Exploration of the use of reserve planning software to identify potential Marine Protected Areas in New Zealand's Exclusive Economic Zone

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Exploration of the use of reserve planning software to identify potential Marine Protected Areas in New Zealand's Exclusive Economic Zone

J. Leathwick
K. Julian
M. Francis

Prepared for

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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

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Reviewed by:

(for) M. Pinkerton

Approved for release by:

D. Robertson

Formatting checked

A. Bartley

Executive Summary

1. This report describes results of an exploratory analysis using reserve selection software (Zonation) to evaluate various scenarios for the identification of Marine Protected Areas (MPAs) within New Zealand's Exclusive Economic Zone (EEZ).

2. Input data used in this analysis consist of gridded (i.e. raster) data layers with a spatial resolution of 1 km, and extending across all of the Exclusive Economic Zone in which average depths were less than the maximum depth recorded in the *fishcomm.* research trawl database (1950 m). Data layers describe: environment-based predictions of the standardized catch of 122 demersal fish species (see Appendix I) as recorded in c. 21,000 bottom trawls; geographic variation in commercial trawl intensity as recorded during the year 2005; the geographic distribution of existing marine reserves, marine parks and sea-mount closures; and, the geographic distribution of a set of benthic protection areas (BPAs) proposed by the fishing industry.

3. Zonation analyses proceed by progressively removing grid cells from around the margins of retained cells, at each iteration seeking to remove the grid cell that results in the least reduction in the biodiversity protection provided by the remaining cells. The resulting hierarchical ranking of the value of each grid cell (its ability to protect an adequate representation of the ranges of all species) can then be used to identify the set of highest value cells that deliver some nominated level of geographic or biodiversity protection.

4. We produced Zonation scenarios using the following analytical settings:

   - A basic analysis was used to assess the degree of biodiversity protection that would be provided by setting aside different proportions of New Zealand's EEZ as reserves, with selection of sites for reservation proceeding in a completely unconstrained fashion. The measure of biodiversity protection used in this and subsequent analyses, is the average proportion of the predicted geographic ranges of 122 fish species that would be contained in the reserved areas.

   - We then explored the use of varying the weighting of individual species. Results demonstrate the ability to increase the protection provided for nominated groups of species (e.g., endemic or commercially important) when they are given a higher weighting than other species.

   - Using constraints that take account of species mobility, and the low returns from protecting isolated locations, encouraging the identification of more compact groupings of cells, in turn allowing for greater connectivity between sites for mobile species. This also has practical advantages in reserve management.

- Incorporation of commercial trawl intensity as a cost layer produced a scenario in which the opportunity costs of protection (prohibition of trawling) were substantially reduced, while still maintaining a relatively high degree of protection of species ranges;

- The forced retention of grid cells located within existing marine reserves until all other grid cells had been removed demonstrated the relatively unrepresentative nature of existing marine reserves, i.e. their bias towards coastal waters, which reflects past protection policies, has resulted in these reserves providing inadequate protection for a full range of fish species;

- The forced retention of grid cells located within the benthic protection areas proposed by the fishing industry indicates that these proposed reserves are predominantly located in parts of New Zealand's EEZ that have very low current value both for fishing and for the protection of demersal fish diversity. As a consequence, the setting aside of these areas would provide a much lower level of protection for demersal fish than would implementation of any of the other reserve scenarios that we demonstrate.

5. We recommend further exploration of the use of Zonation as a tool for identifying optimal sites for biodiversity protection in New Zealand's EEZ. Use of additional data layers describing variation in the uncertainties associated with predicted fish distributions would increase confidence in the ability of particular reserve configurations to deliver their indicated biodiversity protection outcomes. Further exploration of the appropriateness of boundary quality penalties used would be desirable, and more comprehensive description is required of spatial variation in commercial trawl effort if this is to be used as an indicator of protection cost. Inclusion of more comprehensive biological data would also be desirable, but is unlikely to be achievable in the short term, given the considerable gaps in our knowledge of the distributions of many marine organisms.

1. Introduction

Over the last decade there has been a steady growth in the development of systematic methods for implementing strategies for protecting biodiversity (reviewed for example in Margules & Pressey 2000). While in the past, the focus of much of this research has been on protection of terrestrial ecosystems, increasing recognition is being given to the need to extend these efforts to also include marine ecosystems (e.g., Kelliher 1999, Lubchenko et al. 2003, Gleason et al. 2006), reflecting the ability of such reserves to contribute to both the protection of biodiversity and the sustainable management of fisheries (e.g., Hastings & Warner 2003, Roberts et al. 2003). In New Zealand, this imperative is recognised in the national biodiversity strategy, which calls for the development and implementation of “a strategy for establishing a network of areas that protect marine biodiversity” (New Zealand Biodiversity Strategy 2000) with a specific target of protection of 10% of New Zealand’s marine environments by 2010.

One of the most influential decisions in determining the success of any conservation strategy is the robust selection of reserves that are representative of the wider patterns of variation in ecosystem character (e.g., Margules & Pressey 2000, Gladstone 2006). The practical challenges of selecting a representative set of reserves over extensive geographic areas that support numerous species has led to the development of a number of computer-based numerical tools, based on a variety of strategies including iterative selection, linear programming, and simulated annealing (Leslie et al 2003). A number of these tools are now being applied in the design of protected area networks in marine environments (Araime et al. 2003, Leslie et al. 2003, Gladstone 2006, Gleason et al. 2006).

Most of the available techniques for reserve selection aim to identify the minimum area for protection that will allow the delivery of desired conservation goals, taking into account considerations such as the costs of setting aside reserves, and the degree to which these reserves protect representative examples of the ecosystems and biota occurring in the wider landscape (Margules & Pressey 2000, Leslie et al. 2003). Here we evaluate the use of one such approach for identifying a representative set of marine protected areas for New Zealand’s Exclusive Economic Zone (EEZ). This research forms part of a wider body of work that explores the definition of a marine environmental classification (MEC) specifically tuned to facilitate the conservation management of demersal fish communities (Leathwick et al. 2006a), and the production of a demersal fish community classification, based on the predicted distributions of 122 demersal fish species (Leathwick et al. 2006b).

Initial research for the Department of Conservation to explore the use of reserve planning software for defining marine protected areas (Weatherhead & Image 2003, Image & Weatherhead 2004) focussed on the use of Marxan (Possingham et al. 2000). This software is designed to work with data referenced to management units, and has a limited capacity to deal with spatial inter-relationships between units. While this software has been widely applied with smaller datasets, it proved problematic when attempting to analyse grid-based (raster) data at the scale of New Zealand's entire EEZ. As a consequence, in this study we evaluated an alternative approach, Zonation (Moilanen 2005, Moilanen et al. 2006), which has a similar purpose to Marxan, but achieves this using algorithms that are designed for the analysis of extensive spatial data stored as gridded data layers. Data presented as grids with a relatively fine grain are particularly useful in a marine setting where species vary continuously in their abundance over large areas but with often marked changes in abundance over short distances, particularly in regions typified by steep environmental gradients.

The purpose of Zonation is to create reserve scenarios by iteratively discarding those grid-cells that produce the lowest reduction in the protection provided across all species, resulting in the calculation of a conservation ranking for all cells (Moilanen et al. 2006). Cells are only removed from around the margins of remaining patches, promoting the maintenance of connectivity between high priority cells. In calculating the value of retained cells, Zonation calculates the proportion of the range that remains protected for each species, weighted by some measure of occurrence or abundance (in this case catch). As part of the range of a species is removed, the value of the remaining cells in which it occurs increases, resulting in protection of at least some of the core range of all species, including those that occur in species-poor areas.

The hierarchical nature of the Zonation ranking of sites results in the 5% of highest value cells being nested within the 10% of highest cells, and so on. Associated results include a set of loss curves, one for each species, that indicate the progressive reduction in protection as grid cells are removed from the solution. As a consequence, once results are imported into a GIS, they can be easily used to identify the grid cells that together compose the most efficient or parsimonious set of sites to achieve particular levels of protection. A level of protection might then be chosen either to meet some minimum protected area criteria (e.g., the best 10%), or to identify those sites required to deliver a nominated average level of protection across all or particular species. Analysis options are available to reduce the effects of fragmentation by encouraging the identification of groups of contiguous cells (Moilanen & Wintle 2006), to cater for uncertainty in the underlying biological data (Moilanen et al. 2006), or to incorporate information describing spatial variation in the costs of reservation (Cabeza & Moilanen 2006)

In this study we demonstrate how Zonation could be used to identify an optimal set of sites for protection within New Zealand's EEZ. This study was designed to provide a "proof of concept" of this approach, rather than delivering a comprehensive analysis – a more exhaustive investigation would be required if it is to be used as the basis for making final decisions. This process would need to include further exploration of the data and analytical settings used in this study, and would also require consideration of other factors. At an ecological level, consideration is required for example, of the dispersal ability of species and the consequent optimal physical arrangement of reserves to maximise returns for biodiversity protection, particularly for mobile fish species (e.g., Botsford et al. 2003, Halpern & Warner 2003). At a social and economic level, consideration is required of the impacts of protection on sustainable harvest and recreational use. In addition, we highlight at the outset that our analysis focuses on (i) a geographic subset of New Zealand's EEZ that includes only those grid cells having an average depth less than the maximum trawl depth recorded in the *fish_comm* research trawl database (1950 m), and (ii) the use of distribution data for 122 demersal fish species, rather than descriptions of the distributions of species from a full range of ecological groups.

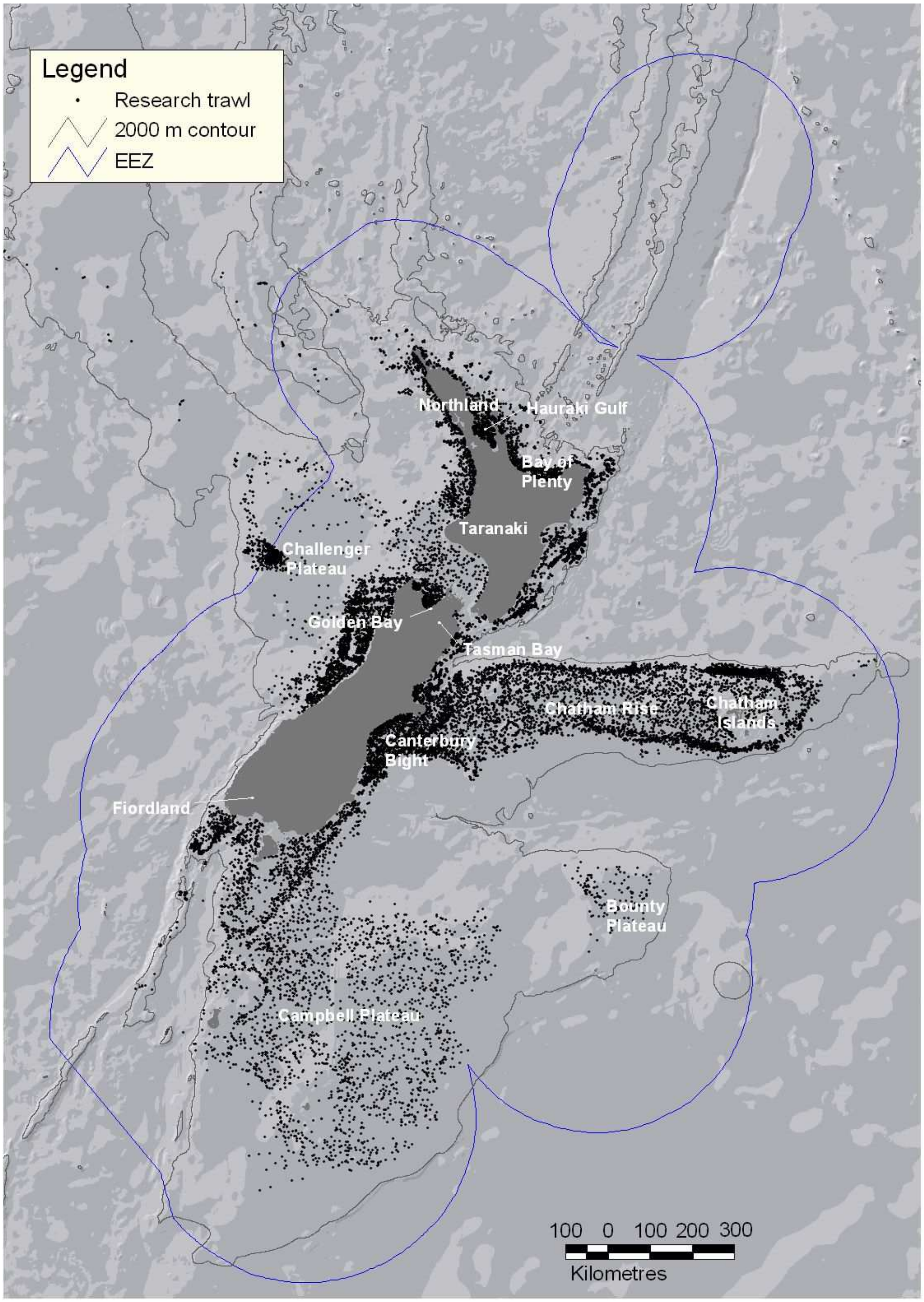

Figure 1: Locations of research trawl database (*fish_comm*) trawls used to construct predicted distribution maps for 122 fish species. The 2000 m contour defines approximately the maximum depth currently fished by bottom trawling.

