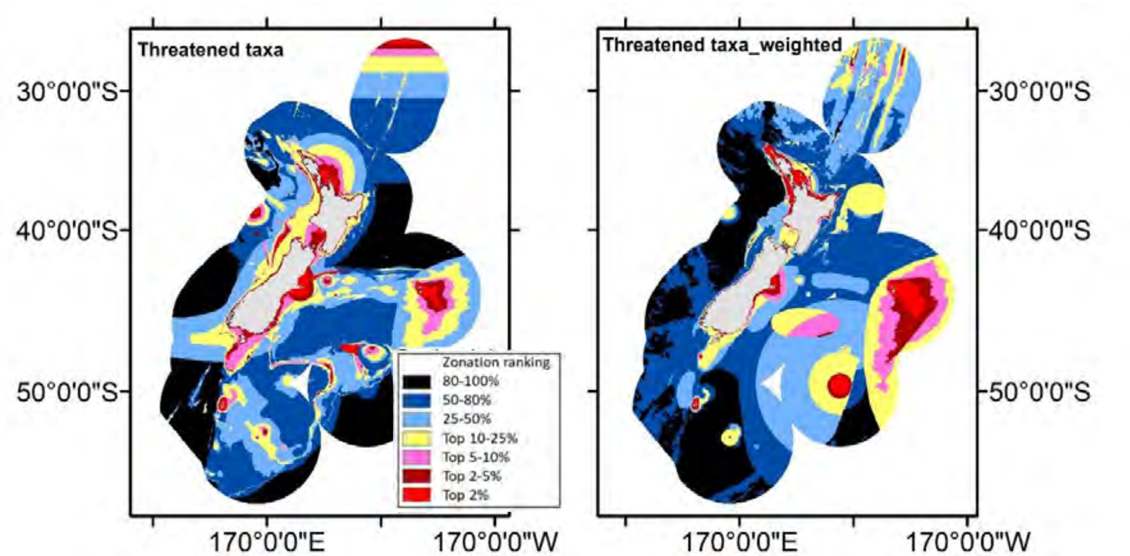

Figure 4-38: Spatial prioritisation based on KEA layers associated with threatened taxa, showing a comparison with and without weighting given to species with higher threat ratings. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

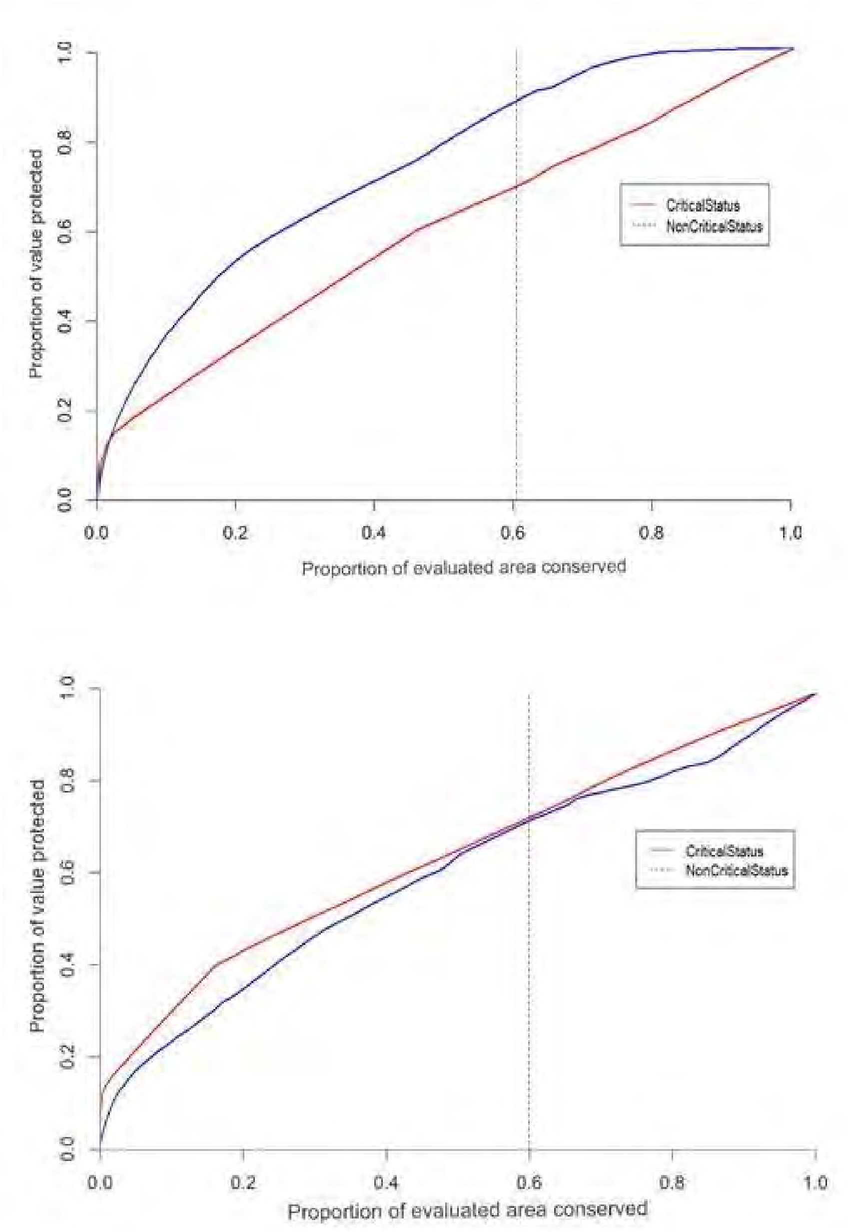

Figure 4-39: Feature conservation curves for taxa pooled into a critically endangered group, and those with a lower threat status. The top panel shows the performance curves where all input layers are given equal weights of 1, while the bottom panel shows the performance curves where all critically endangered taxa were weighted by 10 and taxa with lower threat status given a weight of 1. .

4.4.5 Biological Productivity

The productivity KEA criterion is defined as “area containing species, populations or communities with comparatively higher natural biological productivity” (Lundquist et al. 2020a). A substantial range of spatial layers may contribute to this criterion including different measures of primary and secondary productivity, the spatial extent of habitats that are known for high productivity (kelp forests, hydrothermal vents, upwelling and frontal zones) and the distribution of species that directly contribute to primary productivity (e.g., macroalgae). Layers that represent the extent of productive habitats may also be relevant inputs for several other criteria. For example, hydrothermal vents and kelp forests are often considered vulnerable and fragile habitat, thus these layers may be better placed under a vulnerability scenario.

The inclusion of different metrics reflecting primary productivity raises concerns resulting from biases in sampling methods and collinearity among metrics used in the same scenario.
Most layers used to provide a spatial representation of primary productivity are derived from remote sensing observations. Estimates of chlorophyll a concentration, derived from raw measurements of ocean colour, provide an indication of the distribution of primary productivity in surface waters. Based on modelled relationships between the surface chlorophyll concentration, environmental factors (e.g., turbidity) and the rate of carbon flux to the deep sea, productivity metrics are further refined for different habitats (e.g., coastal, offshore, deep-sea). However, as the key input variable for these productivity metrics is surface chlorophyll concentration, there may be strong correlation among the derived metrics in certain locations, which must be considered when including representative spatial layers in a single zonation scenario. Further, despite significant advances in algorithms used to estimate chlorophyll concentration in turbid areas, there may be issues in some highly turbid locations where chlorophyll estimates are skewed by very turbid surface waters (e.g., nearshore habitat).

Similar options to those used to minimise double-counting of layers can be used for highly correlated input layers within the same scenario, such as removing or strongly down-weighting layers that are of limited importance for the productivity scenario, down-weighting layers that may contain spatial biases due to correlates with environmental variables (i.e., turbidity), or setting correlated productivity layers as silent layers so they do not contribute to the final prioritisation.

As an example, we have produced a biological productivity KEA scenario that includes measurement of surface chlorophyll concentration, a layer representing gradients in chlorophyll concentration (as a proxy for frontal activity), and two measures for deep sea productivity – POCFlux (vertical flux of particulate organic carbon) and VGMP (net primary production by the vertically-generalised production model) (Pinkerton 2016). Due to the likelihood of the surface chlorophyll layer being influenced by highly turbid locations, we also show a second productivity scenario where we weight the other layers in this scenario higher (weight of 2). In these scenarios, we chose not to include layers representing macroalgae distribution, kelp forest and hydrothermal vents due to overlap with other scenarios.

The unweighted productivity scenario highlighted the majority of the coastal waters of NZ's marine environment as high priority. High priority areas were also located around the Auckland, Campbell and Chatham Islands, and this scenario exhibited a large medium-priority area north of the Chatham Rise (Figure 4-40). While the NZ's coastal waters are productive, this scenario is likely to have missed key locations on the Chatham Rise and along the sub-tropical convergence where productivity is known to be high. This result is likely due to the incorporation of chlorophyll a surface concentration, which may be correlated with turbidity in coastal waters. However, the prioritisation did perform well, with a higher mean value protected across the three priority areas (Figure 4-41).

In contrast to the unweighted productivity scenario, the weighted prioritisation had more high prioritisation values offshore – particularly on the northern edge of the Chatham Rise and areas dominated by the sub-tropical convergence (i.e., the Southland front) to the south and west of the South Island (Figure 4-42).

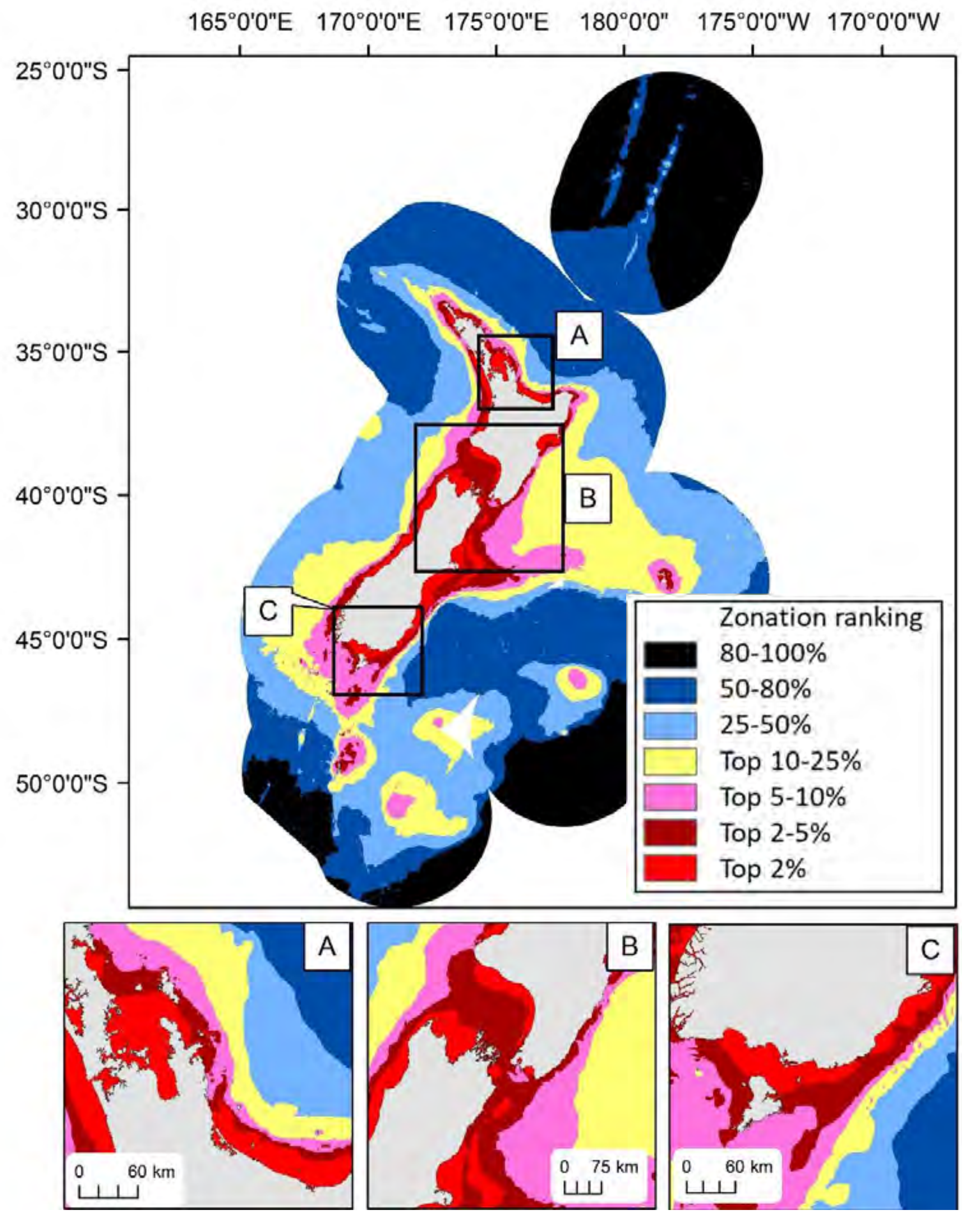

Figure 4-40: Spatial prioritisation based on KEA layers associated with productivity. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

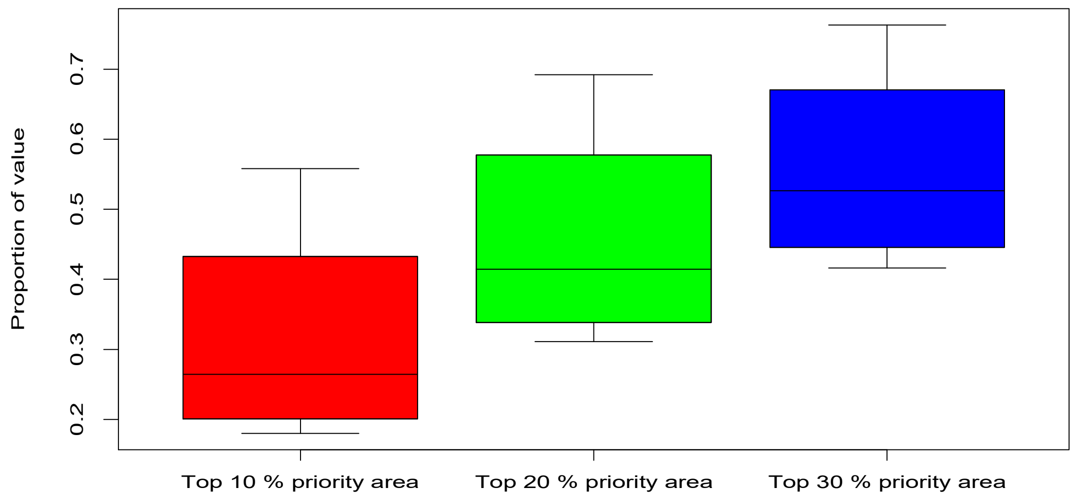

Figure 4-41: Performance of a spatial prioritisation for productivity criteria across 10, 20 and 30% of the top priority areas. Performance is measured by the proportion of biodiversity value retained within top priority areas.