2. Methods

In carrying out this study, we explored a sequence of analyses starting with a basic analysis, to which we then add differential weighting of endemic versus more widespread species, boundary quality constraints, and consideration of costs of protection. We then demonstrate how Zonation can be used to evaluate the trade-off between cost and biodiversity protection (= average proportion of species ranges protected) both for existing reserves and for a set of Benthic Protection Areas (BPAs) recently proposed by the fishing industry (Clement and Associates undated).

2.1 Data

A range of spatial data layers were used in this preliminary analysis, including descriptions of the distributions of fish species, commercial bottom trawl effort, and the locations of existing and proposed reserves.

Predicted fish distributions – biological data layers used in this analysis consisted of maps of the predicted distributions of 122 demersal fish species (including benthic, bentho-pelagic and pelagic species – see Appendix I). These were the same layers as used in the creation of a parallel demersal fish community classification (Leathwick et al. 2006b) as part of this project. All layers were produced from statistical models describing the relationship between environment and catch as recorded in data from 21,000 trawls stored in the *fish_comm* research trawl database (Fig. 1). This database is a groomed version of the Ministry of Fisheries *trawl* database of bottom trawl tows carried out by research vessels between 1979 And 2005. Grooming procedures placed special emphasis on the accuracy of species identification and the geographic coordinates of trawl tows. The research trawls comprehensively sample the vast majority of those parts of the EEZ where commercial fishing occurs, although with fewer trawls from deep waters (> c. 1200 m).

Two statistical models were fitted for each species; the first described the probability of a catch from presence/absence transformed data from all trawls; the second described the amount caught conditional on a catch occurring, and used log-transformed catch data from only those trawls in which the species was caught. These models were then used to predict both the probability of capture and catch (kg/trawl) under standardised trawl conditions across New Zealand's EEZ, and the two predictions were combined to produce a final prediction of distribution and abundance. Predictions were made for all 1 km grid cells in which the average depth was less than the maximum trawl depth recorded in the *fish_comm* database, i.e. 1950 m. Further details of the modelling methods are provided in Leathwick et al. (2006b).

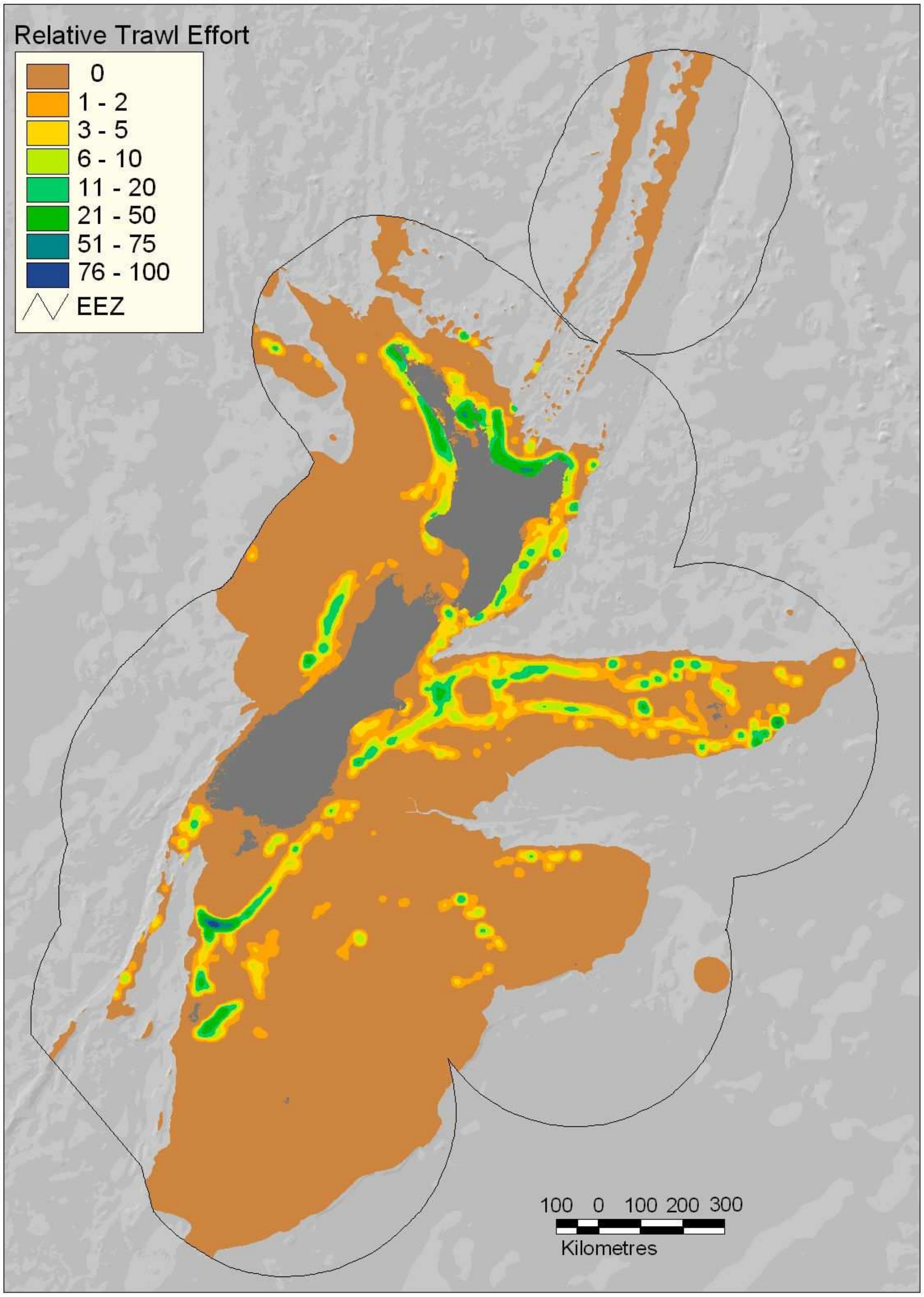

Figure 2: Spatial variation in commercial trawl effort across those parts of New Zealand's Exclusive Economic Zone with depths of less than 1950 m. See text for details.

Trawl effort – a data layer describing spatial variation in commercial trawl effort[1] (Fig. 2) was derived from typical start location data for approximately 47,000 trawls undertaken during the 2005 calendar year as reported by commercial fishers for either bottom or pair trawling in the Trawl Catch and Effort Processing Return (TCEPR) database. This database does not record trawl locations for many small inshore trawlers, most of which report their location only by broad statistical reporting areas. All start locations were assembled in R (version 2.0.1, R Development Core Team 2004), and a spatial smoothing routine was used to calculate the average trawl density in 1 km grid cells, smoothed across a 20-cell by 20-cell neighbourhood, with resulting values indicating the density of trawls/km^2. The resulting grid layer was then exported to ArcView where it was rescaled into a 0–100 range to produce a grid of relative trawl effort for use as a cost layer.

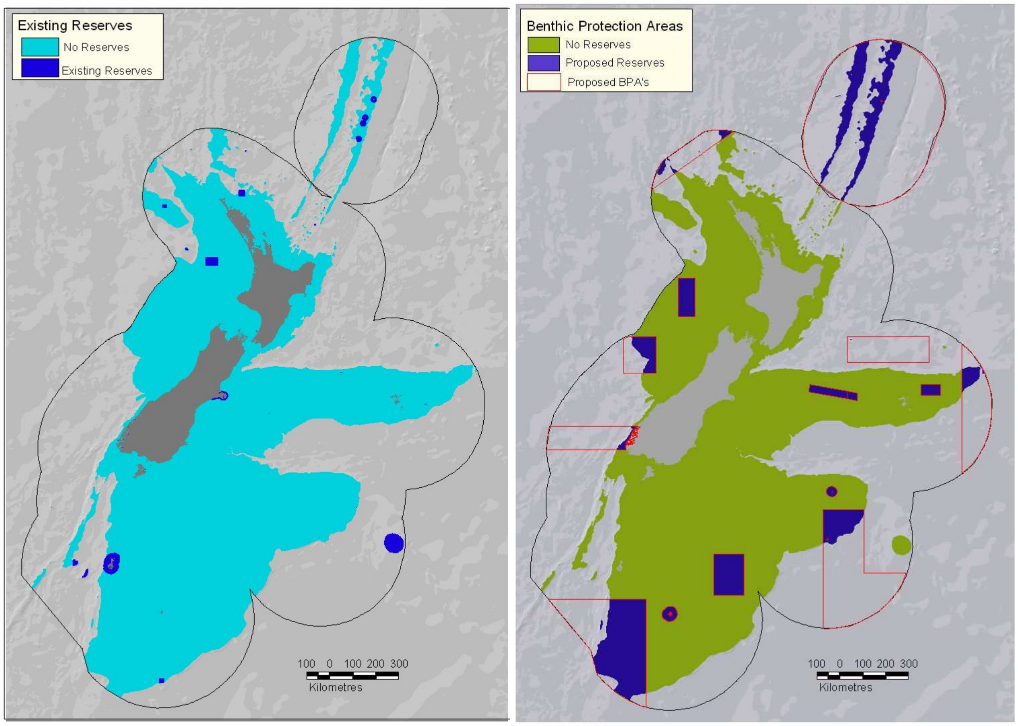

Figure 3: Existing and proposed reserve layers used in this analysis. a) Existing marine reserves, marine parks and seamount closures (most coastal marine parks and reserves are too small to be visible at this scale); b) Benthic Protection Areas proposed by the fishing industry. Note that only 27.7% of the BPAs fall within the depth range sampled by the research trawls – the remaining 72.3% falls within areas in which depths are beyond those currently regarded as trawlable. Layers extend only across those parts of the EEZ (black bounding line) with depths < 1950 m.

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[1] Note that these data are separate to the research trawl data used for predicting species distributions.

Existing or proposed reserves – spatial descriptions of a number of existing trawling closures, mostly sea-mounts and marine reserves or parks (Fig. 3a), were used in some analyses to assess the protection provided for demersal fish by areas already designated as reserves. We also assessed the potential conservation value for demersal fish of Benthic Protection Areas (Fig. 3b) proposed by the fishing industry. For this latter analysis we used spatial data provided by the Department of Conservation.

2.2 Analysis

A number of analyses were run using Zonation with varying combinations of input data and settings in the follow sequence.

Basic analysis – all fish species were equally weighted, and no geographic constraints were placed on either the removal or retention of grid squares. This is the simplest analytical approach, and indicates the sequence of cell removal that maximises conservation returns, assuming that protection can be implemented in any geographic configuration, with no consideration of either the effects of fragmentation of high value areas or the costs of protection.

Weighted analysis – this analysis was identical to the basic analysis except that, endemic species were given a five-fold increase in weight when calculating conservation returns. When compared with the basic analysis, results show the trade-off between enhanced protection of endemic species and the average protection that would be provided across all species. This analysis is used as a basis for comparison with the constrained analyses shown below, which also use a weighting of five for endemic species.