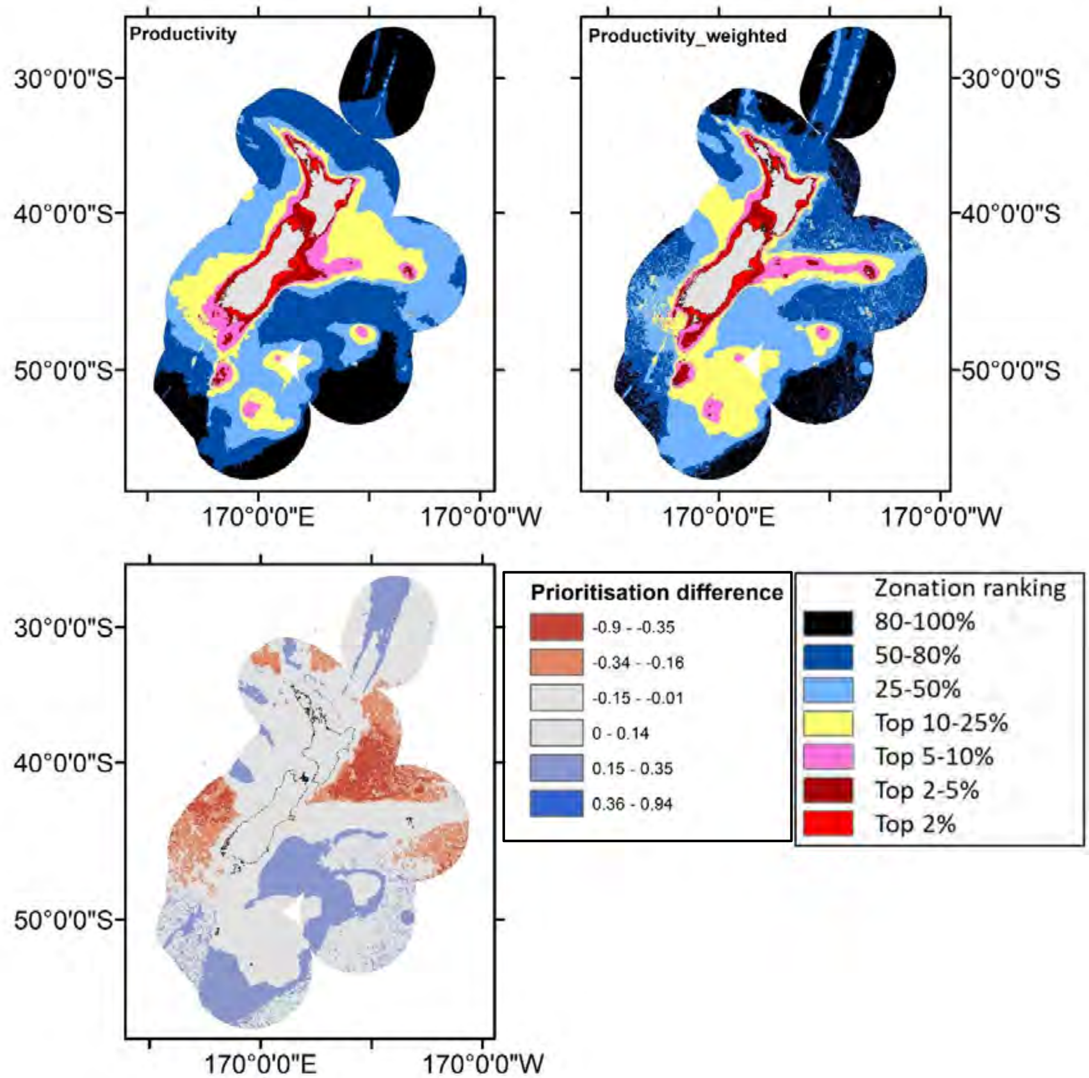

Figure 4-42: Spatial prioritisation based on KEA layers associated with productivity, with and without higher weighting given to taxa with higher threat ranking. Lower figure illustrates relative differences in prioritisation values between the two scenarios, with red indicating lower prioritisations for an area with productivity excluded, and blue indicating higher prioritisation with productivity excluded. The Zonation ranking legend indicates higher priority areas for conservation in red, and lowest in black.

4.4.6 Biological Diversity

Defined as an "area contains comparatively higher diversity of ecosystems, habitats, communities or species, or has higher genetic diversity", the 'diversity' criterion is another important consideration for most spatial planning projects. There are several ways of representing this criterion in a Zonation prioritisation. For the present project, spatial layers representing species richness were generated for five taxa groups (cetaceans, demersal fish, benthic invertebrates, reef fish, macroalgae) by summing the predictive models for all taxa in these taxa groupings. As models were only available for taxa with a sufficient number of presence locations, the resultant taxa richness layers represent relative rather than absolute richness (as many of the rarer or poorly sampled taxa will not be represented).

The relative richness layers were generated to represent the diversity criterion scenario and so there is no overlap with scenarios for other KEA criteria or taxa groupings.

An alternative representation of diversity is to generate a scenario where SDMs for all available taxa are used as input biodiversity features. Using the 'core area' Zonation cell removal rule, Zonation will attempt to include 'hotspots' for each input layer, whereby the highest priority areas are likely to represent important areas for the largest number of taxa. In such a scenario, there will obviously be overlap between a diversity analysis and each of the individual taxa prioritisation scenarios.

An additional decision point for the diversity prioritisation scenario is around whether certain habitat types should be represented as ADMUs, recognising that there may be significant differences in diversity among habitats. If ADMUs are used, it is possible to allow for this distinction and thus avoid a prioritisation of a small number of very diverse habitat types (e.g., all reef may be protected but limited soft sediment habitat is protected).

We constructed a 'diversity' scenario using five relative species richness layers representing cetaceans, demersal fish, macroalgae, benthic invertebrates and reef fish (Figure 4-43). Each layer was weighted equally. To illustrate the effect of implementing an ADMU for habitat type, we compared diversity scenarios with and without an ADMU for reef habitat (Figure 4-44).

The primary diversity scenario identified a combination of broad and fine scale features that are important for this criterion, which are dispersed throughout NZ's marine environment (Figure 4-43). Most of the Chatham Rise is classified as medium or high priority, with the north and south slopes of the Rise being particularly high. The majority of sampling of both demersal fish and benthic invertebrates was undertaken on the Chatham Rise or similar habitat, and thus there may be some sampling bias introduced into the SDM generation that influences the occurrence of the entire Rise as a medium-high priority area. A large part of the continental shelf break around both main islands is also determined as high priority for the diversity criteria, as are fine scale cluster of cells within the Hauraki Gulf and along the Southland coast that likely represent reef habitat with high diversity (Figure 4-43).

Setting an ADMU function for reef habitat makes very little difference to the distribution of zonation prioritisation areas at the broad scale (Figure 4-44). The extent of reef habitat, compared to the extent of the EEZ, is very small, and thus while such an analysis may establish which reef systems are particularly important, it is unlikely to have a significant influence on the prioritisation as a whole.

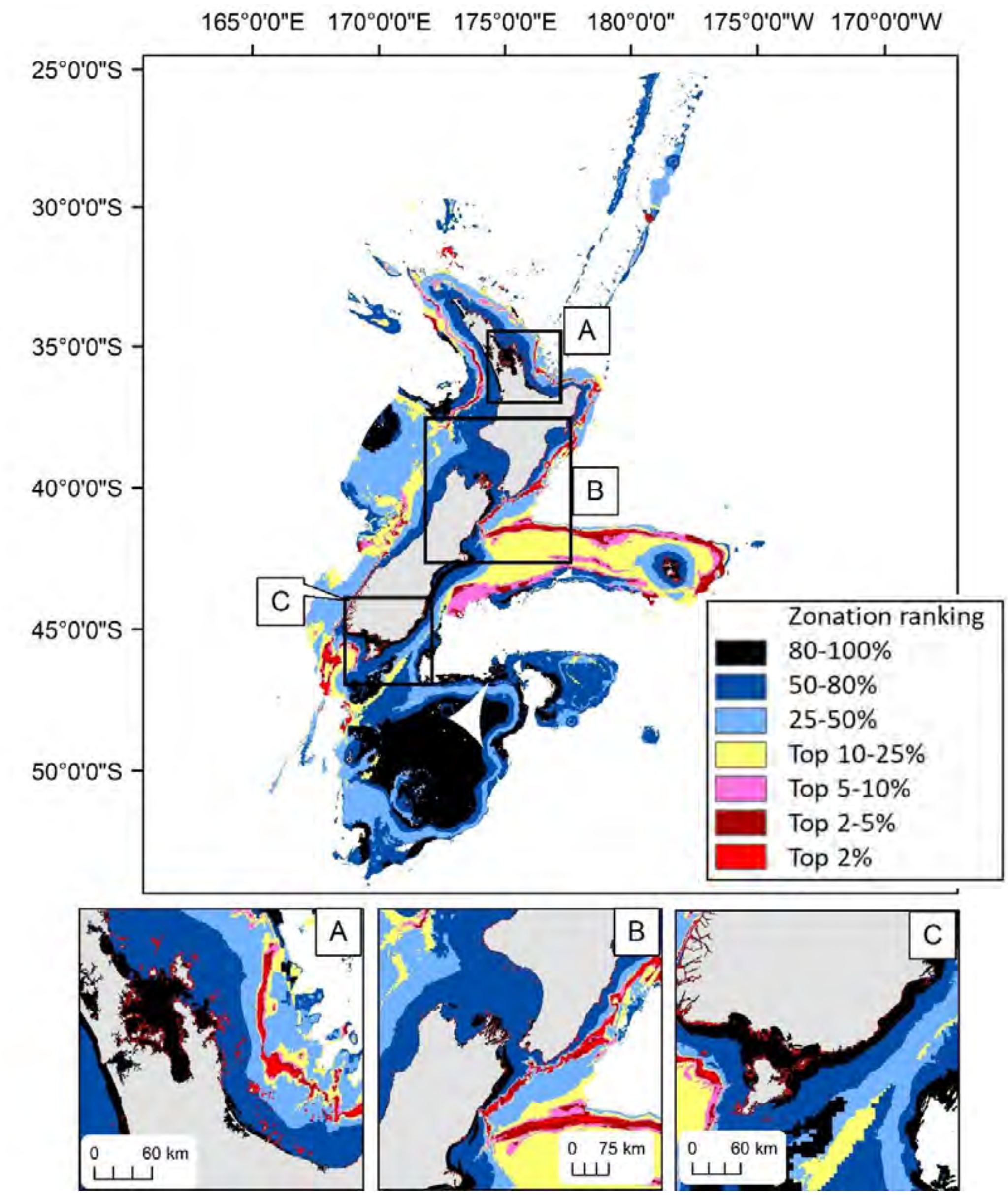

Figure 4-43: Spatial prioritisation based on KEA layers associated with diversity. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

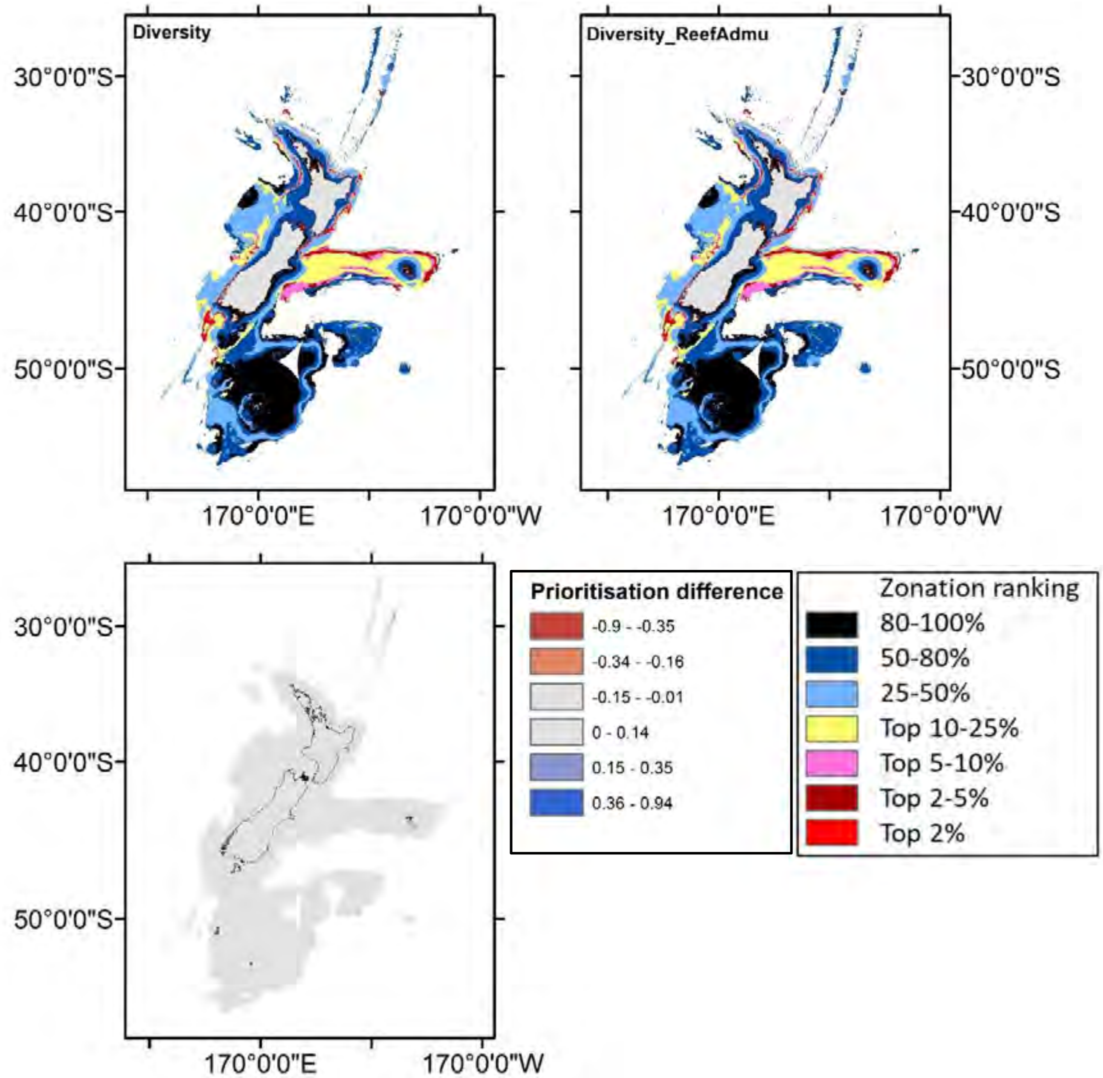

Figure 4-44: Spatial prioritisation based on KEA layers associated with diversity, with and without balancing across Administrative Units representing reef layers. Lower figure illustrates relative difference in priority between the two scenarios presented with red indicating a high negative difference an blue a high positive different in prioritisation value. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

The diversity scenario performed relatively well, with mean values of proportion protected being high across the three priority areas. The boxplots also show a broad range in the distribution of proportion of value protected, with high values approaching 100% protected. This is due to the inclusion of species richness layers for macroalgae and reef fish that are predicted to a comparatively small extent (the distribution of reef habitat). Due to this small extent with comparatively high richness values (i.e., all non-reef habitat has 0 value for macroalgae/reef fish), Zonation selects the majority of reef habitat as a high priority and thus protects and large proportion of habitat for reef dwelling taxa (Figure 4-45).

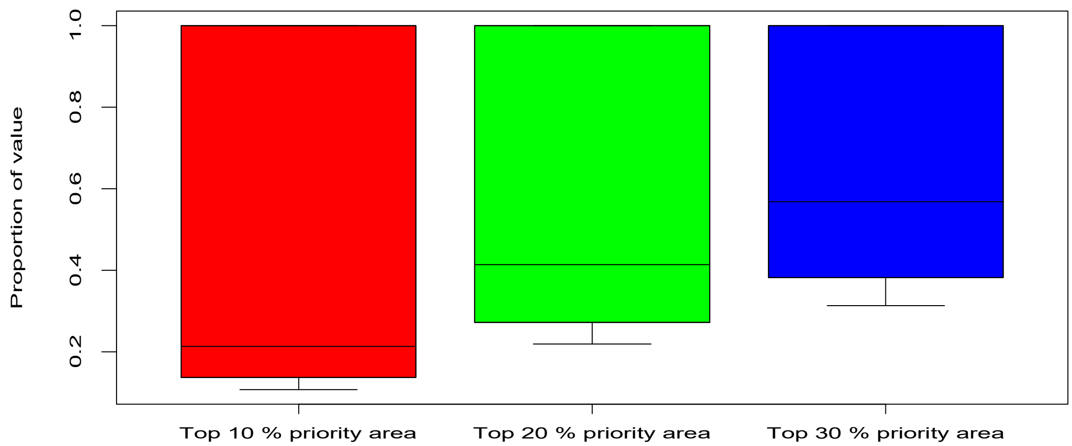

Figure 4-45: Performance of a spatial prioritisation for biodiversity criteria across 10, 20 and 30% of the top priority areas. Performance is measured by the proportion of biodiversity value retained within top priority areas.

4.4.7 Naturalness

The KEA criterion of naturalness is defined as “areas with a comparatively higher degree of naturalness as a result of the lack of or low level of human-induced disturbance or degradation” (Lundquist et al. 2020a). How naturalness is applied is strongly influenced by the priorities of the spatial management project. For example, some projects may seek out more pristine areas in order to conserve them while a contrasting objective may seek to prioritise degraded areas for restoration. A range of naturalness layers have been made available through the KEA and associated projects including the distribution of anthropogenic impacts (i.e., threats to biodiversity) such as fishing footprints, oil and gas infrastructure and land use impacts. Additionally, proxies for areas of high naturalness are available in the form of the boundaries of New Zealand’s 44 marine reserves, Type 2 MPAs including Cable Protection Zones, Benthic Protection Areas and seamount closures. Such proxies assume that the status of these management areas results in increases to naturalness through the removal of stressors to biodiversity, or alternatively that they were selected for marine conservation due to high levels of pristineness.

Not all management areas may contribute significantly to naturalness and thus practitioners may need to deliberate which management areas to include in such a scenario. When available, data that summarises the benefits of certain management classes for enhancing naturalness can be used to inform this decision. We illustrate a scenario where the ‘mask’ option is used in Zonation to force prioritisation of these managed areas, allowing assessment of the relative protection provided by these management strategies in terms of biodiversity and habitats included within their boundaries, as well as assessing which additional areas are most complementary in the representation of biodiversity should further protection be allocated. As expected, the output of this prioritisation shows high priority areas occurring within the management areas included as masks, such as the BPAs in the sub-Antarctic, Marine Mammal Sanctuaries around Banks Peninsula and the west coast of the North Island, and larger marine reserves such as those around the Kermadecs and Auckland Islands (Figure 4-46). This scenario performed worse than the original scenario for demersal fish (Figure 4-47), likely due to the forced inclusion of more marginal habitat for demersal fish that occurs in some of the management areas.

The majority of naturalness layers are unlikely to also be included as biodiversity inputs, thus double counting of these layers is unlikely. However, naturalness layers may also be represented as threats and cost layers, particularly when there is a clear association with industry. The application of threat and cost layers is discussed in detail in section 4.6, but it is advised that individual naturalness or threat or cost layers be used only once within a scenario to avoid compounding potentially substantial influences on prioritisations.

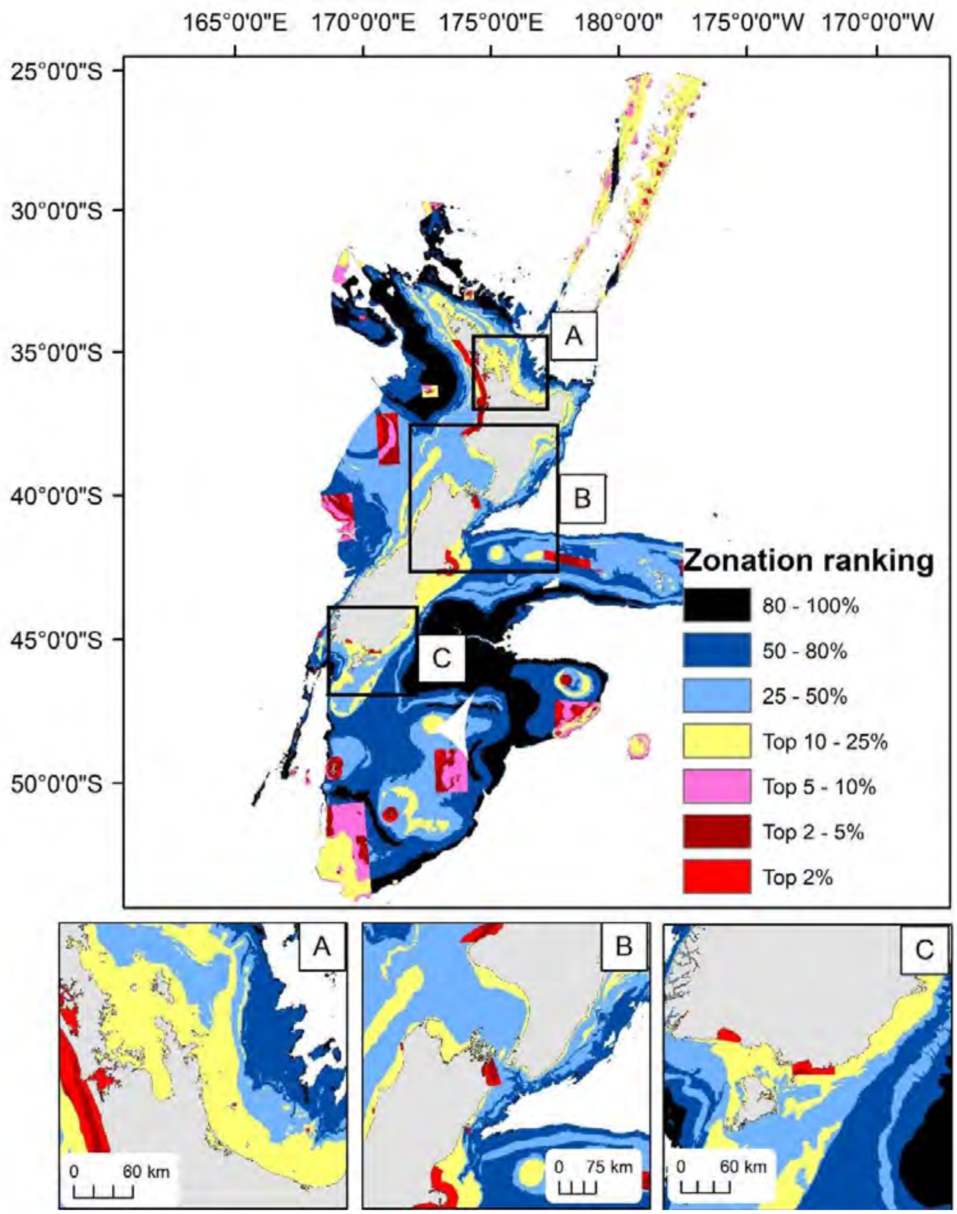

Figure 4-46: Spatial prioritisation based on demersal fish species occurrence models, using mask to prioritise selection of MPAs, BPAs and seamount closures. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

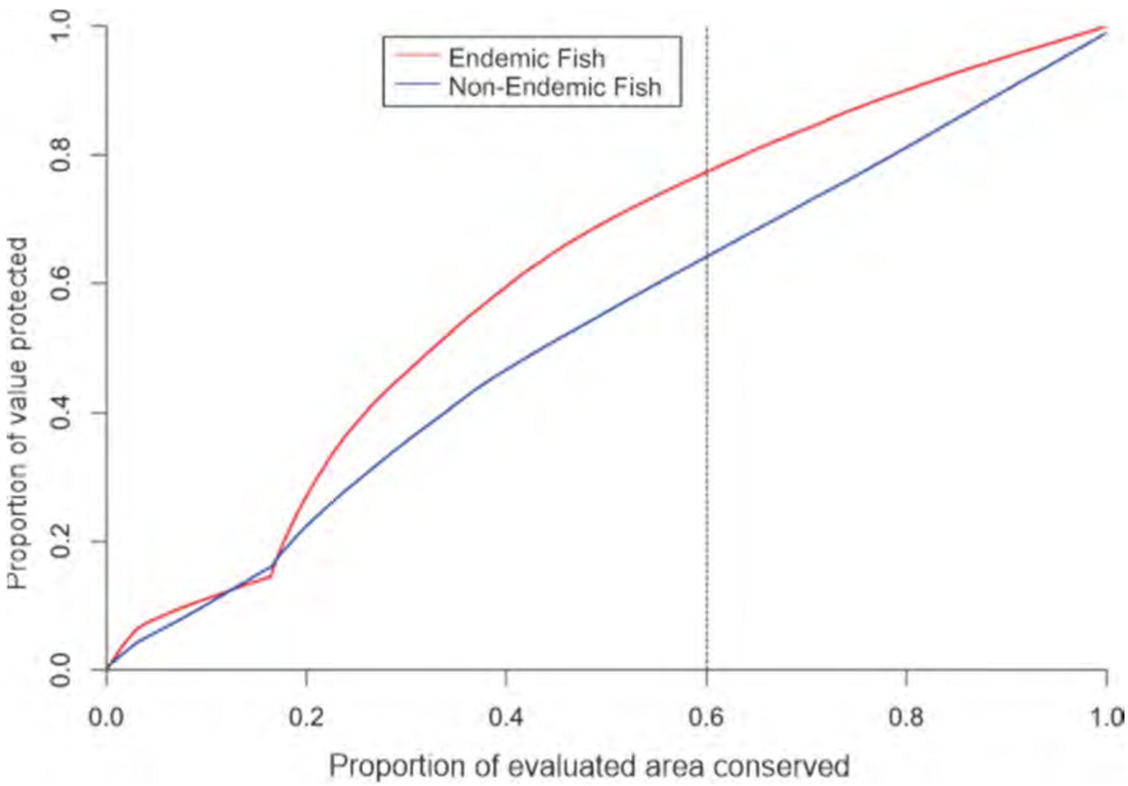

Figure 4-47: Feature conservation curves for taxa pooled into endemic and non-endemic taxa. Performance is measured by the proportion of biodiversity value retained within top priority areas.

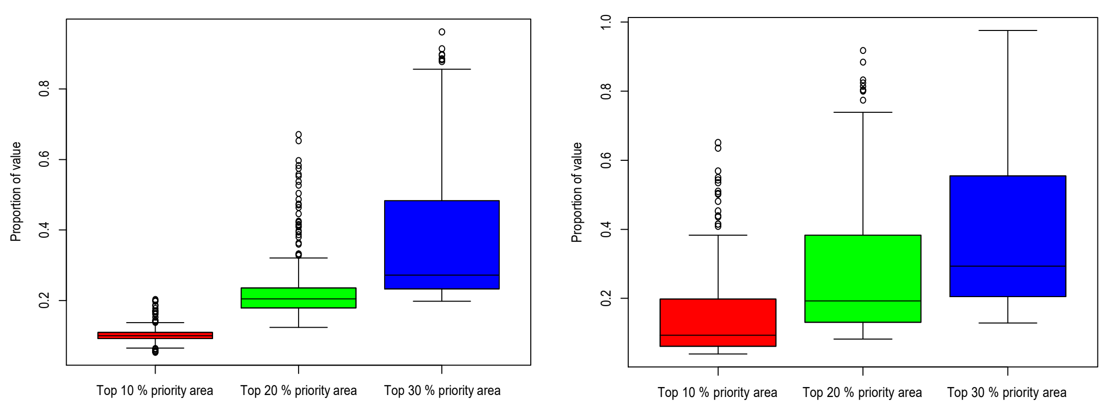

Figure 4-48: Performance of a spatial prioritisation for biodiversity criteria across 10, 20 and 30% of the top priority areas. Performance is measured by the proportion of biodiversity value retained within top priority areas. Left pane is the performance of the scenario using MPAs as masks for a demersal fish prioritisation; the right pane is performance of the original demersal fish scenario.

4.4.8 Ecological Function

The Ecological Function criterion is defined as 'areas containing species or habitats that have comparatively higher contributions to supporting how ecosystems function'. There is a paucity of detailed datasets with which to represent the ecological function criteria, particularly at broad scales. Under the KEA2 project (Lundquist et al. 2020a), we developed two datasets that fit this criterion – however, each have severe caveats that limit their current use. The first dataset represents the distribution of a family of mesopelagic fishes (Myctophidae) that have an important role in nutrient recycling, carbon sequestration and supporting higher trophic levels. This dataset collated pooled observations of myctophids caught during NIWA research trawls, and from OBIS datasets. Both contained observations of myctophids from around New Zealand and was represented as a point dataset that was later converted to a density distribution using a kernel density estimate. However, the myctophid dataset is highly biased to areas with a high degree of sampling and to sampling methods that are most likely to retain these small fish with research tows (e.g., oblique trawls). Much of this type of sampling occurs on the Chatham Rise, which reflects the significant clustering of myctophid point records in this area within the collated database.

The second dataset is a representation of groups of benthic invertebrates with important ecological roles that can be determined by their functional traits. Based on known traits, benthic invertebrate records were grouped into five 'functional groups', each representing an important ecological role. The distribution of these functional group records, however, strongly reflects the sampling distribution of the benthic invertebrate database as a whole, and does not illustrate an accurate distribution of these taxa. Similar to the dataset for myctophids discussed above, a kernel density estimate was performed for each of the five functional groups, thus the layers can be represented by a density distribution.

To illustrate a possible scenario for the ecological function criteria, we have run a prioritisation using the kernel density estimate layers for myctophids and the five benthic invertebrate functional groups (Figure 4-49). Given the caveats of these datasets, this scenario is meant for illustrative purposes only and does not represent an accurate prioritisation for this criterion.

The prioritisation for ecological function identified several high priority areas throughout New Zealand's waters. The first of these was the Chatham Rise – which is consistent with the high degree of sampling this area has received for all the datasets that were analysed in this scenario. Hawke's Bay and Bay of Plenty were also determined as high priority locations for ecological function. The shape and size of the prioritisation 'hotspots' is a clear reflection of the use of kernel density estimates as input data. Particularly for patchy/aggregated point datasets, kernel density analyses often result in density contouring (gradual linear fade of density values from an aggregation of points). In many cases, these contours are not a true representation density and are often driven by sampling distribution. Thus, care should be taken when using kernel density estimates, particularly with sparse or highly aggregated point datasets.

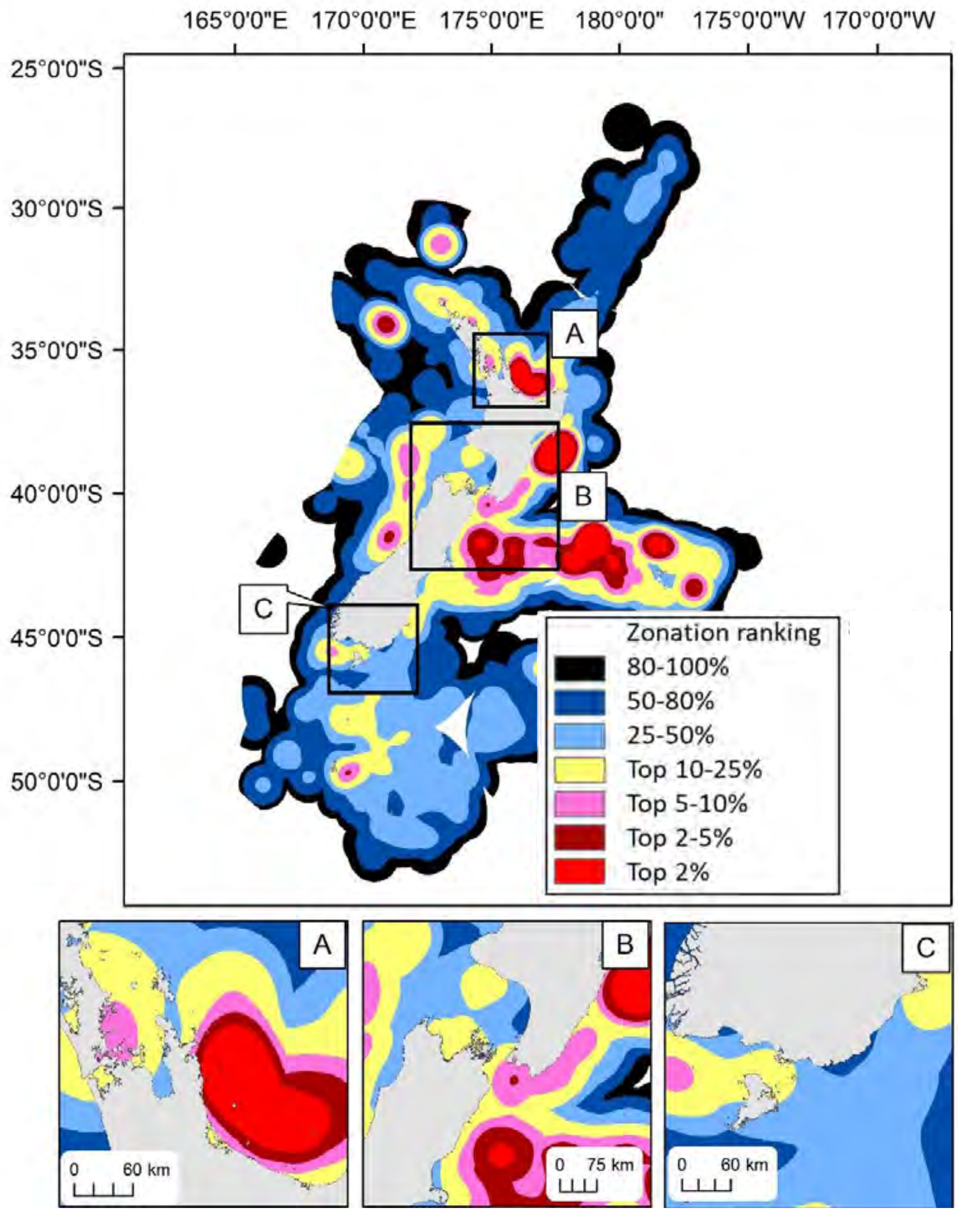

Figure 4-49: Spatial prioritisation based on KEA layers associated with ecosystem function. Lower figure illustrates subregions of the scenarios presented. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

4.4.9 Ecological Services

The Ecological Services criterion is defined as 'areas containing diversity of ecosystem services; and/or areas of particular importance for ecosystem services'. Only one spatial layer is currently available for the ecological services criterion within the KEA database (predictive models of biogenic habitats, for inshore areas only). As such we have not included an example of how this layer can be used in a Zonation-based KEA prioritisation process.