Use of layers describing uncertainty in species predictions – Zonation allows for the use of information about spatial variation in the uncertainties associated with the individual species predictions. It uses this to down weight the value of sites where the prediction uncertainties are large relative to the predicted abundances, typically sites where greater variability occurred in the trawl data used to fit the models. In trial analyses we tested this approach with a subset of species for which uncertainty layers were created by fitting models to 100 bootstrap samples of the trawl data and calculating the standard errors of the fitted or predicted values for each trawl site. These values were then predicted across the entire EEZ using a model that related them to environment. The resulting uncertainty layers were used in a Zonation analysis, and where the predicted value for a species was less than four times the standard error, the abundance at that grid cell was set to zero. This reduces the inclusion of sites in which predictions of species catch are least certain, in turn resulting in a higher level of confidence in the identification of high priority sites.

Use of boundary quality penalties – this allows penalties to be applied when calculating the biodiversity protection offered by individual grid cells, depending on the degree to which adjacent grid cells have already been removed. This simulates the likely loss of protection offered to mobile species where a single cell is left geographically isolated. In practical terms, it favours the selection of contiguous groups of cells, rather than selecting more fragmented sets of cells as can occur in an unconstrained analysis. This in turn offers advantages in terms of greater connectivity to allow dispersal of mobile species, and can also foster more practical and cost-effective reserve management (Leslie et al 2003).

The degree of penalty that is applied to any grid cell as its surrounding cells are removed can be varied by altering the number of adjacent cells over which this calculation is made, e.g., a one-cell buffer calculates the penalty by taking account of the proportional removal of the eight immediately adjacent cells in a three cell by three cell square centred on the cell in question. Similarly, a two-cell buffer takes account of the 24 adjacent-most cells. Using differing loss curves can also vary the degree of penalty. For example, for low-mobility species, a grid cell might retain its full value provided that less than 50% of the surrounding cells are removed, but then decline in value by 50% with progression to removal of all adjacent cells. By contrast, for a highly mobile species, removal of 50% of the surrounding cells might diminish its value by 80%, while removal of the remaining 50% of cells might reduce its value completely.

For this exploratory study, we ran an initial boundary quality penalty analysis with a two cell buffer for all species, and using a linear decline in which cells were credited with their full potential biodiversity value when surrounded by other cells, but with a progressive decline to zero as all the surrounding cells were removed.

We also ran a more complex analysis in which we used differing buffer size and penalty curves for pelagic, bentho-pelagic and benthic species, with species placed into these categories by C. Duffy (Department of Conservation). A buffer size of three cells (a square of 7 by 7 cells) was used for pelagic species (e.g., barracouta, hoki, southern blue whiting), a buffer of two cells (5 by 5) was used for bentho-pelagic species, and a buffer of one cell was used for benthic species. Loss curves were also varied, with that for pelagic species defining a steep initial loss (80% loss of value at 50% neighbour removal), and then a decline to zero when all neighbours were lost; for bentho-pelagic species we used a linear curve declining to 20% for cells with no remaining neighbours, and for benthic species we used a gradual loss curve showing no decline in value up to 50% loss of neighbours and then declining to 50% value with 100% neighbour loss. These settings represent a first estimate of values that would be appropriate for these different species groups, but this aspect requires further investigation.

Cost-benefit tradeoffs – to assess the sensitivity of analysis outcomes to spatial variation in the costs (loss of fishing opportunity) of protection we ran an analyses using a spatial layer indicating the intensity of commercial trawling (Fig. 2) – while species weighting was applied to both these analyses, time precluded use of boundary quality penalties. For these analyses, cells were removed based on the ratio of the biodiversity protection they provide compared to the loss of fishing given their removal, so that where two cells offered equal species protection, that with the higher fishing cost was removed first. This contrasts with the preceding analyses in which costs were assumed to be uniform, so that cells were removed in an order determined solely by the species protection they offered.

Assessment of existing and proposed reserves – two reserve assessments were carried out for this study, one examining the biodiversity protection offered by existing marine reserves, and the second assessing the protection offered by a set of reserves proposed by the fishing industry. In both analyses, cells within the existing or proposed reserves were retained until all other cells had been removed. From this point on, cells within the reserves were progressively removed, with those offering the highest protection left until last.

Assessing the opportunity cost of different protection options – to assess the costs of the protection solutions suggested by the various Zonation analyses, we used a geographic information system (ArcView 3.2) to calculate the percentage reduction in trawling opportunity that would result from their possible implementation, in this case, protection of the 10% of grid squares having the highest biodiversity protection rankings. This calculation was performed by creating a mask indicating for each Zonation scenario the location of the highest priority grid squares, and then calculating the cumulative sum of the matching grid cells in the trawling cost layer. These were then divided by the total sum of the trawl cost layer across the entire EEZ to indicate the proportional loss of trawling opportunity.

3. Results

3.1 Basic analysis

Results from the basic analysis indicate the sequence of grid–cell removal that results in the maximum protection of demersal fish without any spatial constraints (Fig. 4). It indicates that while sites with high priorities for protection are located throughout the trawlable parts of the EEZ, there is a particular concentration of these sites in inshore waters and along the Chatham Rise. Inshore locations of high priority include the Hauraki Gulf, inshore parts of the south Taranaki coast, and Tasman and Golden Bays and Canterbury Bight; offshore locations occur around the continental shelf edge, particularly in the north, along both sides of the Chatham Rise, and around the margins of the Campbell and Bounty plateaux and off the west coast of central New Zealand. Note that the spatial distribution of high value cells is relatively fragmented, reflecting the lack of any boundary constraints in their selection – the biodiversity protection value of cells is effectively assessed without reference to the values provided by their neighbours. If a reserve network was based on this solution by taking for example the best 10% of cells, the ratio of the boundary to the protected area would be 0.78 km/km^2.

More specific details of the relationship between the protection of species ranges and the removal of grid cells is shown in Fig. 5, calculated both as an average across all species, and for a small group of selected species. The curves in this figure show the progressive decline in the proportions of species ranges that are protected (vertical axis) as cells are removed from protection (horizontal axis). Selecting a high level of protection (left of the horizontal axis) provides high average levels of protection, but as cells are progressively removed (right of the horizontal axis), the proportions of species ranges that remain protected declines.

In this example, there is a slow initial decline in the average protection across all species, which maintains a value greater than 0.8, even when the 50% of cells having the lowest conservation values are removed. However, there are marked differences in the losses for different species, with basketwork eels (BEE), a species occurring only in relatively species-poor deeper waters suffering the most rapid loss. By contrast, species whose curves remain in the upper right part of Fig. 5 (e.g., SNA = snapper) are provided with high levels of protection even when the majority of grid cells have been removed. Removal of 90% of cells, i.e. protecting the most valuable 10% of the EEZ shallower than 1950 m, would result in the protection of 32% of the predicted species ranges, averaged across all species.

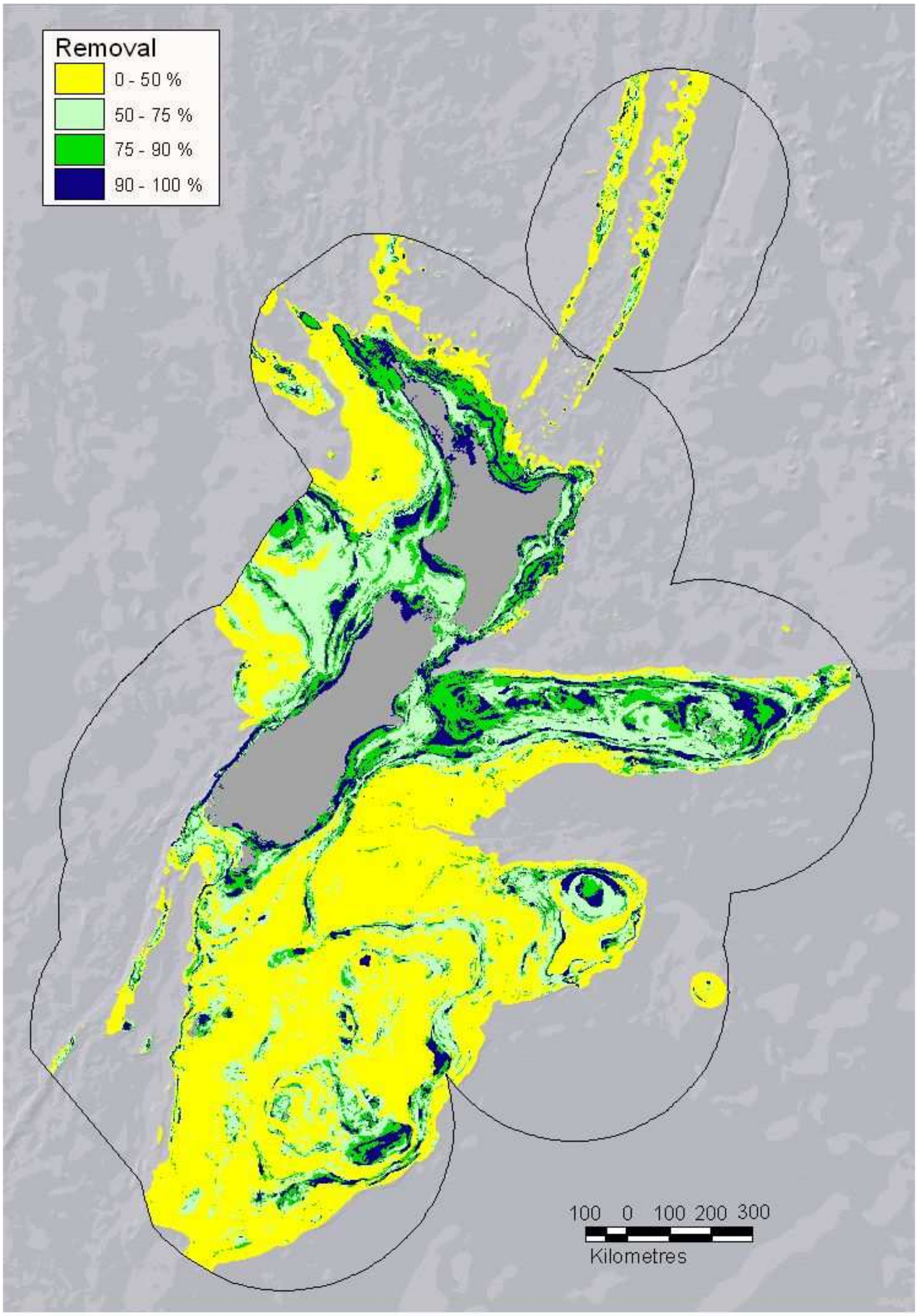

Figure 4: Relative conservation ranking of 1 km grid cells as calculated from the basic analysis. Rankings are shown for all cells occurring within New Zealand's Exclusive Economic Zone and having average depths less than 1950 m. Values indicate relative conservation value, so that, for example, cells with a value greater than 90% comprise the 10% of cells with the highest conservation value.

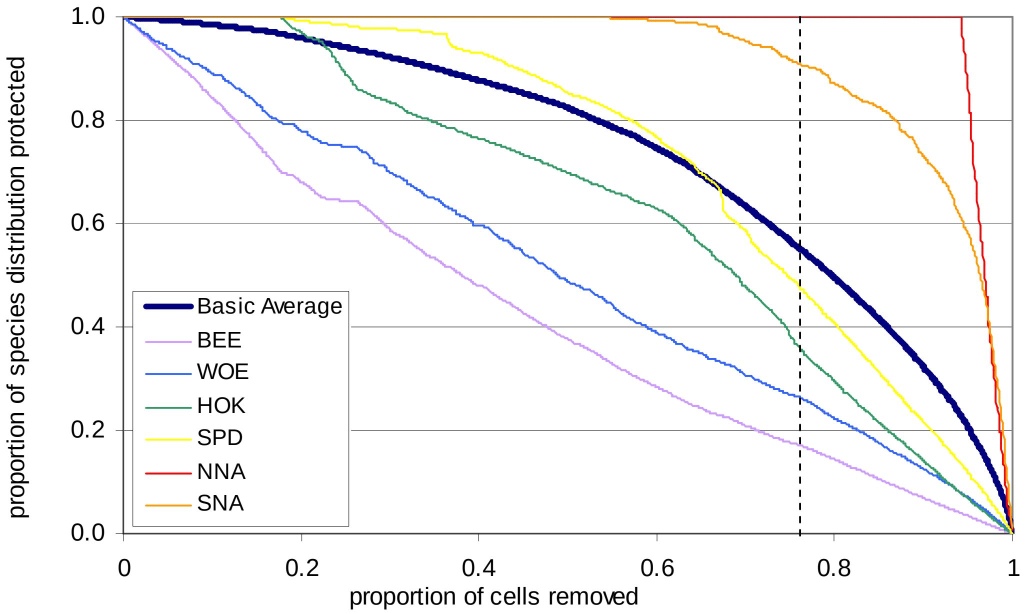

Figure 5: Relationship between conservation protection and cell removal as calculated from the basic analysis, both averaged across all species, and for selected species with contrasting protection:removal curves (BEE – Basketwork eel, HOK – hoki, NNA – *Nezumia namatahi*, SNA – snapper, SPD – spiny dogfish, WOE – warty oreo). The dashed vertical line indicates a 10% level of closure to fishing.

3.2 Weighting to increase protection for endemic species

Preferentially weighting endemic species increases the relative priority they receive in the calculation of the biodiversity protection offered by individual 1 km grid cells. This in turn alters the spatial distribution of the highest value cells (Fig. 6) compared to the configuration produced by the basic analysis (Fig. 4). Highest priorities for protection are similar to those in the basic analysis, but with greater emphasis both on inshore locations along the east and west coasts of the South Island and in certain offshore locations, particularly across the south east of Campbell Plateau, south-western Chatham Rise and at shallower depths on the Challenger Plateau. This solution also has a slightly lower ratio of boundary to area (0.61 km/km^2) than that produced from the basic analysis.

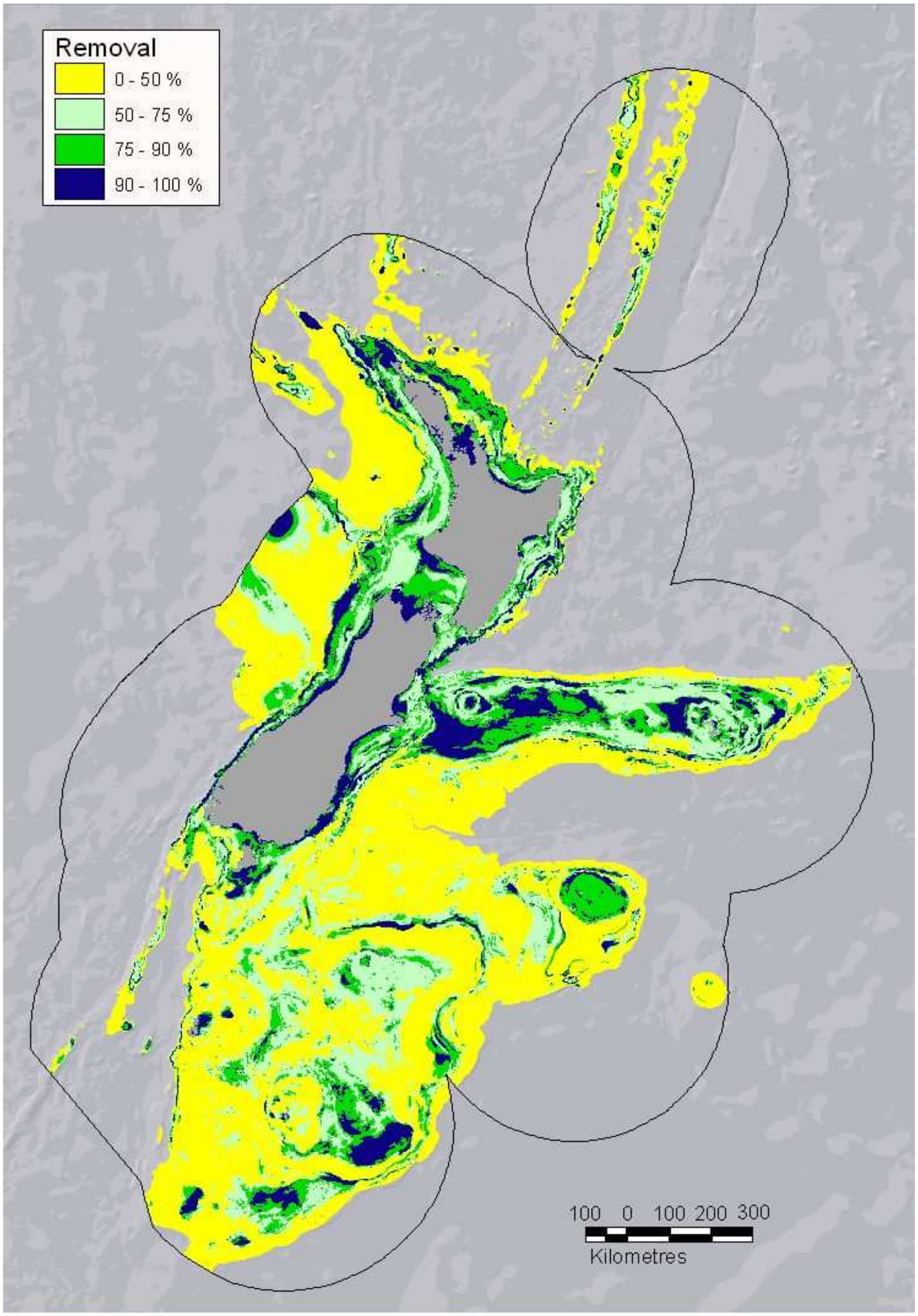

Figure 6: Relative conservation ranking of 1 km grid cells as calculated from an analysis in which endemic species were given a higher weighting. For details see text and Figure 4.

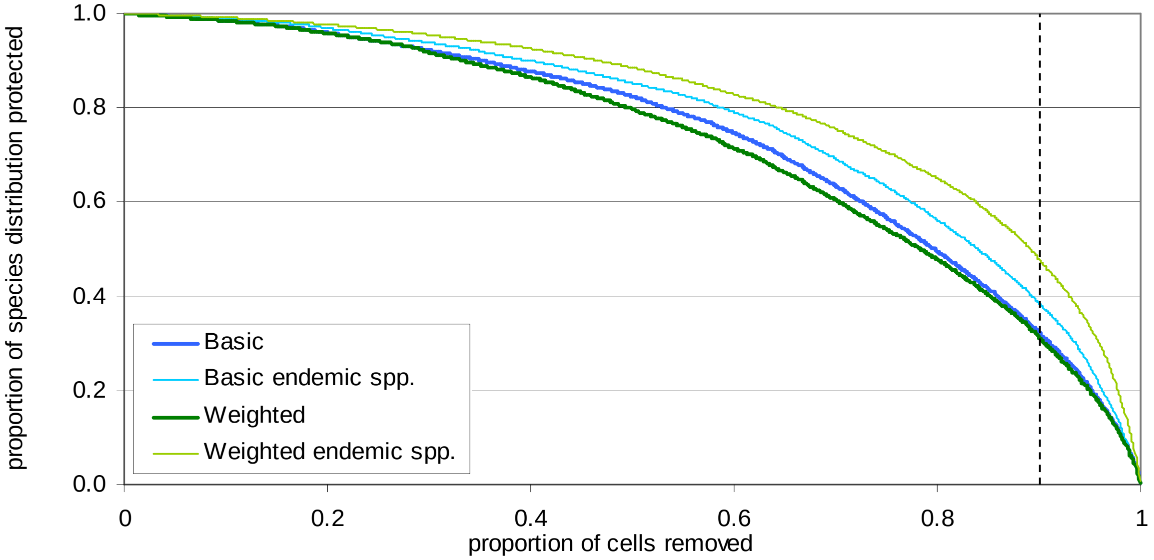

Figure 7: Comparison of the relationship between conservation protection and cell removal as calculated from the basic and weighted analyses. Results are shown averaged both for all species, and for endemic species. The dashed vertical line indicates a 10% level of closure to fishing.

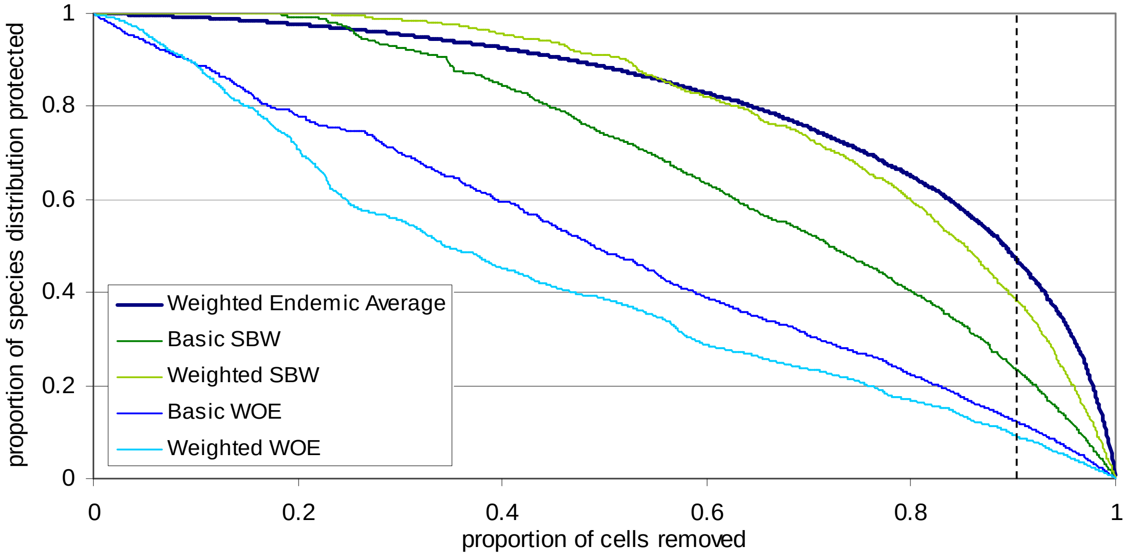

Figure 8: Protection:removal curves for the endemic southern blue whiting (SBW) and non-endemic warty oreo (WOE) as calculated by the basic and weighted analyses. The dashed vertical line indicates a 10% level of closure to fishing.

The relationship between cell removal and average proportion of ranges protected for all species for this analysis closely tracks that for the basic analysis (Fig. 5 vs. Fig. 7). However, the average protection for endemic species is increased, e.g., at a 90% level of removal, the protection for endemic species increases from 38.4% in the basics analysis to 47.8% in the weighted analysis. Protection curves for typical endemic and non-endemic species (Fig. 8) indicate that southern blue whiting (SBW), an endemic sub-species, is accorded increased levels of protection, while the non-endemic species warty oreo (WOE) shows a decrease in its protection of similar magnitude. Weighting as implemented here was used in all subsequent analyses.

3.3 Use of uncertainty estimates

We tested the feasibility of using uncertainty estimates for the individual predicted species distribution, working with a subset of 18 widespread species for which we used bootstrap resampling to estimate prediction uncertainty. This resulted in small changes in the spatial pattern of the results, with reduced conservation priority indicated for locations for which predictions were less certain. However, we were unable to fully implement this procedure in the time available for this study, because of the computer-intensive nature of the bootstrap procedure needed to produce realistic uncertainty estimates over these large areas. Nevertheless, it would be achievable in a more relaxed time frame.

3.4 Use of boundary quality constraints

Addition of boundary quality penalty (BQP) constraints to the configuration used for the weighted analysis substantially slows calculations because of the requirement to assess the degree of removal of neighbours when calculating the value of each cell. However, this results in a final solution that is much more ecologically realistic and more practical for management.