4.5 Step 5. Use of habitat classifications as a proxy for biodiversity

Section 4.5: Key messages

- Habitat or bioregional classifications present an opportunity to fill knowledge gaps when limited biodiversity information is available.
- The Seafloor Community Classification (SCC) is a recently developed numerical classification based on the relationship between environmental characteristics and seafloor community assemblages. The SCC spans the breadth of the NZ marine environment and is currently classified to a level of 75 groups.
- Metrics that summarise the representation of the environmental characteristics of defined classification groups can be used to determine the best locations to protect certain seafloor communities, or the best places to protect the characteristics of a broad range of seafloor communities.

Due to the quantifiable relationships between the environmental characteristics and biological assemblages, and uncertainty within and among classification groups, habitat classifications can be used to generate spatial layers that can represent diversity and to investigate the representativeness of a prioritisation output.

Environmentally-based habitat classifications offer an opportunity to fill knowledge gaps when limited biodiversity information is available (Rowden et al. 2018, Stephenson et al. 2020b), such as areas of very low environmental coverage. These types of habitat classifications use physical data to divide areas into discrete habitat types based on their environmental characteristics, with an assumed or demonstrated (in the case of numerical classifications) relationship with biological community composition (Rowden et al. 2018). Aotearoa New Zealand has a newly developed numerical habitat classification for seafloor communities - the New Zealand Seafloor Community Classification (SCC, Stephenson et al. 2020b), which has been classified to a level of 75 groups and spans the entire New Zealand EEZ. As an environmentally-based numerical classification, the SCC is based on species-environmental relationships characterised by community turnover functions which were developed using gradient forest statistical models (Stephenson et al. 2020b). Using the environmental characteristics of cells within each group, values for intra- and inter-group similarity were calculated that describe the similarity, in terms of the multidimensional environmental space, of cells from within the same classification groups, or among groups.

Intra-group variability at the level of an individual cell was calculated by determining the difference in environmental space between a cell and the centroid of the group to which it belongs. An intra-group similarity was generated for each SCC group, where cells outside of the group are set to 0. Intra-group similarity determines the representativeness of each cell within a SCC group, which may help to prioritise the best locations for prioritisation of a given group.

For inter-group similarity, the difference between each cell in the SCC classification and the environmental centroid of an individual group are calculated – providing a spatially explicit measure of the similarity between a certain group and areas beyond its boundaries. High value areas under a prioritisation scenario using inter-group similarity would reflect locations that best represent the environmental characteristics of all groups, i.e., areas that have the highest summed similarity over the 75 intergroup layers. This approach can thus provide candidate sites that would best protect a broad range of habitat types and their associated biodiversity features, as introduced in Stephenson et al. (in press) as a proxy for inclusion of both representativeness and through anticipated coverage of rare and unique species.

We provide two prioritisation scenarios to illustrate the use of habitat classifications. In the first SCC scenario (Figure 4-50), we use a combination of both inter- and intra-group similarity to maximise the representation of habitat types within and between groups. This scenario shows high prioritisation values for inshore areas around both main islands with particular high priority areas at North Cape, the Hauraki Gulf, Hawke's Bay, Cook Strait and Golden Bay, the south Canterbury Bight and Foveaux Strait. Offshore high priority areas include various topographic features on the Chatham Rise, seamounts of the North East of the North Island and shelf habitat of several sub-Antarctic Islands (e.g., Snares, Bounty Island). As with any prioritisation, the performance of this scenario can be assessed across any single or combination of input biodiversity features. In the case of the SCC, summarising the performance of a prioritisation across different groups of input features (e.g., inter- or intra-group similarity), may be of interest depending on the desired use of the scenario. For example, investigating the performance of a scenario at protecting intra-group similarity may be desired if the outcome is to distinguish the best locations for prioritising cells that best represent each of the 75 groups. In contrast, the protection provided by a scenario to inter-group similarity may be desired if users were interested in understanding the areas that have a high representation of environmental characteristics of many groups.

Under the first SCC scenario, we have provided a summary of the performance of the SCC prioritisation at protecting inter-group similarity (Figure 4-51). Under this assessment the performance of the scenario was low - using the top 30% of the prioritisation area, on average less than 30% of the intergroup similarity of SCC groups is protected. This may be due to intra-group similarity contributing disproportionately to the prioritisation, where Zonation finds more efficient solutions for the smaller areas that represent the best locations to protect individual groups. Depending on the aims of the prioritisation, it may be important to explore weighting to balance the relative contribution of layers informing a habitat classification scenario. However, this scenario provides a good example of how habitat classification layers provide an opportunity to afford some protection to areas with little to no information (Figure 4-50).

The second SCC scenario (Figure 4-53) illustrates a prioritisation with the same habitat classification layers, with additional layers included in the prioritisation to represent diversity (species richness layers for demersal fish, benthic invertebrates, cetaceans, macroalgae and reef fish). The distribution of high priority areas is very similar to that in Figure 4-50, with the only notable changes being an increased prioritisation of the outer Hauraki Gulf and a decrease off the northern West Coast of the South Island.

The inclusion of the species richness layers should increase the representation of the variability in habitat described by the SCC. Based on the similarity with the previous scenario, it is likely that intra-group similarity is contributing disproportionately to this prioritisation, and that the diversity layers may need to be weighted higher if they are to be the main contributor to this scenario (i.e., using the SCC to fill gaps rather than drive the prioritisation). This provides another good example of the need to consider balancing the inputs to a prioritisation based on the desired objectives. The use of the species/taxa curves of this scenario provides a good understanding of how the prioritisation offers protection to the diversity layers from the different taxa groups and the representativeness determined by the SCC intergroup similarity (Figure 4-52). Two obvious groupings occur between the reef fish and macroalgae diversity values and those of demersal fish and benthic invertebrates. This result is due to the habitat representing each of these groupings being very similar, reef and deep continental shelf waters (due to the high sampling of benthic invertebrates and demersal fish in this habitat). The linear trend of intergroup similarity reflects the significant spread of the SCC values across the EEZ.

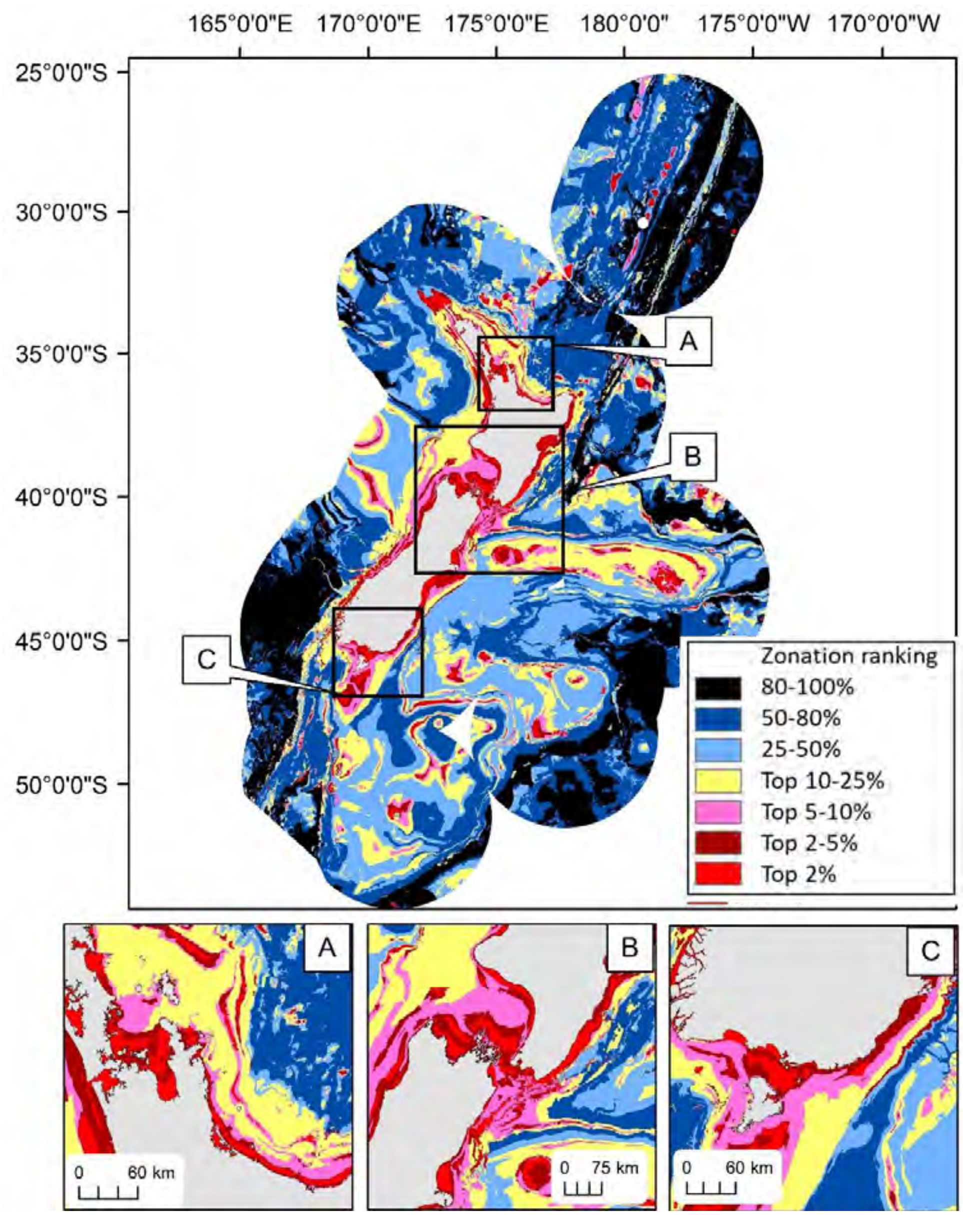

Figure 4-50: Spatial prioritisation based on Seafloor Community Classification intra- and inter-group similarities. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

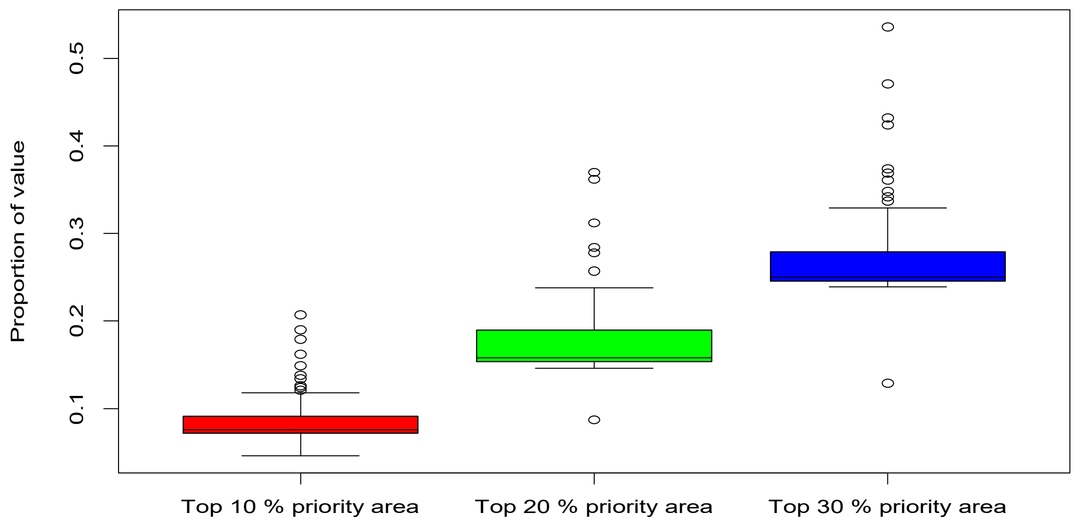

Figure 4-51: The performance of a scenario using layers derived from the SCC habitat classification at protecting the value of 75 different habitat classes defined.

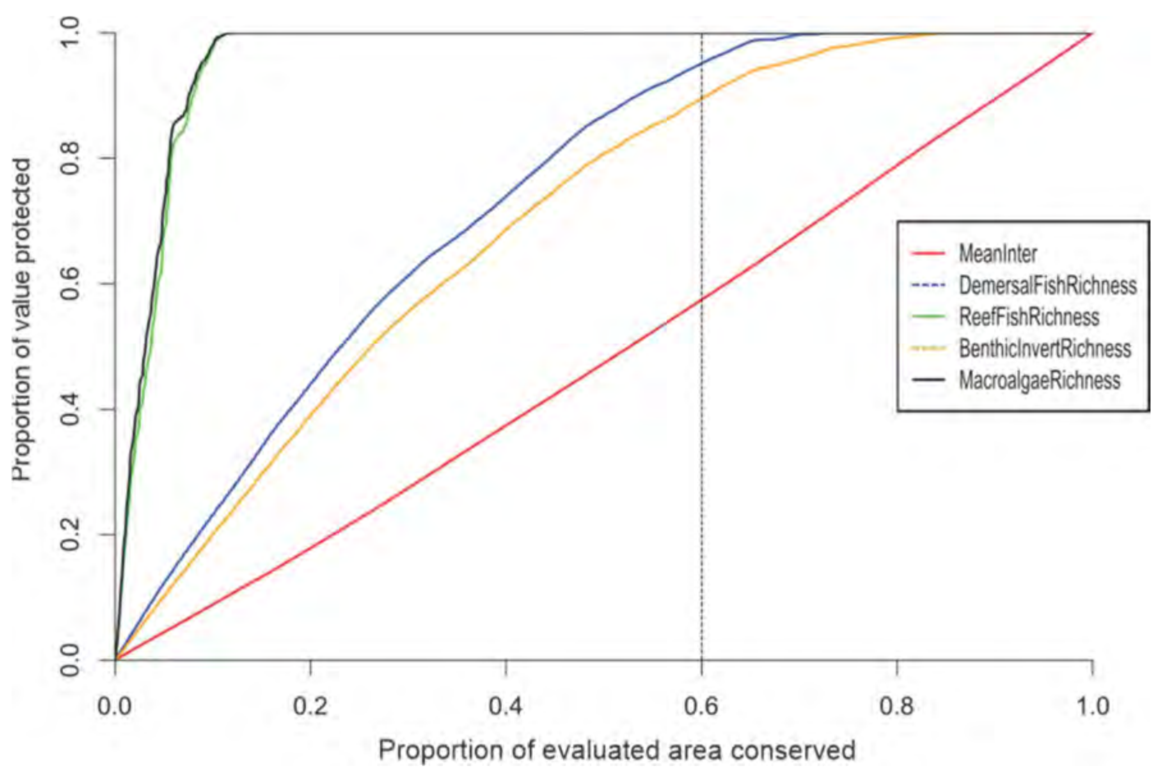

Figure 4-52: Feature conservation curves for the second SCC scenario. This scenario uses SCC habitat layers to fill gaps in a prioritisation of diversity (represented by species richness).

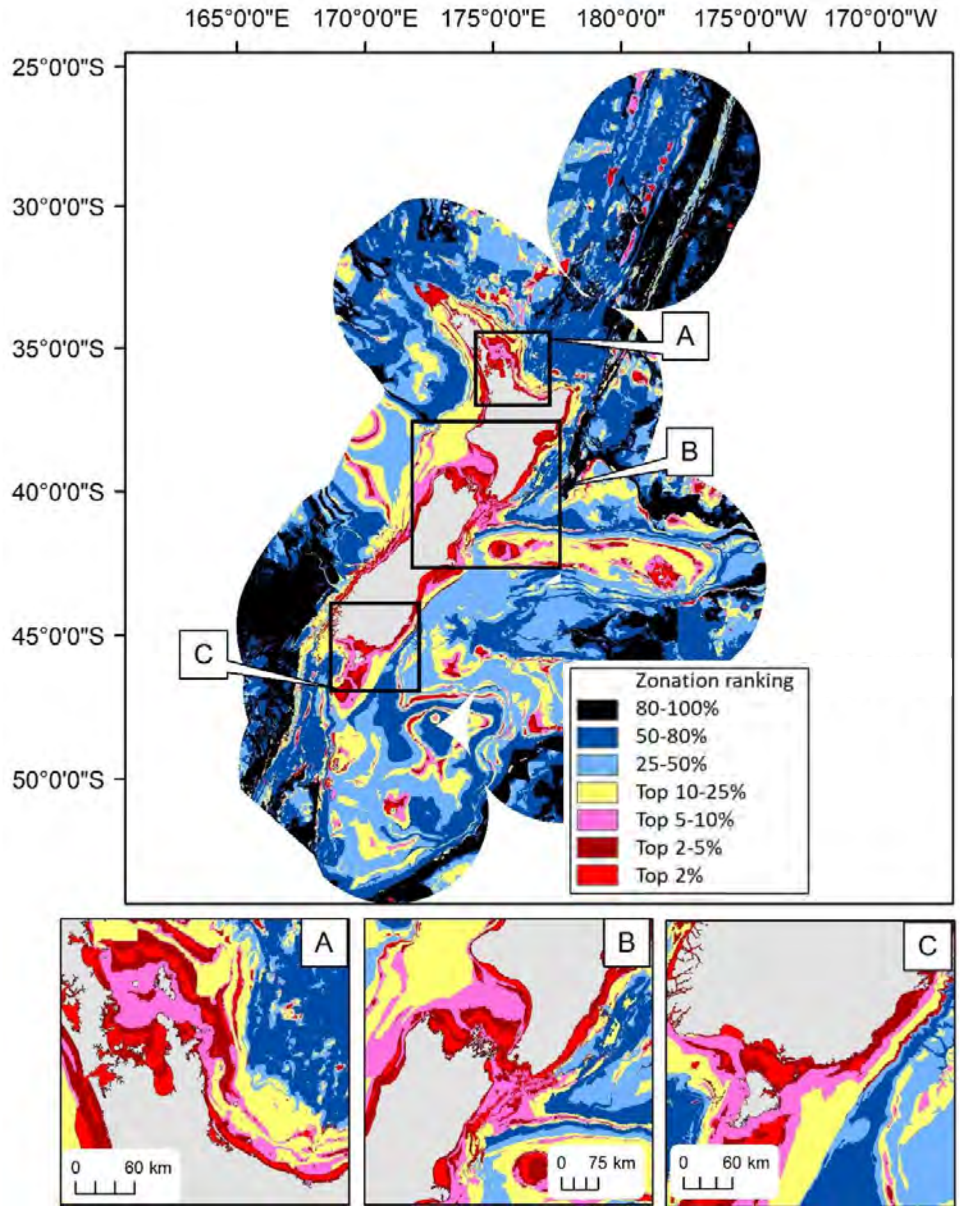

Figure 4-53: Spatial prioritisation based on Seafloor Community Classification intra- and inter-group similarities, combined with additional species richness layer. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

Habitat classification systems may also be used as bioregional layers using the Zonation 'administrative units' option. Earlier, we used a lower level of classification to represent bioregions, rather than the full suite of 75 SCC groups (e.g., 7 groups; see section 4.2) which can be used to balance prioritisation of biodiversity features across bioregional or latitudinal gradients. A final consideration with respect to integrating the SCC and environmental coverage in the prioritisation analysis is ensuring understanding of the overlap of different SCC groups with low environmental coverage thresholds.

An intersect analysis of the SCC groups with environmental coverage layers demonstrates a number of poorly sampled groups and areas of the New Zealand EEZ (Table 4-1). While 62% of all 75 groups have <10% overlap with the 10% environmental threshold, 12% of SCC groups have >90% overlap with the 10% environmental threshold layer (Figure 4-54). When compared by area, this approach reflects biases apparent in this layer's distribution, as a substantial portion (62%) of the EEZ by total area is within the 10% low environmental coverage (Figure 4-55). While the majority of the low environmental coverage is in deep offshore regions (e.g., SCC groups 1-9), there is also overlap of low environmental coverage with some inshore coastal regions, particularly in large estuaries and harbours.

Table 4-1: Percentage of each Seafloor Community Classification group within the low environmental coverage thresholds of 5% and 10%. Groups with >90% overlap are indicated in red.

Group	% overlap with 5 % environmental coverage	% overlap with 10 % environmental coverage	Group	% overlap with 5 % environmental coverage	% overlap with 10 % environmental coverage
1	100.00	100.00	39	0.00	0.00
2	100.00	100.00	40	0.00	0.00
3	99.99	99.99	41	9.51	24.98
4	98.41	99.71	42	0.20	4.33
5	100.00	100.00	43	0.00	0.13
6	96.32	98.12	44	0.40	0.69
7	98.20	98.68	45	4.42	12.85
8	80.66	88.14	46	0.00	0.00
9	54.91	77.61	47	0.63	11.83
10	7.61	12.95	48	30.75	48.68
11	0.00	0.07	49	0.17	0.33
12	5.25	28.22	50	0.32	0.46
13	0.52	3.51	51	0.49	1.07
14	27.22	71.13	52	4.37	9.67
15	8.05	31.99	53	3.05	5.31
16	14.58	34.34	54	0.47	1.63
17	0.05	0.35	55	0.35	0.73
18	0.10	0.12	56	4.75	10.10
19	0.00	0.00	57	0.00	0.39
20	0.00	0.00	58	0.00	0.00
21	0.00	0.00	59	11.14	47.93
22	0.03	0.38	60	0.00	0.00
23	0.72	1.54	61	56.44	80.11
24	0.00	0.00	62	0.98	5.88
25	54.81	93.57	63	0.00	0.00
26	81.38	97.71	64	0.00	0.00
27	0.00	0.00	65	0.13	0.26
28	0.00	0.06	66	6.54	13.29
29	0.00	0.00	67	0.00	0.00

Group	% overlap with 5 % environmental coverage	% overlap with 10 % environmental coverage	Group	% overlap with 5 % environmental coverage	% overlap with 10 % environmental coverage
30	0.00	0.00	68	0.04	0.08
31	0.00	0.00	69	0.41	0.93
32	0.00	0.00	70	1.33	3.60
33	0.00	0.00	71	4.40	13.20
34	0.01	0.03	72	17.86	46.43
35	0.67	2.27	73	16.34	50.00
36	0.00	0.00	74	2.00	6.86
37	0.00	0.00	75	3.91	22.98
38	0.03	0.50			

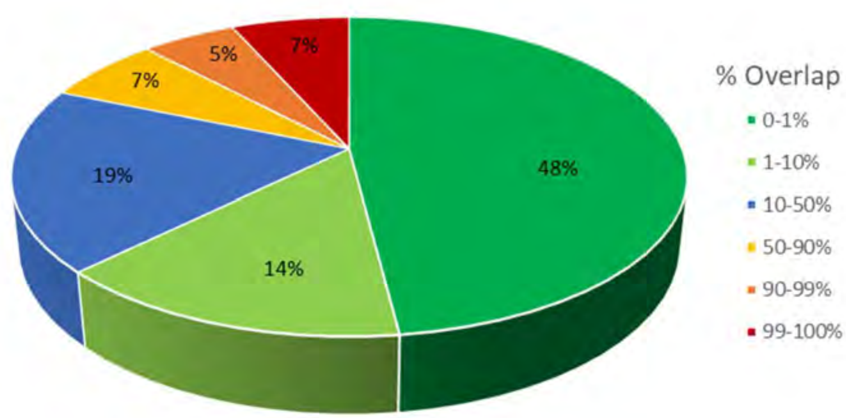

Figure 4-54: Proportion of Seafloor Community Classification groups within the low environmental coverage threshold of 10%.

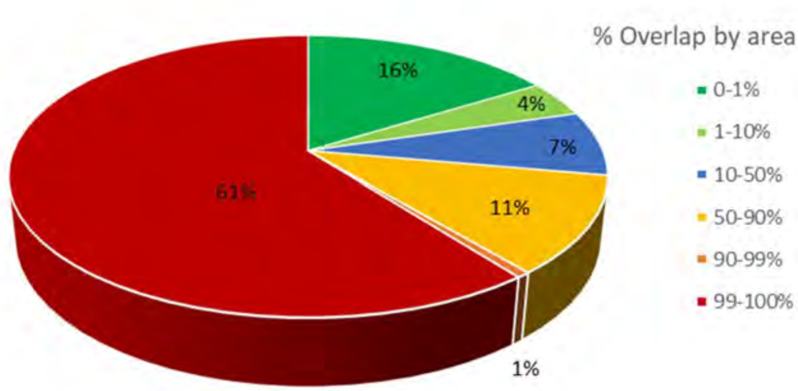

Figure 4-55: Proportion of total area of the EEZ within the low environmental coverage threshold of 10%.

Thus, environmental coverage can indicate areas where we have limited data to validate models of marine biodiversity, where using an environmental classification approach may be a suitable alternative to gaps in predictive models of species distributions. However, as demonstrated, overlaps with environmental coverage showcase that the SCC is similarly informed by only limited data in large portions of the EEZ. These poorly sampled areas can potentially be supplemented by other datasets, for example international and national datasets that showcase the locations of features such as vents, seeps or seamounts. Distributions of megafauna with wide ranging distributions may correlate with hydrodynamic features that concentrate animals in areas of high productivity.

4.6 Step 6. Adding in threat/impact/existing protection layers

Section 4.6: Key messages

- Cost layers may be employed in Zonation as a spatial representation of the trade-offs between biodiversity protection and resource use. These layers may indicate the spatial extent of certain industries, or may include quantitative data on the value of cells to resource users.
- Condition layers or layers that represent the distribution of threats can be used to offset a prioritisation to areas of high or low condition and threat prevalence. Users may choose to target areas of low condition for restoration priority, or alternatively areas of high condition in order to identify and conserve pristine areas.
- The Condition function available within Zonation identifies high priority areas that have low condition but high biodiversity values. It is also possible to include a threat/condition layer as negative weighted biodiversity layer, where Zonation avoids areas with high values of stressors to biodiversity.

An important part of many spatial management projects is how and whether to represent areas that should be avoided by the prioritisation. This avoidance may be due to habitat that is perceived as highly degraded, unsuitable or has high 'costs' associated with its protection. 'Cost' layers are a spatial reflection of the trade-off between biodiversity protection and resource use associated with the marine environment. Cost layers may simply represent the spatial extent of certain types of 'use', e.g., commercial or recreational resource use/extraction, seabed disturbance for infrastructure development and maintenance, cultural harvests. Alternatively, a cost layer can include continuous data on the realised importance of cells to a certain societal sector. For example, the fishing industry may develop a cost layer that is based both on the location of fishing events and the monetary value of catch within a cell. Such layers are often commercially sensitive and are developed in partnership with the respective sector.

When a spatial representation of threats or condition is deemed appropriate within a prioritisation, it is important to consider whether there is satisfactory evidence as to the relationship between biodiversity values and the threat in question. For example, while the inclusion of a layer representing fishing intensity may be an appropriate indication of threat or condition for some biodiversity features, it may not be appropriate for each feature in a prioritisation (e.g., taxa or habitat values not affected by fishing). Thus, the incorporation of threat/condition layers is an important decision point that merits careful consideration.

Spatial layers that reflect habitat condition (e.g., naturalness), or the distribution of threats can also be used to offset the prioritisation to areas with high or low condition (depending on objectives) and threat prevalence. As mentioned above, prioritisations may choose to select areas that are degraded in order to guide restoration, or they may choose to identify the most pristine sites for protection. Similarly, most prioritisations would integrate threat layers in order to avoid locations with a high prevalence of threats to biodiversity. However, if a prioritisation's objectives are to minimise the overlap between threats and biodiversity features, a more effective prioritisation may be to target locations where threats are high. Threats facing the marine environment are diverse and thus a wide range of layers may be useful at providing a spatial representation of threats. These layers may include the distribution of commercial and recreational fishing, mining, shipping, anthropogenic noise, pollution and sedimentation for example. There is obviously overlap between layers that may be incorporated as threats and those that could contribute as cost layers. In general, a cost layer is best used if stakeholders are interested in understanding the impact of a prioritisation output on a particular stakeholder group, where costs may necessarily require quantification of the protection as a resource use trade-off.

Cost layers are included using a specific 'cost' function with the Zonation settings file. There are two main ways that condition or threat could be incorporated into Zonation prioritisations. Within the settings file, a 'condition' function allows users to supply condition layers that can be linked to different biodiversity groups or individual features. The value of a condition layer varies between 0 (all habitat value has been lost) and 1 (pristine). The condition function establishes the highest priority sites as those that have low condition (i.e., have been degraded), but still have high biodiversity value (in comparison to pristine sites that have high biodiversity value). Thus, using the condition function would be most appropriate for prioritisations seeking to restore sites. An alternative method is to include condition or threat layers as negatively weighted biodiversity layers. Under this method, the layers are included within the species file along with other biodiversity layers but are attributed a negative weight value. This approach has the benefit of allowing flexibility around the degree of influence a threat layer may have on the outcome (by exploring alternative negative weighting values). However, unlike the condition function, a negative biodiversity layer would impact on the prioritisation across all biodiversity features and cannot be made to be group specific. Using a negative biodiversity layer causes Zonation to avoid areas with high values of threats and is thus better suited for identifying and protecting more pristine areas for conservation.

In order to illustrate the use of a threat layer, we constructed a scenario that performs a prioritisation for all taxa (cetaceans, demersal and reef fish, benthic invertebrates, macroalgae) using SDMs for species/genera in these groups. A threat layer was applied in the form of a spatial representation of commercial fishing effort, using footprint information from bottom trawling events as a readily available layer. This threat layer was applied as a negatively weighted biodiversity layer, with two weightings (-5 and -20) in order to showcase how different negative weightings influence the final prioritisation.

The inclusion of fishing intensity as a threat layer had a substantial effect on the 'all taxa' prioritisation. Without fishing, the prioritisation highlights larger areas of the coastal waters of both islands, the Challenger Plateau and the Chatham Rise, as high and medium priority areas. Under the scenario with fishing, all such high value areas were deemed low priority, and new high priority areas were established outside of the fishing footprint (Figure 4-56). Few of these new areas were included in the scenario without fishing, with some examples in the Campbell Plateau and areas that are protected from fishing (marine reserves in the Auckland and Kermadec Islands). For illustrative purposes, we also depict the use of a threat layer with relatively high weighting (-20) (Figure 4-56). Due to the significant influence on the prioritisation, there are likely few situations where a threat layer would be weighted so highly, however this comparison provides a good example of an extreme case in the utilisation of a threat layer.