Combining a uniform 24-cell neighbourhood and a linear loss curve for all species produces a configuration (Fig. 9) that has a boundary to area ratio (0.26) less than half of that for an equivalent analysis without boundary constraints (0.61). However, maps for the respective solutions (Fig. 9 vs Fig. 6) show that, despite this reduction in fragmentation, the high priority locations (best 10%) from these analyses show strong overlap (81%). Both solutions also deliver similar levels of protection (Fig. 10), e.g., at a 10% level of reservation the BQP solution delivers average biodiversity protection of 32.1% compared with 31.1% for an equivalent unconstrained solution. Use of the more complex settings described in the methods section produced a result differing to only a minor degree from those for the analysis with uniform settings for all species.

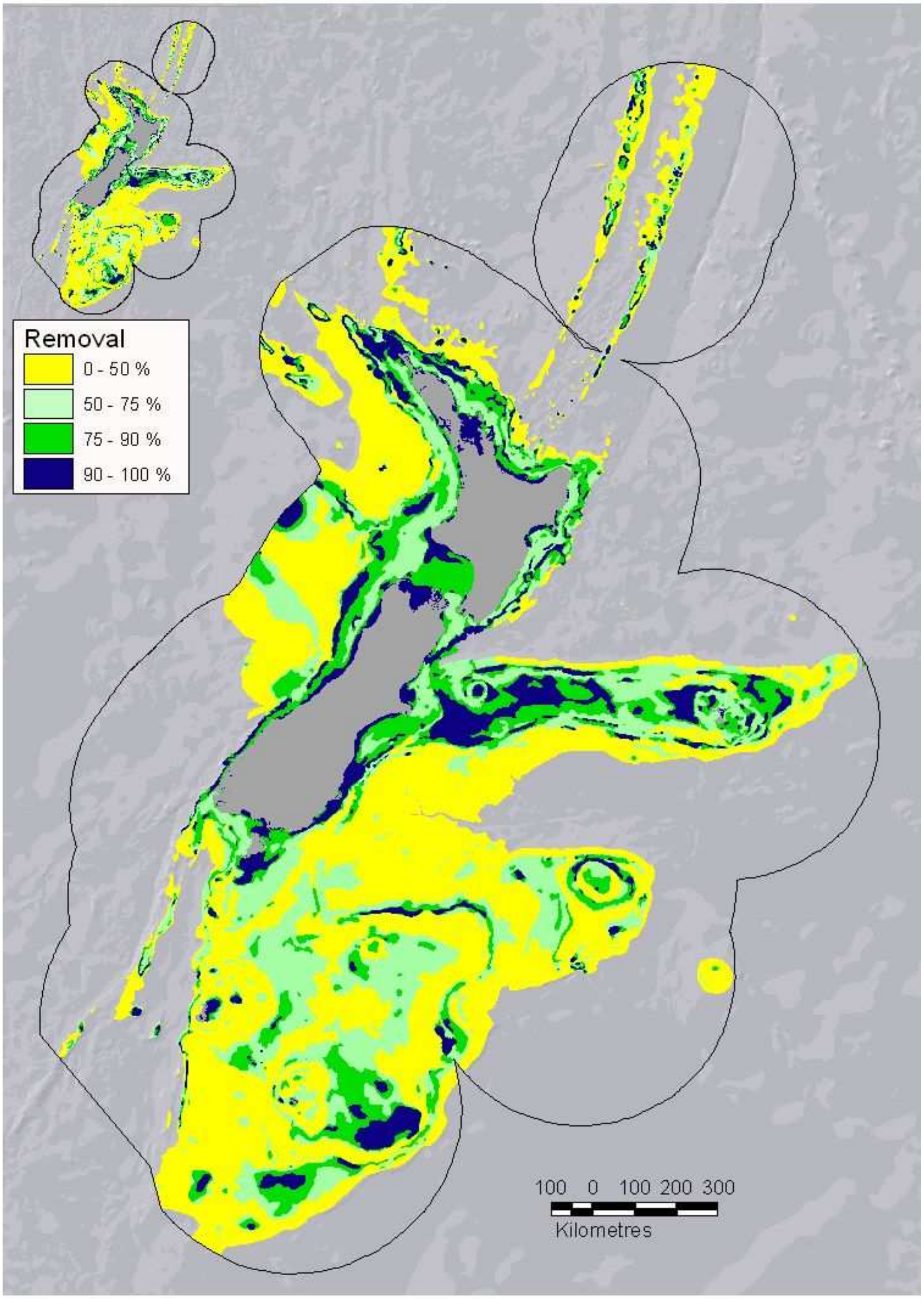

Figure 9: Relative conservation ranking of 1 km grid cells as calculated from an analysis using differential weighting of species and boundary quality penalties. Results from the weighted analysis are inset for comparison.

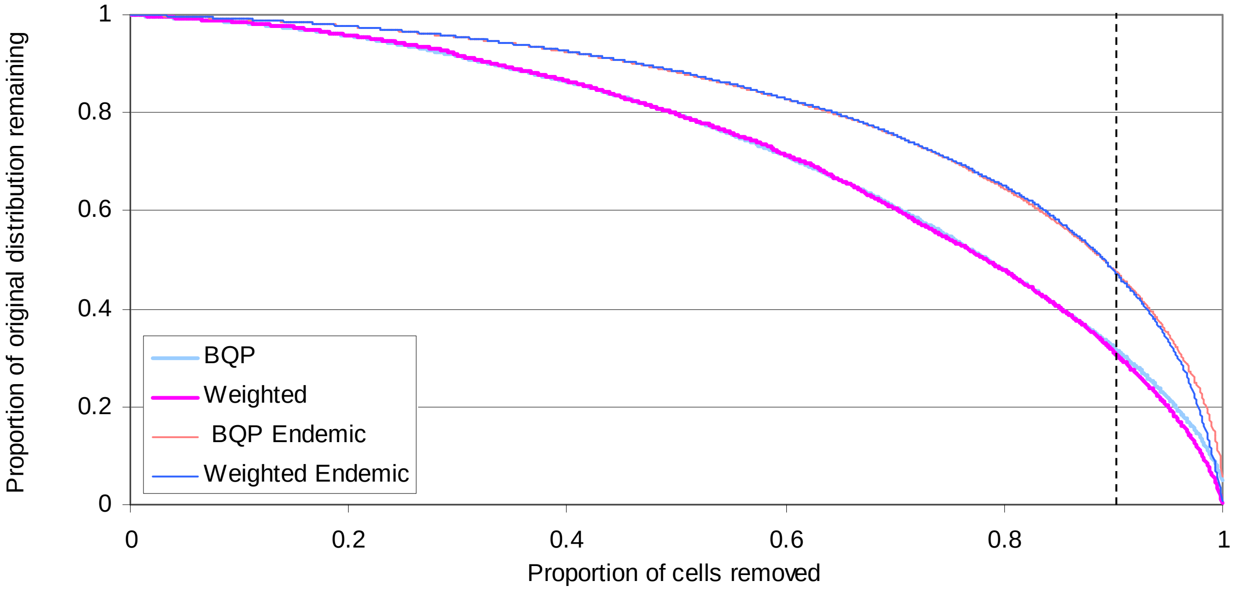

Figure 10: Comparison of the relationship between conservation protection and cell removal as calculated from the weighted analysis and an analysis using weighting and boundary quality penalties (BQP). Results are shown averaged both for all species, and for endemic species. The dashed vertical line indicates a 10% level of closure to fishing.

3.5 Introducing consideration of costs of protection

Adding consideration of the costs of protection, in this case indicated by the potential loss of trawling opportunity as measured by fishing effort during 2005, substantially changes the spatial distribution of sites having highest priority for protection (Fig. 11). In particular, it shifts the distribution away from sites favoured for trawling because of their high ‘cost’, towards sites that are less suitable for trawling. In spatial terms, the most obvious changes are the reductions in conservation priority for sites on the continental shelf from eastern Northland to the Bay of Plenty (see inset of Fig. 11), along the shelf edge off the west coast of the South Island, and on the western end of the Chatham Rise, where areas previously identified as having high conservation value in the weighted analysis (Fig. 6) are now accorded much lower priority for conservation because of their high fishing value. These changes are matched by a concomitant increase in the cost-adjusted analysis in the protection priority for sites off the northern Taranaki coast, along the Fiordland coast, east of the Chatham Islands and on the Bounty Plateau, all of which are sites that have relatively low value for trawling (Fig. 2).

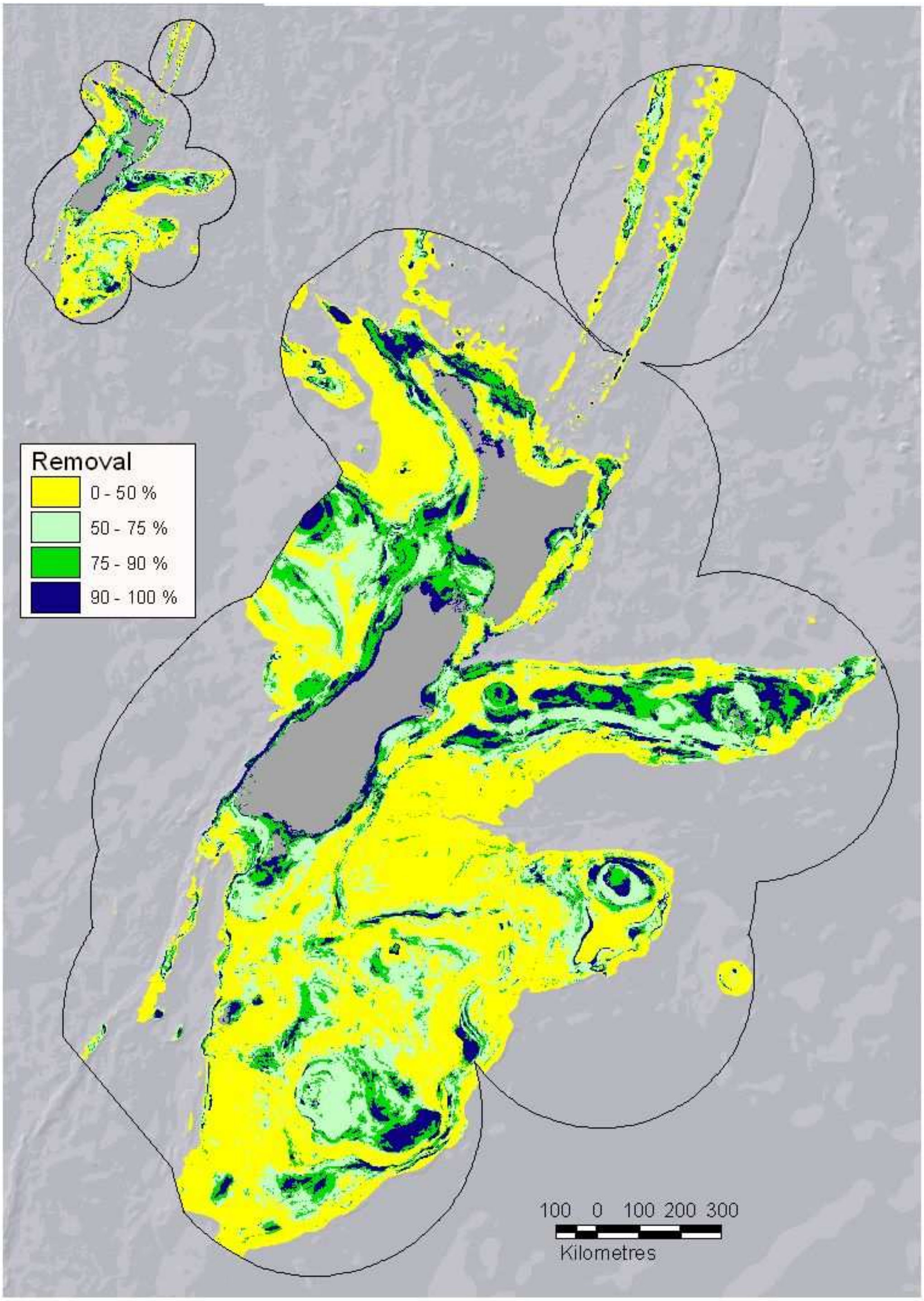

Figure 11: Relative conservation ranking of 1 km grid cells as calculated from an analysis using differential weighting of species and a cost layer describing spatial variation in trawl intensity. Results from the weighted analysis are inset for comparison.