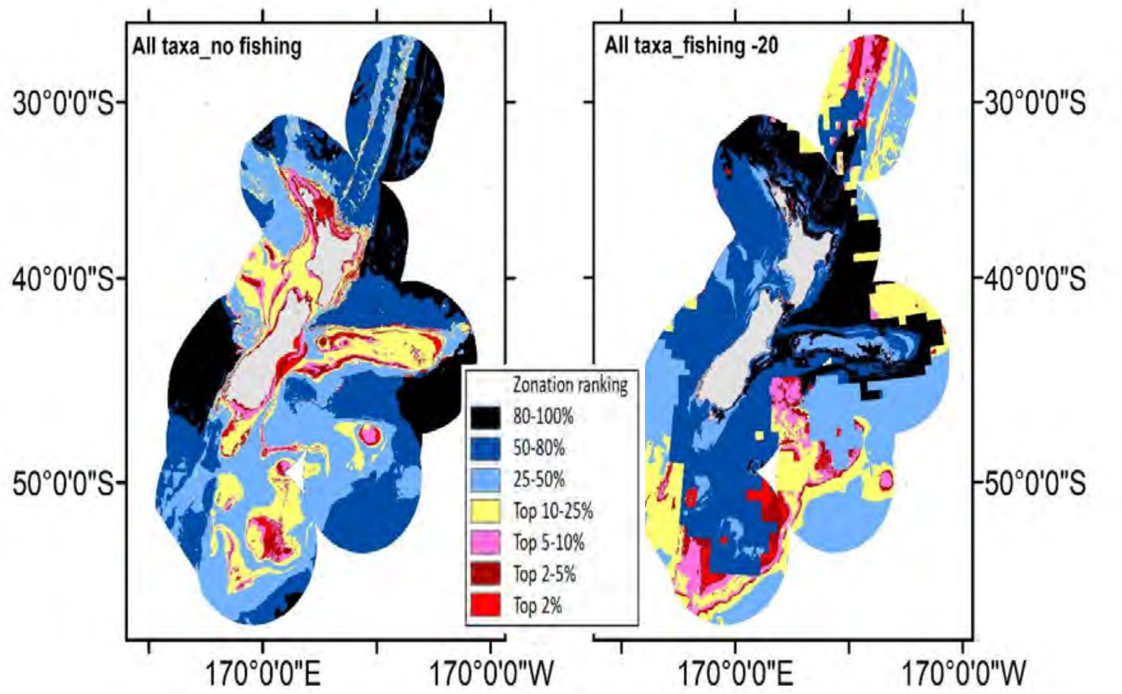

Figure 4-56: Comparison of two scenarios using the same biodiversity layers (all taxa SDMs), with and without a threat/impact layer. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

The relative influence of the threat layer can be interpreted by viewing the feature conservation curves for the scenarios with different weightings of fishing intensity (Figure 4-57). The proportion of value protected, across all taxa is higher under the scenario with a lower threat weighting (-5). For reef fish and macroalgae, under a lower threat weighting these taxa achieve total value protected (1.0) at around 30% of the evaluated area. Under a high threat weighting, this is not achieved until 50% or 100% of the evaluated area is protected for macroalgae and reef fish respectively. The targeted avoidance of areas with fishing intensity is shown by the black line of the conservation curves. Under the lower threat weighting, slightly more of the fishing intensity value is lost at earlier stages in the prioritisation (between 0.2 and 0.4 of the evaluated area).

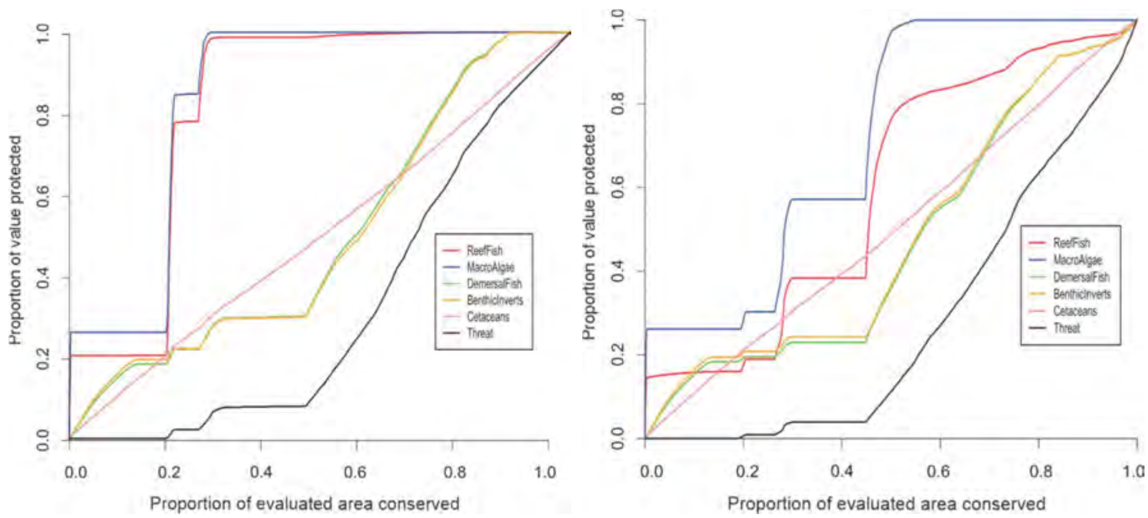

Figure 4-57: Comparison of feature conservation curves for scenarios with the incorporation of fishing as a threat with a 5 (left) or 20 (right) negative weighting.

Depending on the distribution of a threat layer, there may be disproportionate effects for certain taxa/biodiversity values. In situations where the majority of a taxa or group's distribution overlaps with high values of a threat, these features will be most strongly affected by the inclusion of a threat layer. Such a trend is evidenced in our scenario where macroalgae and reef fish undergo substantial declines in proportion of value protected when the threat layer is included (Figure 4-58). Under the all taxa scenario with no threat layer (Figure 4-33), each taxa grouping obtains a significantly higher proportion protected value compared to the scenario including a threat layer (Figure 4-58). The decline for macroalgae and reef fish are particularly large compared to the no threat scenarios illustrated previously. This result is due to the prediction of their distribution being limited to reef habitat, which is predominantly located in coastal habitat where fishing intensity is high.

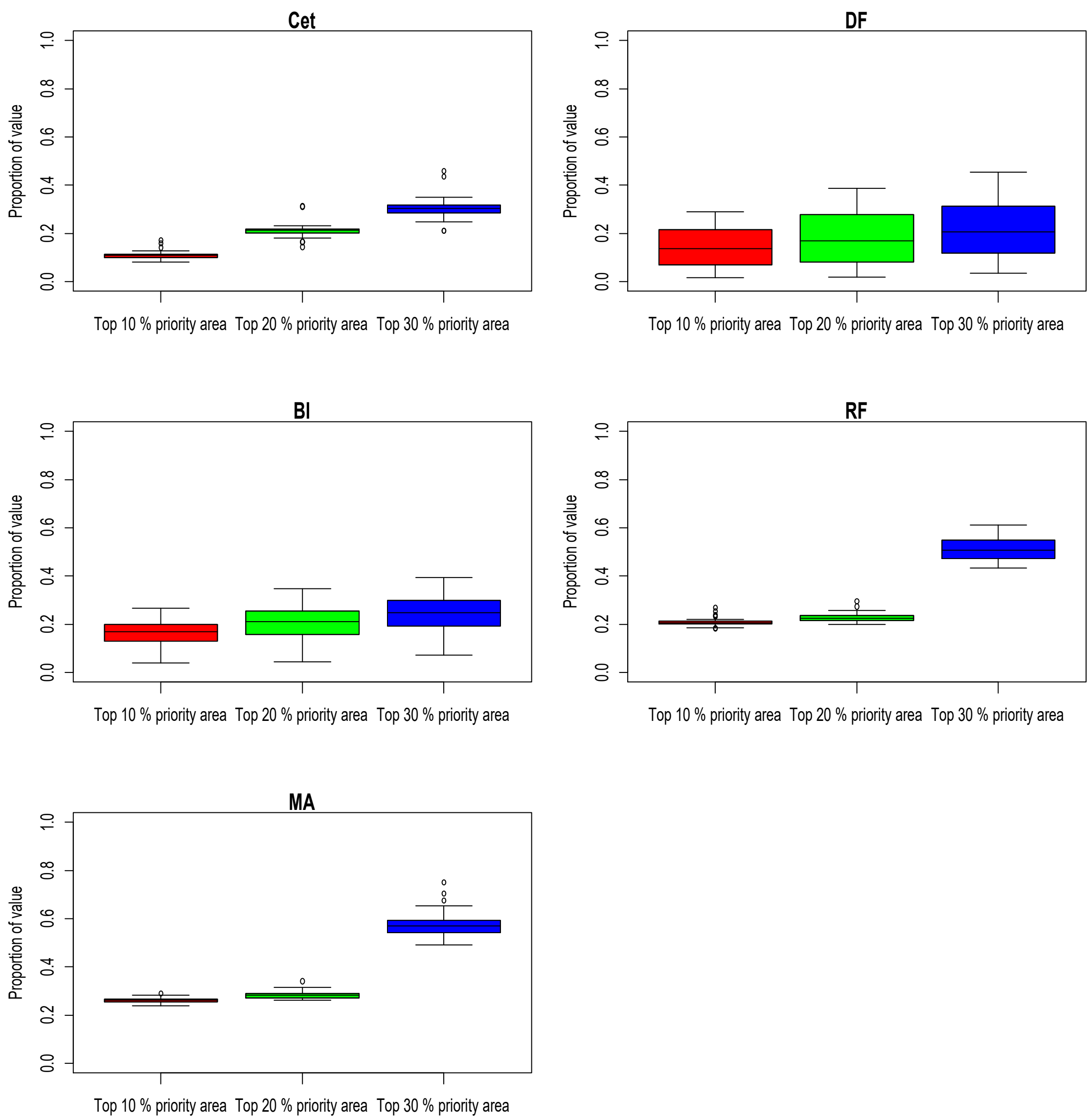

Figure 4-58: Performance of a spatial prioritisation for all taxa across 10, 20 and 30% of the top priority areas. Fishing intensity has been included as a threat layer in this scenario that can be compared to results of Figure 4-30. Performance is measured by the proportion of biodiversity value retained within top priority areas. Cet: cetaceans; DF: demersal fish; BI: benthic invertebrates; RF: reef fish; MA: macroalgae.

4.7 Step 7. Bringing it all together – the all-inclusive analysis

Section 4.7: Key messages

- The simplest option for an all-inclusive Zonation scenario is to include the broad range of taxa, habitat classification, KEA and threat layers as single, equally weighted layers within a prioritisation. This option allows each layer to contribute equally to a prioritisation, though it will be dominated by groups that have a large number of layers.
- Another option is to weight layers so that groups of features (in combination) contribute equally to a prioritisation. This approach is achieved by using an aggregate weighting for each group, with the weighting resulting in balancing the influence of each group of features.
- If users desire certain groups to contribute more to an all-inclusive prioritisation, the aggregate weighting for each group can be changed to reflect the degree of influence of a group within a prioritisation.
- It is important to assess the performance of an all-inclusive scenario at affording protection to the various groups of biodiversity features. This assessment can be undertaken using box-plots and conservation curves specific to the individual feature groupings.

In most spatial prioritisations, there will be a need to bring together a substantial number of datasets, representing broad ecological and societal values. Such a holistic prioritisation may be necessary to fully represent different aspects of marine biodiversity values (e.g., species distribution, habitats, naturalness) and the various cultural, recreational and commercial relationships with the marine environment within a single analysis. This type of approach has the benefit of allowing the complex trade-offs and biodiversity gains to be explored within a single systematic analysis – whereby the relative protection of different groupings of biodiversity features can be quantified in relation to decreases in human use components. Such analyses are, however, inherently complicated to configure and interpret, and particular attention must be paid to how different features are incorporated. In this study, we refer to this final prioritisation as an all-inclusive analysis. In this section, we discuss two options for configuring an all-inclusive analysis and provide illustrations of the outputs of these prioritisations using the diverse datasets discussed earlier in this report.

Similar to considerations around the incorporation of KEA datasets from several sources discussed in section 4.4, there are several ways an all-inclusive analysis may be configured. Firstly, the simplest option is to include the broad range of features as single, equally weighted layers within a prioritisation. This approach may include entering individual layers more than once if they occur in multiple criteria/groups (e.g., threatened species, species important for productivity).

This method allows each individual layer to contribute equally towards the final prioritisation, however groups of features that have a greater number of individual layers may dominate the outcome of the prioritisation. Further, some layers may contain values with high levels (e.g., stacked species richness, or abundance layers) and may also contribute disproportionately to the outcome. Again, depending on the objectives of the project, having certain groups of features or individual layers driving prioritisations may not be undesirable. However, if equal-weighting of an all-inclusive analysis is conducted, it is important that practitioners are aware of which groups are driving the prioritisation and to ensure that this decision sits within the objectives of the project.

The second option for an all-inclusive analysis is to develop a method to weight layers so that groups of features and individual layers contribute to the prioritisation in a logical, balanced way. This approach could entail groups of features (e.g., predictive taxa models, habitat layers) contributing equally to a prioritisation, in contrast to the previous method where individual features have equal weighting but groups have a higher contribution based on the number of features within a group. Typically, this approach to balance across groups with different numbers of features is achieved by using an aggregate weighting for each feature group. Under a scenario where each group would contribute equally to the prioritisation, this weighting would be the same for each group. This weighting is then divided among the individual layers within a feature grouping (Table 4-2). This scenario is illustrated in the first column of Table 4-2, where we are interested in groups of species layers, habitat classification, productivity, life history and diversity layers contributing equally to an all-inclusive analysis. If we set an aggregate weight of 1000, this weight is then divided among each layer in the group to determine the individual weights attributed to each feature in the Zonation settings files. If we were interested in certain groups having a stronger influence on the prioritisation we could change the aggregated weight (as in columns 1 and 2 in Table 4-2).

Additionally, it is possible within an all-inclusive analysis to weight individual features within groups with ‘sub-criteria’ weights. This approach may be desirable if certain features hold particular importance within groups. This weighting concept is the same as that introduced in sections 4.4.4; for example, threatened species within species SDMs, rare/unique habitat layers, or down-weighting for data biases may all be candidates for sub-criteria weighting. This method is applied by apportioning the aggregated weight among features within groups according to a pre-defined rule, e.g., threatened species are weighted x3 higher. Table 4-2 shows how this can be calculated simply, given the known group aggregation weight and the desired sub-criteria weight. In this example, we use the five KEA diversity feature layers (taxa species richness) and have decided that demersal fish richness is particularly important – providing it a sub-criteria weight of x3 while the other layers remain equal. The aggregation weight is 1000 in this example.

Table 4-2: Criteria used to moderate biodiversity features weights in the Zonation all-inclusive analysis.

Layer	Sub-criteria weighting	Proportion	Feature weighting without sub criteria	New feature weighting with sub criteria
Cetacean diversity	1	0.14	200	142.86
Demersal fish diversity	3	0.43	200	428.57
Reef fish diversity	1	0.14	200	142.86
Benthic invertebrate diversity	1	0.14	200	142.86
Macroalgae diversity	1	0.14	200	142.86
Aggregate weighting			1000	1000

We have run several scenarios to illustrate the decision points around an all-inclusive analysis. We pool features from several of the groups introduced earlier in the study: individual taxa SDMs representing the distribution of 613 different marine taxa, layers representing seafloor habitat from the SCC (intergroup and intragroup similarity), and KEA datasets – productivity, diversity, and life history groupings. We also bring in a cost layer in the form of the accumulated fishing footprint introduced in section 4.6.

The first all-inclusive analysis scenario used the option of equal weighting among input features. Under this scenario (Figure 4-59), high priority areas are reflected throughout the NZ marine environment, with particularly important locations in the coastal environment of both main islands, around the offshore islands, and on the Chatham Rise. It is possible to discern the influence of some key groups of inputs in this scenario. The result shows some similarity from that of the all taxa run, with high priority locations on the Chatham Rise, the Challenger Plateau and around some of the sub-Antarctic Islands. Given the size of the taxa group of layers (>600 layers), we would expect an unweighted all-inclusive analysis to bear resemblance to the "all taxa" prioritisation, though it is possible to discern the influence of other key groups. In particular, the KEA life history criterion has exerted substantial influence on this all-inclusive analysis as evidenced by some of the circular high priority areas around the offshore islands (product of the bird colony layers). The mosaic-like pattern of the medium to low priority areas is similar to the patterns seen in the SCC habitat classification scenarios and suggests this all-inclusive analysis is appropriately incorporating information from the SCC where knowledge is sparse.