Despite these relatively major changes in the geographic pattern of protection priority, the conservation returns provided by reservation of the highest priority 10% of sites (Fig. 12 – 28.6%) remains similar to that which would be provided by the preceding scenarios (c. 31-32%). However, at a species level there is a marked reduction in the protection provided for northern inshore species such as snapper, trevally, and kahawai, reflecting the way in which intense fishing occurs throughout the range of these species. By contrast, most offshore species maintain reasonable levels of protection, because fishing is generally concentrated in particular geographic subsets of their ranges. Protection of the 10% highest priority sites identified by this scenario would result in reserves having a boundary/area ratio of 0.59.

We note that development of a more spatially comprehensive description of fishing effort would be required before such a result could be used in an operational manner, and this would need to accurately reflect effort in inshore fisheries for which reporting of precise trawl locations is not currently obligatory.

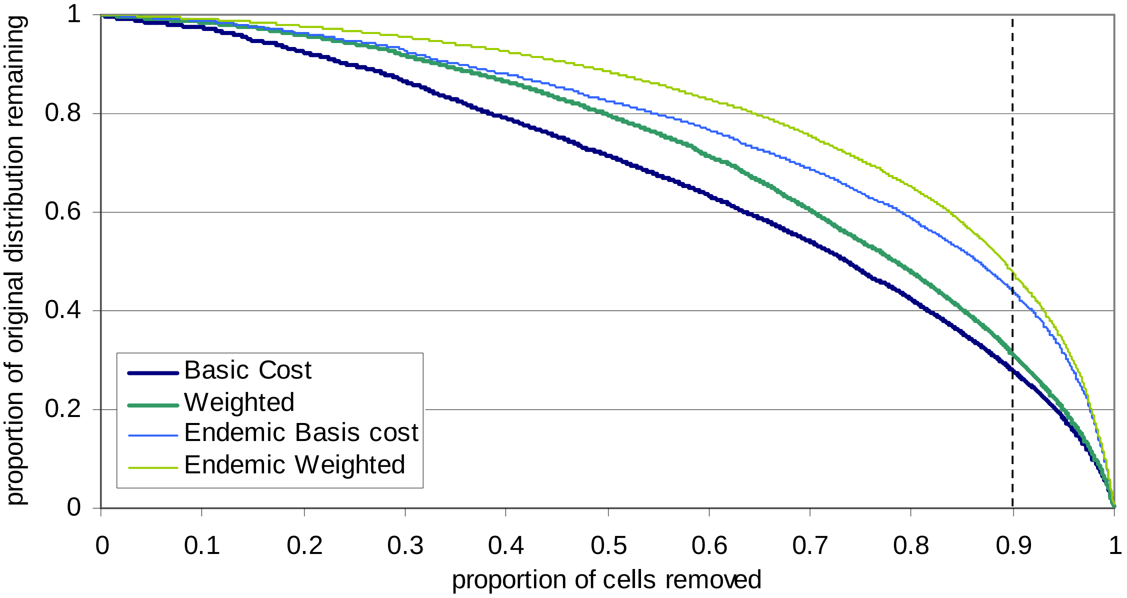

Figure 12: Comparison of the relationship between conservation protection and cell removal as calculated from the weighted analysis, and a weighted analysis in which conservation ranking was calculated using trawl intensity as a cost layer. Results are shown averaged both for all species, and for endemic species. The dashed vertical line indicates a 10% level of closure to fishing.

3.6 Conservation gains from existing and proposed reserves

Finally, we demonstrate how Zonation can be used to assess the biodiversity protection provided both by existing reserves (marine reserves and parks, and sea-mount protection zones) and the set of Benthic Protection Areas proposed by the fishing industry (Clement and Associates undated). These two reserve designations were analysed separately, and in each case, all 1 km squares located within reserves were tagged, resulting in their enforced retention until after all non-reserve squares had been removed. This allows objective assessment of the protection that these reserves currently or could potentially provide, compared to the protection provided by either the unconstrained or cost-adjusted selection of sites as described for the previous analyses.

3.6.1 Existing reserves

Analysis of existing reserves, which cover 22 922 km^2 or 1.26% of the area of the EEZ with trawlable depths, was carried out first. Because these reserves comprise such a relatively small proportion of the EEZ, their retention until the end of the analysis resulted in little change in the overall pattern of protection priority (Fig. 13) compared to that produced by an equivalent analysis without such constraints (i.e. ‘weighted’ – Fig. 6).

The small extent of the existing reserves also results in close similarities between the biodiversity protection curves for these two analyses (Fig. 14), which show only minimal differences throughout much of their range. However, the amount of protection provided by areas contained within the existing reserves (average = 1.48%) is less than 20% of the protection that would be provided by an equivalent area chosen solely for its biodiversity values (7.68%). This difference is a direct reflection of the non-representative nature of the existing reserves, which are biased towards both inshore waters and seamounts where they provide disproportionate protection of these habitats at the expense of habitats that support markedly different fish assemblages.

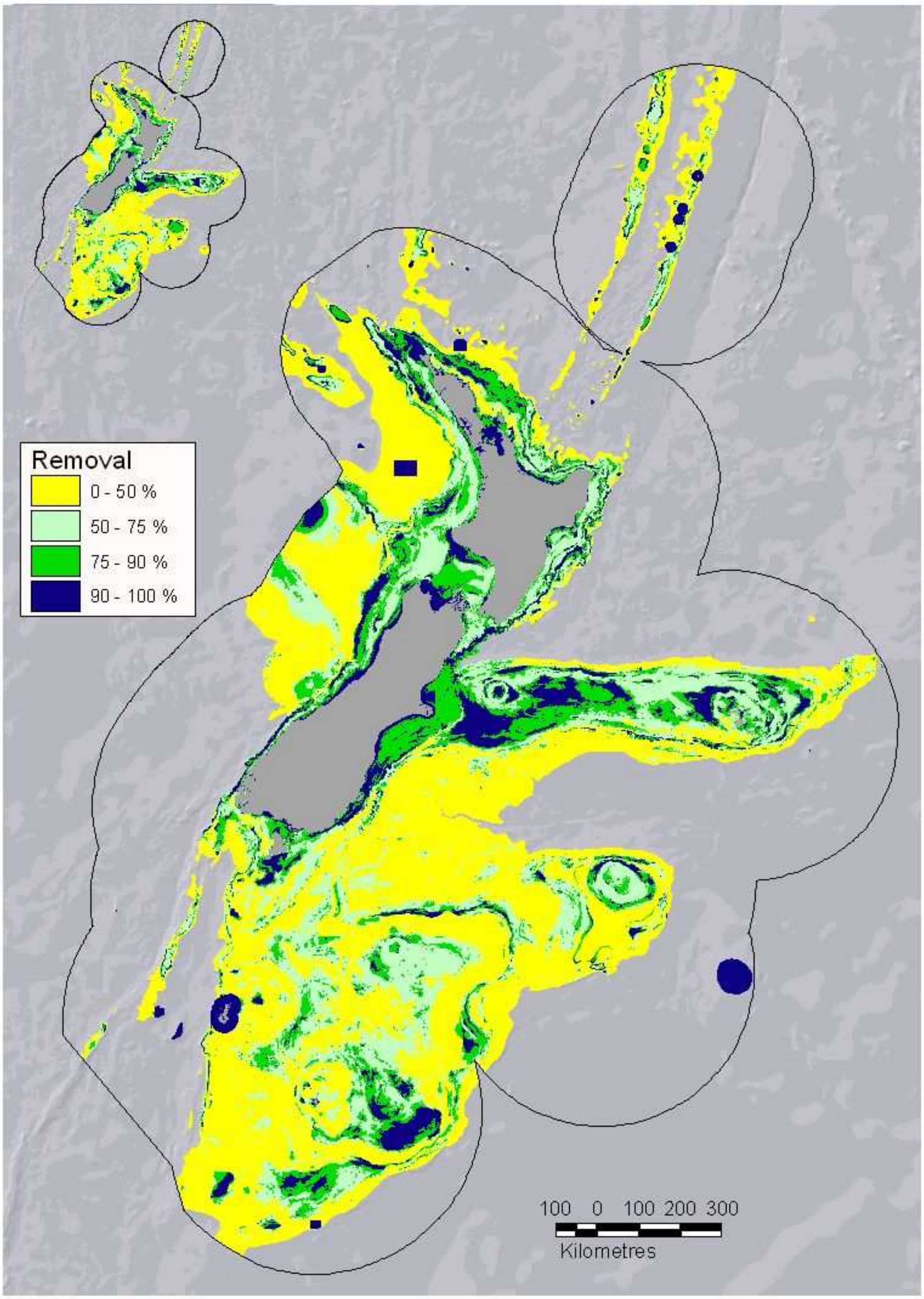

Figure 13: Relative conservation ranking of 1 km grid cells as calculated from an analysis using differential weighting of species, and in which cells located within existing reserves were retained until all non-reserve cells had been removed. Results from the weighted analysis are inset for comparison.

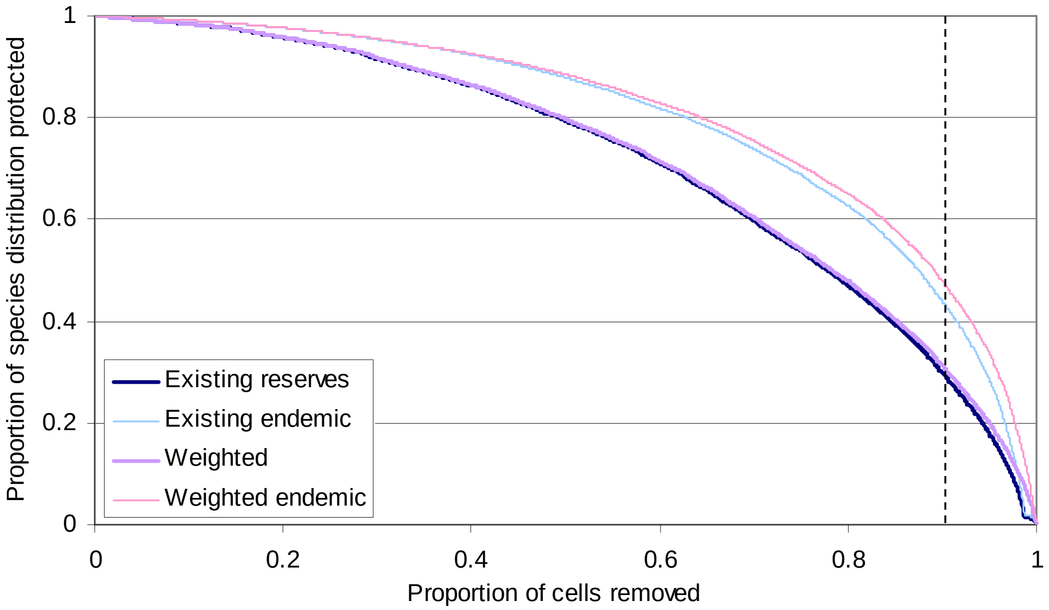

Figure 14: Comparison of the relationship between conservation protection and cell removal as calculated from the weighted analysis and an analysis in which cells located within existing reserves were retained until all other cells had been removed. Results are shown averaged both for all species, and for endemic species. The dashed vertical line indicates a 10% level of closure to fishing.

3.6.2 Industry-proposed Benthic Protection Areas

Retention of cells within the Benthic Protection Areas has a much more marked effect on analysis outcomes (Fig. 15) than was evident in the previous analysis. In part this reflects their greater spatial extent, as they comprise 14.3% of the area of trawlable depth within the EEZ. However, they also coincide strongly with areas of low biodiversity value as identified by the previous analyses (e.g. Fig 6). This results in pronounced differences in the species range protection curves for the BPA analysis and the previous unconstrained analyses (Fig. 16, 17), particularly for endemic species. As a consequence, the average protection for all species provided by the 14% of the EEZ contained within the proposed BPAs (9.26%) is less than a quarter of the protection that would be provided by an equivalent area chosen solely for its biodiversity values (39.2%). The disparity for endemic species is even more pronounced, with the BPAs providing average protection of 6.8% compared with protection of 56.7% that would be provided by an unconstrained selection of sites. The one advantageous feature of the proposed BPAs identified by this analysis is their compact shape, which results in a low boundary length/area ratio of 0.053, compared with a ratio of 0.548 for a 14.3% selection based on the weighted analysis, and 0.224 for an equivalent area selected using boundary quality penalties.

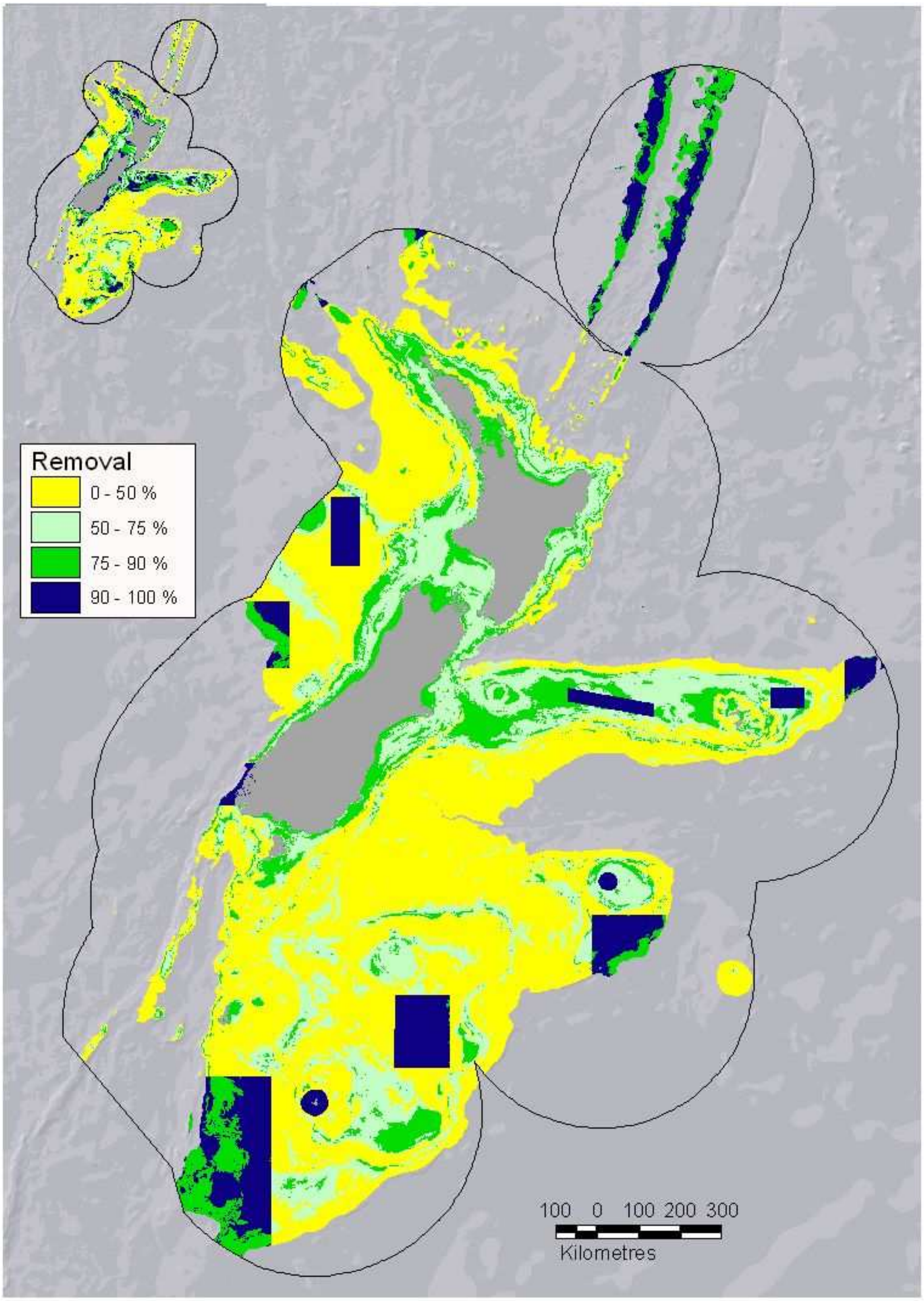

Figure 15: Relative conservation ranking of 1 km grid cells as calculated from an analysis using differential weighting of species, and in which cells located within the proposed Benthic Protection Areas were retained until all cells outside these proposed reserves had been removed. Results from the weighted analysis are inset for comparison.

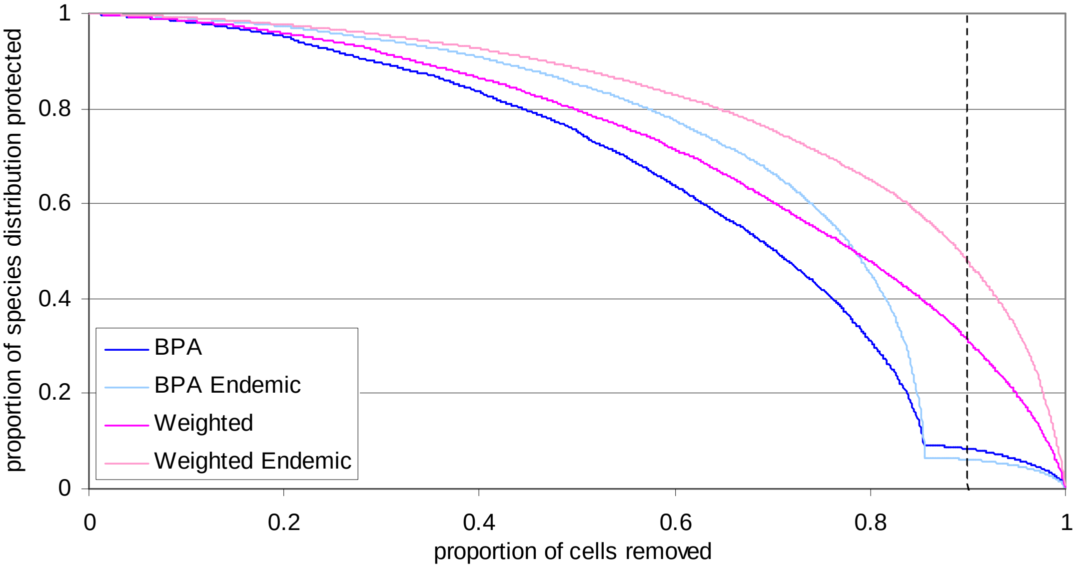

Figure 16: Comparison of the relationship between conservation protection and cell removal as calculated from the weighted analysis and an analysis in which cells located within Benthic Protection Areas proposed by the fishing industry were retained until all other cells had been removed. Results are shown averaged both for all species, and for endemic species. The dashed vertical line indicates a 10% level of closure to fishing.

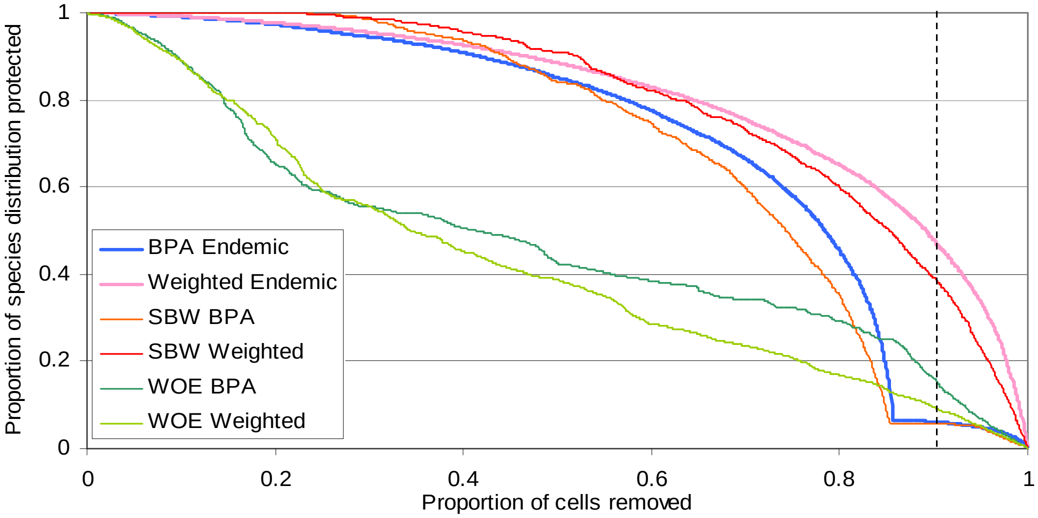

Figure 17: Comparison of the relationship between conservation protection and cell removal for two species, southern blue- whiting (SBW) and warty oreo (WOE) as calculated from the weighted analysis and an analysis in which cells located within Benthic Protection Areas were retained until all other cells had been removed. Average results across all species are also shown for both analyses.

3.7 Opportunity cost of different Zonation scenarios

Examination of the costs of implementing the different Zonation scenarios to provide protection for 10% of the geographic extent of the trawlable part of the EEZ indicates that there are marked disparities between them (Table 1). Note that this table also includes an assessment of the conservation returns of the different scenarios, re-calculated using boundary quality penalties, as for the BQP analysis. This was achieved by loading the conservation rankings produced by each scenario into Zonation, and recalculating its returns with the BQP calculation option turned on. This left the original conservation rankings intact, but took into account the negative effects of fragmentation when assessing their conservation returns. Results are as follows:

- Implementation of a 10% level of geographic reservation based on the first three scenarios (basic, weighted, BQP) would result in a reduction in fishing opportunity of the order of 20%. While the initial assessment indicates an average protection of demersal fish ranges averaging a little over 30%, recalculation using boundary quality penalties reduces the protection provided by the basic and weighted analyses to around 28%. This clearly indicates the superiority of the BQP scenario, reflecting its more compact nature and reduced negative effects of fragmentation.

- Implementing a similar level of reservation based on the cost-constrained Zonation scenario would reduce costs by over 90% but would still result in average levels of fish protection (28.6%, or 25.5% with BQP) only a few percent lower than that achieved by the unconstrained analyses. However, implementation of this scenario would require careful consideration of its impacts across a full range of species. In particular, species that are largely restricted to areas subject to high trawl pressure would be accorded much lower levels of protection than in the preceding scenarios. Additional reserved areas might be required to protect these species.

- Implementing a 10% level of reservation by expanding existing reserves in accordance with species' abundances as indicated by Zonation, is slightly more cost effective than the first three scenarios, reflecting the existing exclusion of fishing from small areas accorded high conservation priority area because of their enforced retention until all other cells had been removed. This option would deliver almost as high a level of protection as the unconstrained scenarios.

- The BPA proposal has by far the lowest costs, i.e. setting aside the best 10% of the area within these proposed reserves would result in a minimal loss of fishing opportunity (0.2%), i.e. only about 1% of the losses incurred by the unconstrained scenarios. However, as already demonstrated, its delivery of demersal fish protection is also considerable lower at only 8.4%. A small increase in its protection benefits to 11.9% is evident when consideration is given to boundary effects, reflecting the geographically compact nature of these proposed reserves. We note however, that this degree of protection would only be delivered if all fishing were precluded in these proposed areas, and this level of fishing reduction is not proposed under the fishing industry proposal.

Table 1: Costs and benefits of protecting 10% of the trawlable part of New Zealand's Exclusive Economic Zone as predicted by different Zonation scenarios. Costs indicate the opportunity cost of fishing that would be imposed by protection, while benefits indicate the resulting degree of protection provided for demersal fish species, calculated with and without BQP constraints.

Scenario	Cost = reduction in trawling opportunity (%)	Benefit = demersal fish protection, averaged across all species (%)	Benefit, re-calculated with boundary quality penalties (%)
Basic	22.4%	32.2%	27.8%
Weighted	19.9%	31.1%	27.8%
BQP	21.2%	32.1%	32.1%
Cost-adjusted	1.6%	28.6%	25.5%
Existing reserves	18.1%	29.8%	26.6%
BPA proposal	0.2%	8.4%	11.9%

4. Discussion

Despite the relatively small amount of resources available for this ‘proof-of-concept’ study, our results clearly demonstrate the power of reserve planning software for exploring realistic scenarios for biodiversity protection over extensive geographic areas. This in turn provides a rational, information-based capability that takes account of the distributions of 122 widespread fish species, while weighing the relative costs and benefits of different reserve configurations. The method used also allows the evaluation of existing or proposed reserves, and the identification of additional high-value sites, should further expansion of the reserve network be required.