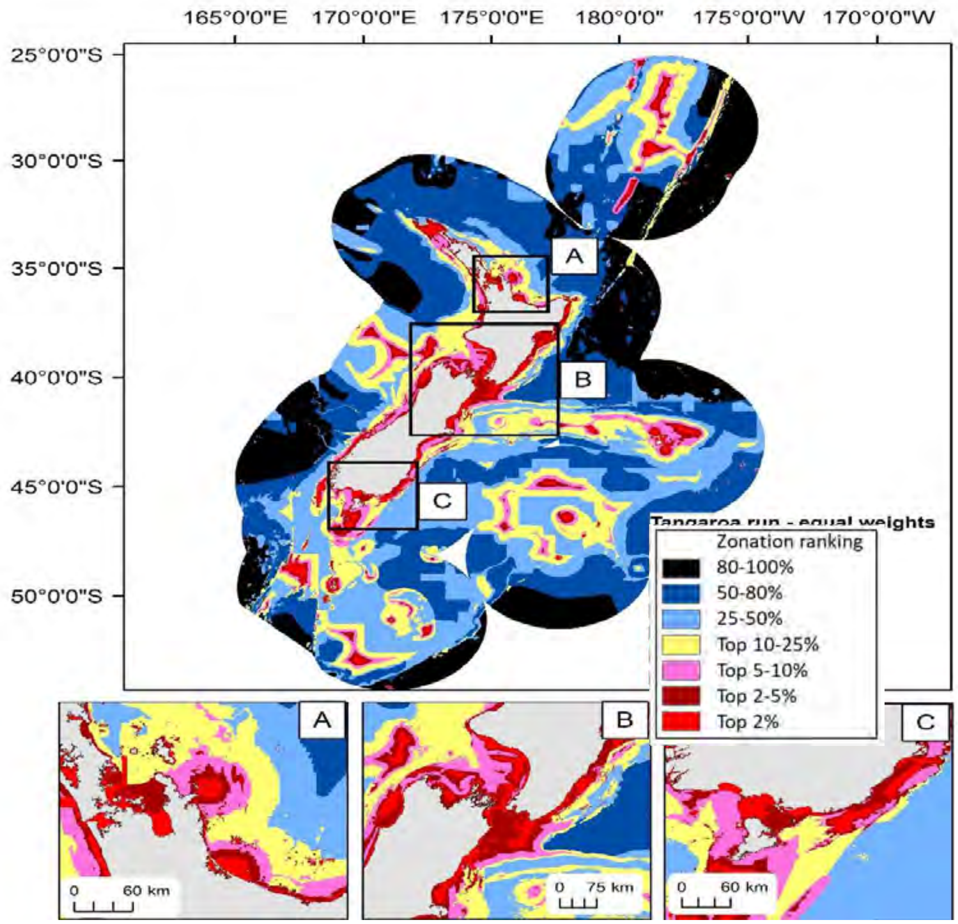

Figure 4-59: An all-inclusive analysis with all input layers equally weighted. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

The second all-inclusive analysis used aggregation weights to standardise the contribution of each group of features equally (Figure 4-60). An aggregation weight of 1000 was set for each group, which was then divided proportionately among features in the group. Under the first iteration of this scenario, the threat layer (fishing intensity) was afforded a value of 1000, being the only representation of a threat group. However, this choice resulted in a large impact on the prioritisation, similar to that seen in Figure 4-56, with no high priority areas being selected in areas where any fishing occurred. To remedy this, we iteratively reduced the weight associated with the threat layer until it had a moderate influence on the prioritisation (final weighting -200). All other input groups contributed equally to the second all-inclusive analysis. In this example, the results of any one contributing group were more difficult to discern. The key difference with the previous all-inclusive analysis was likely due to the increased influence of the threat layer. High priority areas on the Chatham Rise and Pukaki Rise and the Challenger Plateau, areas with known high fishing intensity, decreased under the second all-inclusive analysis. A new high priority location of the south west of the South Island was established, possibly as an expression of productivity KEA layers, that contribute more to the second all-inclusive analysis than the first due to the aggregate weighting.

An important consideration during the execution of an all-inclusive analysis is to calculate the performance of the scenario at achieving protection for the various component feature groups. This aim can be achieved by calculating the same performance metrics as detailed in section 3.3 and presenting them in a boxplot or table. Figure 4-62 provides an example of such a summary for the second all-inclusive analysis. Other than the features that represent the SCC habitat classification, the proportion of value protected for each feature group (taxa or KEA criteria) is very similar across groups at particular protection areas. This result suggests that the aggregate weighting is performing appropriately, with no one group making a disproportionate contribution to the prioritisation.

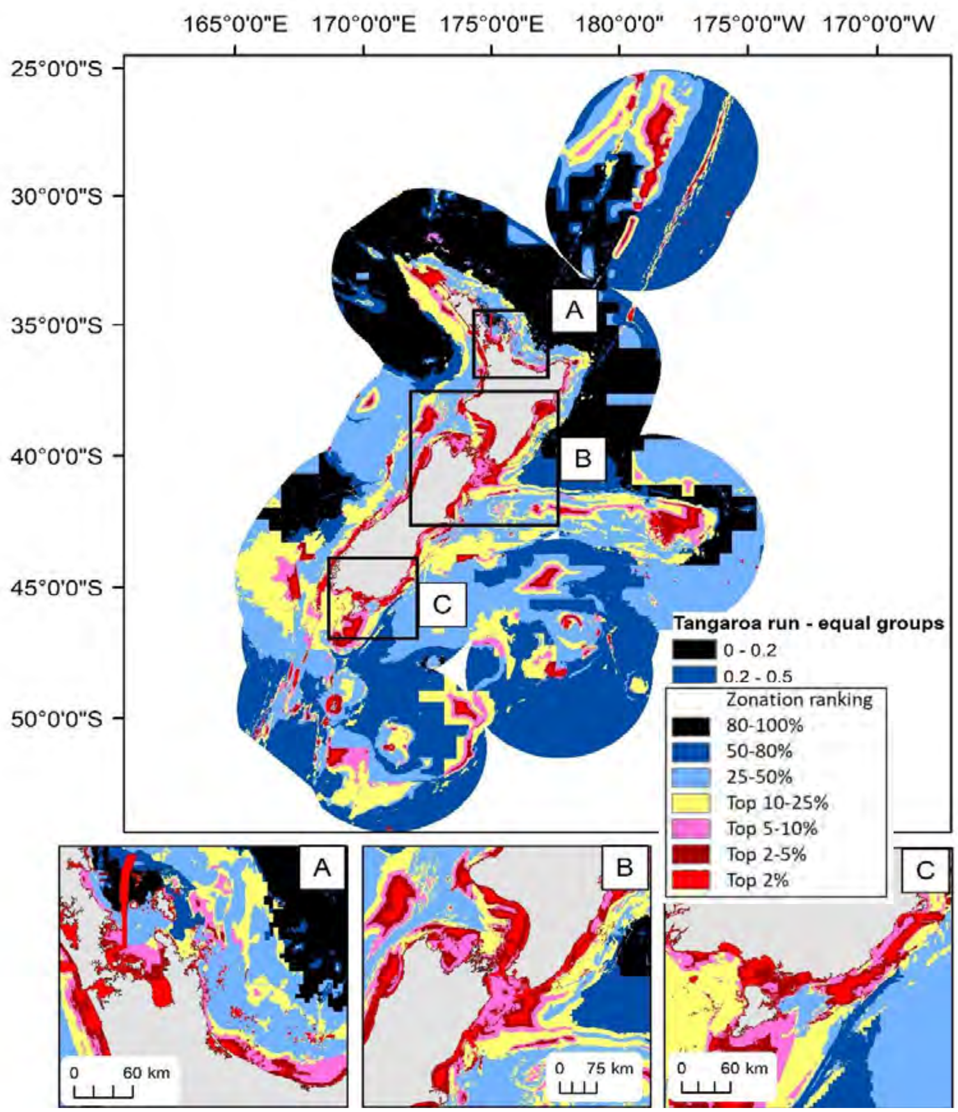

Figure 4-60: An all-inclusive analysis, with feature layers weighted so that groups are balanced with respect to their contribution to the prioritisation. Colour legend indicates higher priority areas for conservation in red, and lowest in black.

The third all-inclusive analysis set different aggregation weights to allow key groups to contribute more to the final prioritisation. We set aggregation weights of 3000 to the individual species SDM grouping and 2000 to the SCC habitat layer groupings. Further we used sub-criteria weights to cause threatened taxa within the individual species grouping to contribute more to the prioritisation. All threatened taxa were weighted x3. Again it was not easy to discern the influences of particular component groups, other than the threat layer. As this scenario used the same aggregate weighting as the second all-inclusive analysis (-200), the impact of the fishing intensity level was very similar, contributing strongly to the prioritisation patterns (Figure 4-61). The strong influence of the fishing intensity layer may be masking some of the increased aggregate weighting for the taxa SDMs, given many high priority areas for demersal fish and benthic invertebrates occur in areas with high fishing intensity. Additional sub-criteria weighting for threatened taxa may be reflected in the increase in prioritisation values around the Chatham and Kermadec Islands, which are part of the foraging range and contain colonies of several threatened seabird species.

There is very little difference between the proportion of biodiversity values protected among feature groupings for the third all-inclusive scenarios (Figure 4-63). It is possible that, given the very large number of layers contributing to these scenario (>800), greater aggregate weightings would be required to ensure certain groups exert more influence on the final prioritisation.

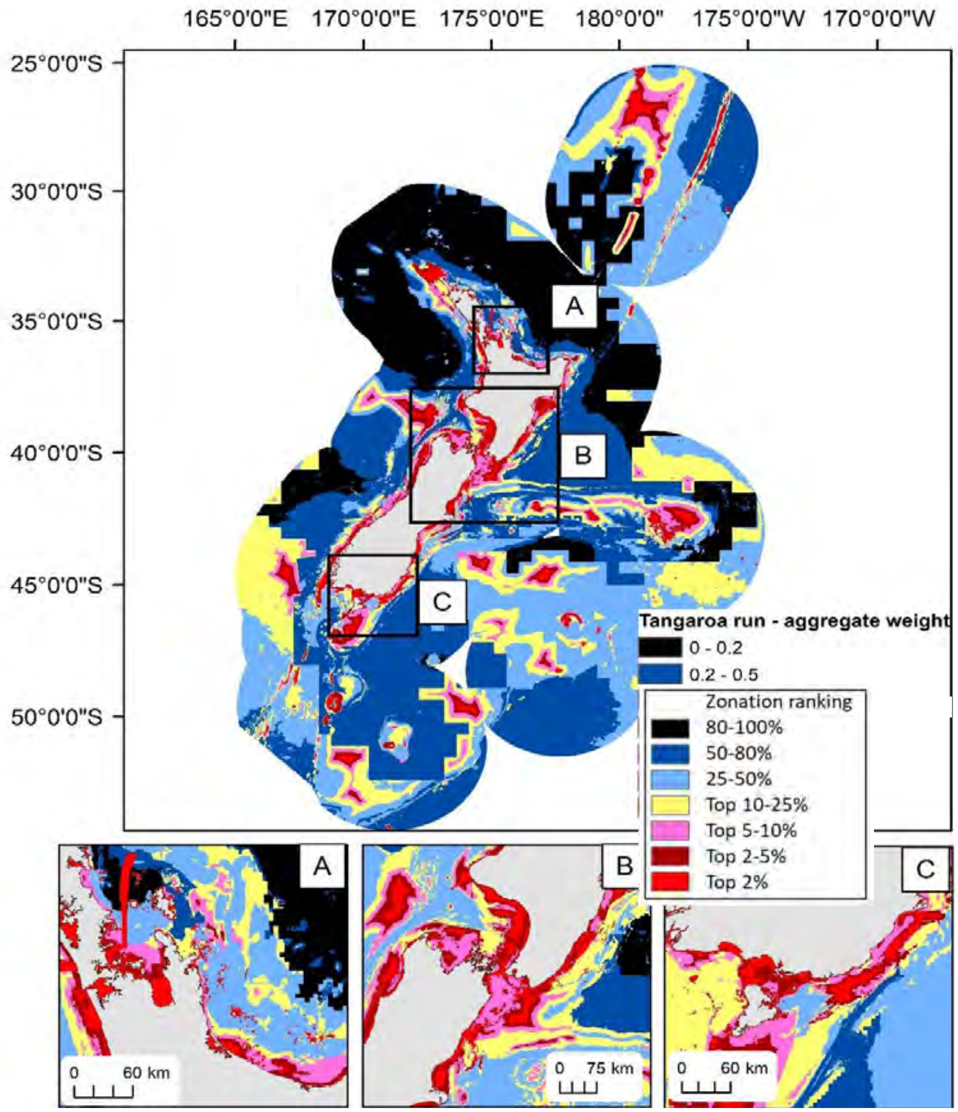

Figure 4-61: An all-inclusive analysis, with feature layers weighted using an aggregate weighting system so that groups of layers contribute disproportionately. Colour legend indicates higher priority areas for conservation in red, and lowest in black

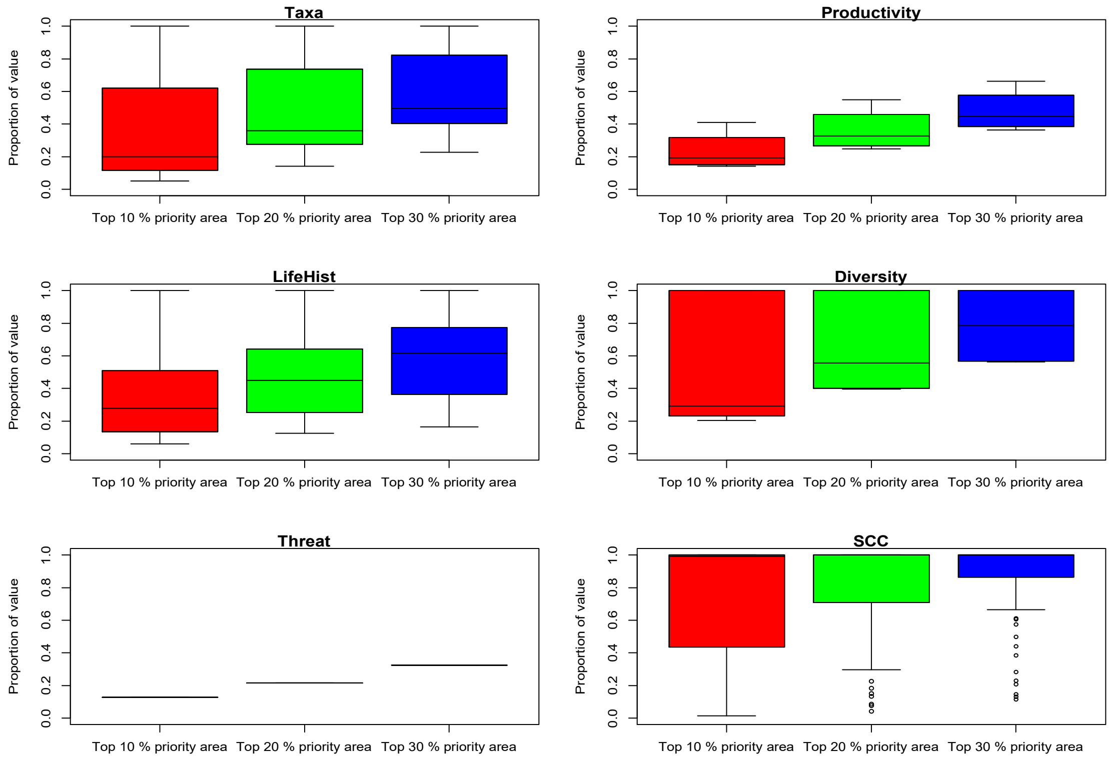

Figure 4-62: Summary of the performance of the all-inclusive analysis with equal weightings among groups of features. Layers are grouped into the 6 major input groups. Performance is measured by the proportion of biodiversity value retained within top priority areas.

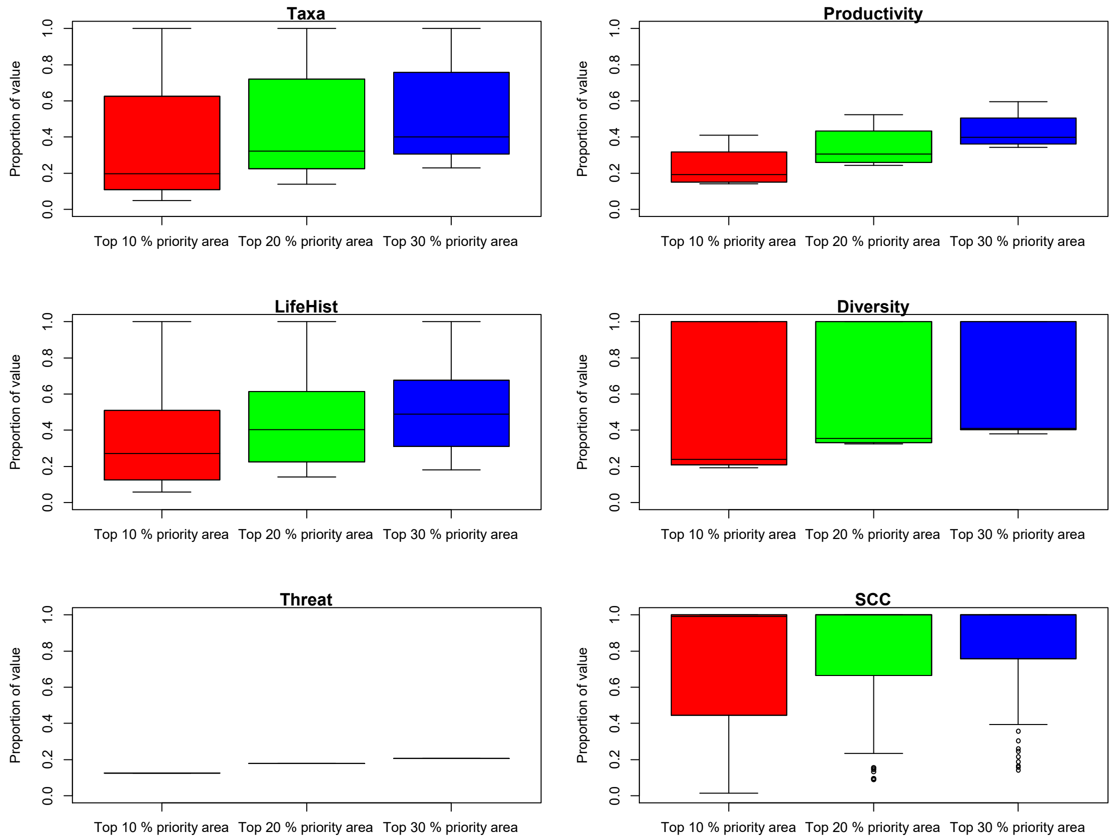

Figure 4-63: Summary of the performance of the all-inclusive analysis with aggregate weightings among groups of features. Layers are grouped into the 6 main input groups. Performance is measured by the proportion of biodiversity value retained within top priority areas.

5 Discussion

The objective of this report is to illustrate a standardised, transparent process for the use of national datasets for informing national priorities for biodiversity conservation or other marine spatial planning or restoration priorities. These guidance points could then be used to inform national marine conservation planning to achieve national and international biodiversity commitments, as well as to provide a standardised framework for regional marine conservation planning exercises. These tools can also be used to identify gaps in available information at national and regional scales to inform management priorities.

The scope of this particular project is limited to identifying optimal areas for biodiversity conservation, but certainly this guidance can be applied to other marine management contexts such as the identification of optimal areas for restoration, aquaculture zones, or other resource uses. Further, these guidance points are envisioned to be integrated within stakeholder participatory processes where other social, economic and cultural objectives will be considered alongside biodiversity protection objectives.

5.1 Model approaches

As identified throughout section 4, there is a set of steps (Figure 5-1) which needs careful consideration to ensure conservation prioritisation scenarios, using the Zonation decision-support tool, are meeting their defined objectives. Conservation targets may be provided through policy guidance, though in some cases, there may be no clear rules around the best choice for scenarios or parameters to include or exclude. Thus, it is important that the various options and their implications for the scenario are socialised with decision makers and stakeholders involved in planning processes. Model scenarios can be configured and implemented to illustrate the consequences of the choices made at each step during a planning process. In this way, stakeholders can visualise how their choices and values influence final model outcomes, providing transparency to the decision-making process. In this section we revisit the steps to establish possible priorities for the identification of optimal areas for marine biodiversity conservation.

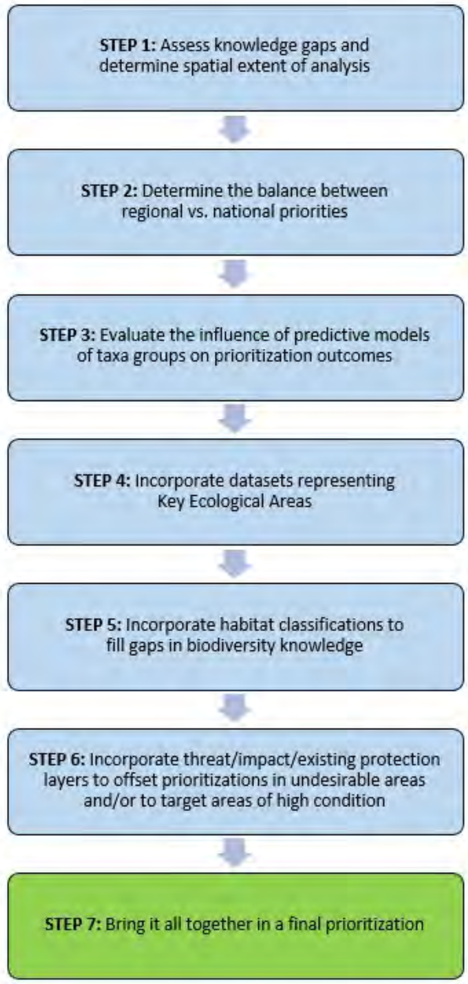

Figure 5-1: Steps requiring careful consideration to ensure conservation prioritisation scenarios, using the Zonation decision-support tool, are meeting their defined objectives.

Dealing with areas of limited data

There are several options for dealing with areas with limited/no spatial data on biodiversity values (as discussed in section 4.1):

- Removing areas with poor data coverage through the application of masks (e.g., for environmental coverage) and the use of habitat classifications to provide proxy information on biodiversity values;
- Changing the scale of the analysis so that the whole model extent is represented by accurate spatial data; or
- Incorporating local or traditional ecological knowledge.

For the latter, appropriate guardianship of traditional knowledge needs to be ensured including agreement with knowledge holders on proper protocols for data use. How traditional knowledge is represented in a prioritisation (e.g., weighting options, value range) requires consideration as it may not be appropriate to allow more qualitative information to have a strong influence on the outcome of a scenario.

Changing the scale of an analysis can have significant influences on the outcome and may not be appropriate if areas perceived as important by stakeholder groups are removed from the analysis. In dealing with data scarcity, the misrepresentation of areas with poor information as having low priority areas is a concern. Masking out areas of poor information may limit this misrepresentation by removing data-poor areas or by gap-filling with proxy datasets from a scenario so they do not bias the analysis. 'Data-poor' regions can also be overlaid on top of a spatial prioritisation so that users can distinguish areas that are low-priority due to data scarcity. Policy guidance could provide approaches to distinguish these low-priority areas for which prioritisations are not suitable. Data-poor regions can be determined quantitatively via environmental coverage type layers, or manually by viewing the distribution of spatial data. Data-poor regions also establish the priority locations for targeted sampling to fill knowledge gaps.

Defining boundaries of a scenario

The Administrative Units (ADMU) setting is a commonly used function within Zonation models to define the boundaries of sub-units within a prioritisation scenario. Individual sub-units or planning areas may represent boundaries of national or regional jurisdiction, bioregions or habitat types. Within Zonation, users can force targets to be achieved either globally (i.e., across the full model region), or further ensure regionally balanced representation of targets within these individual planning areas. The extent to which the targets are balanced across 'local' or 'global' regions is user defined and is a policy or stakeholder decision, as often these units have very limited ecological basis and are rather management boundaries. As with the other decision points, it is recommended that practitioners run models with several ADMU values to determine how each scenario best meets the objectives of a prioritisation.

Inclusion and weighting of biodiversity features

Zonation users can take a range of steps associated with the use of modelled datasets, which include weighting values, the use of uncertainty, silent layers and establishing 'groups' of layers. The most common form of modelled dataset used in Zonation are species distribution models (SDMs), which themselves have a broad range of assumptions underlying their development (Muscatello et al. 2020). Particularly when pooling SDMs from several datasets, practitioners should appraise the model development/validation of SDMs to ensure they are robust and fit-for-purpose. Within Zonation, weighting input SDMs is one of the most used functions (as illustrated in a range of scenarios in section 4), and provides the options for certain taxa/groups to contribute disproportionately to the prioritisation. Among other uses, weights may reflect particularly important input features, confidence in the modelled layer, or are included to cause Zonation to avoid areas important for certain taxa (i.e., negative weighting). An option to incorporate SDM model uncertainty and confidence into a weighting system may involve the use of expert opinion to judge the accuracy of individual SDMs, and would be a worthwhile undertaking if such resources are available.

Uncertainty in modelled biodiversity layers

When and how to include SDM model uncertainty is also an important consideration for the use of modelled datasets. It is advised that, if uncertainty layers are available, they should be used within a scenario, though careful communication may be needed to justify this decision to stakeholders. The info-gap weighting is the major consideration for the incorporation of uncertainty. Again, there is no obvious guidance for how strongly uncertainty should be weighted, and it is recommended that practitioners use a range of values and select one that best meets an agreed level of the degree to which uncertainty influences a prioritisation. It is also important to compare the performance of prioritisation in terms of how certain taxonomic groups are protected.

Such a comparison is typically achieved by grouping input layers into broad taxonomic classes (e.g., fish, seabirds, macroalgae), and calculating the proportion of summed group distributional values within a certain priority area.

Utilising habitat classifications as proxies of biodiversity

The use of habitat classifications within a prioritisation requires careful consideration at a number of steps. Habitat classifications may be used to fill knowledge gaps (see above) and may be used in bioregional analyses (typically through a low-order classification). When a habitat classification is to be used to fill knowledge gaps, decisions must be made on how the classification is represented within a prioritisation. In our example (in section 4.5), we use layers that describe the inter- and intra-group similarity of the 75-group Seafloor Community Classification (SCC) which provides a continuous scale for the measurement of 'distinctness' among and within habitat classes. Alternatively, the distribution of SCC groups could be represented by 75 binary layers denoting the extent of individual groups. Another potential use of a habitat classification is to include the distribution of habitat classes as a zero weighted layer to investigate how well a certain scenario outcome is representative of known distinct habitat types. This approach may be appropriate when certain habitat classes are deemed ecologically important, or when a representative network of marine protected areas is required.

Inclusion of Key Ecological Area datasets

The incorporation of datasets under broad ecological criteria (e.g., Key Ecological Areas, KEA) introduces a range of considerations around minimising double-up of layers between separate criteria, and a lack of comprehensiveness of layers representing several criteria. Double-up should be avoided unless there are clear reasons to include layers more than once (e.g., if a certain taxon is threatened, including it twice may reflect the importance for the prioritisation). A possible option for avoiding double-up is to rank the ecological criteria in terms of their importance at contributing towards the prioritisation. Layers that occur over several criteria are then removed from all but the highest-ranking criterion for which they contribute. Double-up layers may still be included as zero weighted layers within different criteria groupings, allowing a contribution to the measurement of scenario performance among criteria. The lack of spatial comprehensiveness of some biodiversity datasets can be addressed by downweighing those layers with a perceived lack of sampling effort in some areas or strong spatial biases, as evidenced in the productivity KEA scenario (section 4.4.5). The number of layers contributing to the various KEA criteria is highly variable, with some criteria having 100s of layers and others having very few/none. These data gaps should be addressed by the creation of targeted spatial layers to represent each criterion. In the absence of a balanced number of layers among criteria, aggregated weighting (as in the all-inclusive analysis) should be used to attempt to balance the influence of key criteria.

Incorporating threat layers

Threat layers may be incorporated as:

- ‘Cost’ layers representing the trade-off between a biodiversity prioritisation and a marine resource use. Layers may include both the spatial footprint of resource use and the value of the resource;
- Condition layers that prefer selection of areas with lower condition, but high biodiversity value to target areas for restoration; or
- A negatively weighted feature layer that causes Zonation to avoid areas with high values of the threat. Depending on the magnitude of the weighting value, this approach can have a strong influence on the prioritisation. This option also allows for the inclusion of multiple threat layers.

The option that a Zonation user chooses will depend on the type of threat, how the layer is calculated, and the degree to which industry/group species data is available (for a cost layer). For both the cost layer and a negative biodiversity layer, Zonation allows the quantification of the extent to which a threat may need to be modified in order to achieve a biodiversity goal. Currently, Zonation does not have options that allow for inclusion of interactions between threats, and this is the subject of ongoing, targeted research in the Sustainable Seas National Science Challenge.

Final prioritisation assessments

Zonation users have three options for doing a final prioritisation assessment:

1. an all-inclusive analysis which includes the full range of biodiversity and other features being analysed with equal weighting;
2. an all-inclusive analysis which includes the full range of biodiversity and other features being analysed with aggregated weighting to balance the influence of different types of layers;
3. completing a suite of separate analyses for different ecological components within Zonation.

An all-inclusive analysis may provide useful insights into areas that are important for a broad range of ecological components but may be complicated to configure and interpret. Many decision points need to be addressed, including whether all input features should be equally weighted, whether the contribution of groups should be standardised or if certain groups should contribute disproportionately. In an all-inclusive run, the approach of applying aggregated weights (as introduced in section 4.7) assists in balancing across different groups (e.g., taxonomic groups which have varying numbers of feature layers such that groups with fewer individual species are equally contributing to priorities compared to taxonomic groups with many individual species). When configuring an all-inclusive analysis, we suggest practitioners work through the process from equal weightings to aggregated weights in an iterative manner, to ensure the influence of the various weights and the contribution of key layers is more obvious.

An alternative is to perform separate runs for different ecological components and to compare the results of these runs. Locations where high prioritisation values coincide are likely important areas for multiple components of biodiversity. These component runs can also inform how an all-inclusive analysis is being influenced by key components. A bottom-up approach, where scenarios are first performed at the lowest taxonomic/group resolution, can be useful to build towards the pooling of more data as scenarios become more complex, with the all-inclusive analysis being the final scenario (e.g., separate taxa scenarios –> all taxa scenario –> KEA criteria scenario –> all-inclusive analysis).

5.2 Information gaps and other priorities to investigate

Many additional options for using these prioritisation models were beyond the scope of this report. For example, this report was focussed on guidance for priorities for the protection of marine biodiversity, but analyses of threats and how these could be used to identify areas of priority for restoration or mitigation (versus identifying more pristine areas as high priority biodiversity locations) is one of many uses of these tools that could be explored.

Similarly, future proofing these tools, such as to climate change impacts, is another aspect that was out of scope, but it is important to see how changes in predictions of where species are found (e.g., Anderson et al. 2020) might influence changes in spatial priorities that may be more robust to changes in climate, or serve as refuges to vulnerability due to temperature anomalies being less strong in some locations.

5.3 How to use the Cookbook going forward

The cookbook could be utlilised during the technical support phase inside a broader planning process in which technical, social, economic, cultural and political interests together influence objective setting, planning, implementation and monitoring. This allows the needs and values of a full range of the community, stakeholders, tangata whenua: iwi, hapū and whanau, to be acknowledged and incorporated into the planning and implementation process.

At the outset of any planning process, it is important that objectives (aims, goals) are set. This includes explicit consideration of which decision-support tool (if any) is most suitable for the objectives being addressed (which could include Zonation and the use of this Cookbook, or alternative decision-support approaches). Once the decision has been made to use this Cookbook, aspects requiring consideration by management agencies, the community, stakeholders, and tangata whenua, include:

- the identification of objectives of prioritisation;
- which biodiversity features and costs layers to include;
- relative weightings of features and cost layers; and
- how to account for uncertainty in the information that is available.

Having defined the objectives of the prioritisation and prepared the data, it is possible to work through the steps outlined in the Cookbook. However, to understand how different analyses influence results, it is important to develop the analysis in stages of increasing complexity and verify and interpret results at each stage. Consequently, the steps within the Cookbook should be used iteratively to produce spatial prioritisation maps as one component within a broader planning process. Additional input from experts, stakeholders, the community and tangata whenua within the broader planning process may provide insights into factors that have not been included in quantitative form within the analysis (for example cultural and/or spiritual values which are often difficult to spatialise). These layers also provide important context within which prioritisation results are interpreted and translated into informative recommendations for action. Consequently, the Cookbook should be regarded as a decision *support* tool rather than a decision-*making* tool.

While analytical features within the Cookbook are well documented, using the Cookbook requires conceptual understanding about the information feeding into the analysis and analysis options, as well as experience and knowledge on how to establish a sensible workflow. To ensure that everyone involved in the use of the Cookbook has this conceptual understanding, it may be necessary to run workshops prior to establishing and executing a workflow to: (i) introduce the 'Cookbook' approach and ensure familiarity with the Cookbook methodology and key decision points involved in spatial planning scenarios using Zonation, including Zonation's key capabilities and limitations; and (ii) identify and appraise key datasets for spatial completeness, bias and suitability for addressing the defined objectives. Once everyone involved has this conceptual understanding, spatial datasets can be prepared for analysis and a series of additional workshops planned to agree the objectives of the prioritisation, and to develop and iteratively execute the workflow.

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