In this particular setting, our results conclusively demonstrate marked differences between the costs and conservation returns of the different protection options that we explored. While the scenarios suggested by the basic and weighted analyses lack practicality because of their high degree of fragmentation, they clearly demonstrate the potential conservation returns for demersal fish that are possible with protection of only a small proportion of New Zealand’s EEZ. The analysis performed with boundary quality constraints provides a more realistic starting point for defining reserves, and indicates that much more compact geographic areas could be identified than in the basic analyses, with minimal if any loss in protection gains.

Consideration of costs as measured by loss of fishing opportunity adds a new and powerful dimension to these analyses, either when fishing intensity is included directly in the analysis, or when the costs of scenarios developed without cost constraints are assessed retrospectively. The one caveat that applies in these analyses is that they are likely to over-estimate the costs of fishing losses, as the declaration of reserves in particular locations is unlikely to result in an overall reduction in fishing effort, per se. What is more likely is a redistribution of effort with more intensive fishing in formerly less-favoured locations.

Despite this limitation, this approach clearly exposes both the costs and benefits of reserves, whether existing or proposed. For example, our results demonstrate clearly that New Zealand’s existing reserves cannot be relied upon as providing protection of representative range of the fish communities occurring in the wider EEZ. This shortcoming largely reflects past protection policies that emphasised the defining of reserves in inshore waters.

With respect to the Benthic Protection Areas proposed by the fishing industry, our results indicate that implementation of these would produce low returns in terms of demersal fish conservation. We emphasise too that our analysis will have overestimated these returns, because the BPA proposal only precludes the use of bottom trawling in these areas, while allowing continued harvesting using other methods. On the basis of our results we conclude that, despite their large geographic area, the focus of this proposal on excising areas that have both very low fishing value and low fish diversity, makes it a poor option for the long-term protection of demersal fish diversity in New Zealand's EEZ.

While objections to our results might be raised on the grounds that they focus solely on demersal fish in identifying priority sites, we believe that this approach can be justified on three grounds. First, the modelling of biodiversity patterns across New Zealand's EEZ is a relatively recent advent, and demersal fish were the most obvious priority group upon which to focus. This reflects both the wealth of fish distribution data available from research trawl surveys, and the key roles played by fish both economically, and as major components of the biodiversity and biomass in many marine ecosystems. Furthermore, fish make up the bulk of the biomass killed by human activities in the EEZ, and so they are a major target of marine protection measures. Future research is likely to expand the range of biological groups available for consideration in assessing optimal designs of marine protected areas. Second, some justification for an initial analysis based on demersal fish is provided by the dual function that can be provided by marine protected areas, i.e. if large enough, they are one of a number of tools that can be used to maintain sustainable harvesting of fisheries (e.g., Roberts et al. 2003, Halpern and Warner 2003, Hastings & Botsford 2003), while also providing benefits through the protection of a wider range of biological diversity, including fish. Finally, data describing the distributions of benthic macro-fauna in the oceans around New Zealand are extremely limited—while efforts are underway to collect additional data, it will be some time before robust distributional models can be built for many of these biological groups.

Finally, results such as we provide here provide a robust basis on which to determine minimum geographic targets for protection. While current government policy indicates a desire to set aside 10% of New Zealand's marine environments by 2010 (New Zealand Biodiversity Strategy Objective 3.6(b)), our results indicate that substantial increases in biodiversity protection could be achieved with only a small increase in geographic area above this current target. For example, for most of the scenarios we produced, expansion of the reserved area to 20% on a geographic basis would increase average levels of species protection from 30% to nearly 50%. These higher levels of geographic protection would be consistent with minimum area guidelines suggested from other marine studies (e.g., Araime et al. 2003, Halpern & Warner 2003, Gladstone 2006).

4.1 Practical considerations

While a range of software tools is available to address questions related to the selection of an optimal set of sites for conservation, in this study we used Zonation, which is particularly suited to the analysis of extensive raster-based data sets. Our exploration of this software indicated that it is relatively easy to use, and even with data of the magnitude used here, provides relatively rapid analysis times, taking approximately 60 minutes for a basic analysis with 122 species distributed across 1.9 million grid cells. While use of cost or reserve layers carries minimal overhead, use of boundary quality penalties increases analysis time, resulting in total times for analyses of up to 60 hours. All analyses can be done on a typical desktop computer bought in 2006, but with extra RAM (2GB). Development of our 'proof of concept' analysis to an operational level would require:

- Exploration of the use of variance layers that indicate spatial variation in the uncertainties associated with our estimates of the standardized catch of individual species. We have trialled this option for a subset of species, and it places greater emphasis on sites for which predictions of abundance have high reliability. However, we were unable to fully implement this option in the present study because of the amount of time required to produce bootstrap estimates of uncertainty for all species;.

- Further exploration of the appropriateness of the buffer sizes and loss curves chosen for the individual fish species, as used in the boundary quality penalty (BQP) analysis. This is one of the more complex aspects requiring further work, and is made difficult by the complex movement patterns of some species, particularly those that undergo spawning migrations.

- Use of a more comprehensive layer describing the intensity of fishing by trawling to more accurately reflect variation in fishing intensity in inshore waters. This will be challenging for some inshore fisheries, where trawling activity is currently reported only by statistical area, as in the Catch Effort and Landing Return (CELR) Database. This should also include trawl locations from a wider temporal span, and would ideally be built around trawl tracks as defined by their start and end locations, rather than by simply using start locations alone. Inclusion of mid-water trawls, as used for example in the southern blue whiting fishery, should also be considered. It might also be desirable to take into account the differential financial returns of fishing in different locations and for different species.

- A more comprehensive description of existing management designations, including mineral and oil prospecting areas, cable protection zones, taiapure, mataitai, and trawling exclusion zones. While spatial data are available describing the locations of many of these, they require compilation into a common format and map projection before they can be used with confidence.

- The development of further scenarios that combine the use of uncertainty layers for all species, expanded costs layers, and revised boundary quality penalties. Inspection of the results produced by these analyses should be expanded to include consideration of the costs and protection returns for a full range of species, including both endemic and commercially important species.

- The eventual inclusion of biological data from across the entire EEZ and describing the distributions of a more complete set of biological groups (e.g., benthic invertebrates, macro-algae, sea-birds, etc.) would also be highly desirable. However, this is not practicable immediately for many species groups, because data of equivalent quality to that contained in the *fish_comm* research trawl database are not readily available at present.

5. Acknowledgements

This study would not have been possible without the support of a number of colleagues and organisations. Clinton Duffy (Department of Conservation) played a major role both in the setting up of this study, and in providing ongoing comment on the analyses and results, including the categorising of the dispersal ability of the various fish species. He also arranged for access to spatial data describing the distribution of current and proposed reserves. Ministry of Fisheries staff facilitated access to commercial and research trawl data used in this study.

Dr Atte Molianen (University of Helsinki) kindly allowed our use of Zonation and provided both advice and example command files that greatly speeded our introduction to its use. Brendan Wintle (Environmental Sciences, University of Melbourne) shared with us his experience with the setting of parameters for Zonation analyses. Jane Elith (University of Melbourne) and Trevor Hastie (Stanford University) assisted with the identification of the robust methods for calculating data layers describing uncertainties associated with the prediction of fish distributions.

Drs Simon Ferrier (Department of Environment and Conservation, Armidale, New South Wales) and Mark Costello (Leigh Marine Laboratory, University of Auckland) provided invaluable critique and comment of this report in its draft stages.

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Appendix 1: Species codes for 122 demersal fish species, and their equivalent common and scientific names. Values under "Category" indicate the predominant position of species, i.e. B = benthic, BP = bentho-pelagic, P = pelagic; endemic species are identified by a bracketed "E". Values under "Average depth" indicate the depth at which species are most frequently caught as indicated from statistical models relating their probability of capture to environment.

Code	Common name	Scientific name	Category	Average Depth
ANC	Anchovy	*Engraulis australis*	P	32
BAR	Barracouta	*Thyrsites atun*	P	105
BBE	Banded bellowsfish	*Centriscops humerosus*	B	473
BCO	Blue cod	*Parapercis colias*	B(E)	69
BEE	Basketwork eel	*Diastobranchus capensis*	BP	1062
BJA	Black javelinfish	*Mesobius antipodum*	P	1007
BNS	Bluenose	*Hyperoglyphe antarctica*	P	445
BOE	Black oreo	*Allocyttus niger*	P	910
BRA	Short-tailed black ray	*Dasyatis brevicaudata*	BP	21
BSH	Seal shark	*Dalatias licha*	BP	690
BSL	Black slickhead	*Xenodermichthys spp.*	P	871
BYX	Alfonsino & long-finned Beryx	*Beryx splendens & B decadactylus*	BP	434
CAR	Carpet shark	*Cephaloscyllium isabellum*	B(E)	100
CAS	Oblique banded rattail	*Caelorinchus aspercephalus*	BP(E)	422
CBA	Humpback rattail (slender rattail)	*Coryphaenoides dossenus*	BP(E)	936
CBE	Crested bellowsfish	*Notopogon lilliei*	B	109
CBO	Bollons rattail	*Caelorinchus bollonsi*	BP(E)	533
CDO	Capro dory	*Capromimus abbreviatus*	BP(E)	279
CFA	Banded rattail	*Caelorinchus fasciatus*	BP	696
CHA	Viper fish	*Chauliodus sloani*	P	969
CHP	Brown chimaera	*Chimaera* sp.	BP	1196
CIN	Notable rattail	*Caelorinchus innotabilis*	BP	944
CKA	Kaiyomaru rattail	*Caelorinchus kaiyomaru*	BP	1004
CMA	Mahia rattail	*Caelorinchus matamua*	BP	848
COL	Olivers rattail	*Caelorinchus oliverianus*	BP(E)	601
CSE	Serrulate rattail	*Coryphaenoides serrulatus*	BP	988
CSQ	*Centrophorus squamosus*	*Centrophorus squamosus*	BP	816
CSU	Four-rayed rattail	*Coryphaenoides subserrulatus*	BP	981
CUC	Cucumber fish	*Chlorophthalmus nigripinnis*	B	178
CYO	Smooth skin dogfish	*Centroscymnus owstoni*	BP	940
CYP	*Centroscymnus crepidater*	*Centroscymnus crepidater*	BP	919

Code	Common name	Scientific name	Category	Average Depth
EGR	Eagle ray	*Myliobatis tenuicaudatus*	BP	21
ELE	Elephant fish	*Callorhinchus milii*	BP	33
EMA	Blue mackerel	*Scomber australasicus*	P	84
EPT	Deepsea cardinalfish	*Epigonus telescopus*	BP	780
ESO	N.Z. sole	*Peltorhamphus novaezeelandiae*	B(E)	27
ETB	Baxters lantern dogfish	*Etmopterus baxteri*	BP	967
ETL	Lucifer dogfish	*Etmopterus lucifer*	BP	570
FHD	Deepsea flathead	*Hoplichthys haswelli*	B	443
FRO	Frostfish	*Lepidopus caudatus*	P	148
GAO	Filamentous rattail	*Gadomus aoteanus*	BP(E)	1056
GSP	Pale ghost shark	*Hydrolagus bemisi*	BP(E)	646
GUR	Gurnard	*Chelidonichthys kumu*	B	51
HAK	Hake	*Merluccius australis*	BP	624
HAP	Hapuku	*Polyprion oxygeneios*	BP	127
HCO	Hairy conger	*Bassanago hirsutus*	B	681
HJO	Johnson's cod	*Halargyreus johnsonii*	BP	1014
HOK	Hoki	*Macruronus novaezelandiae*	P	606
HPE	Common halosaur	*Halosaurus pectoralis*	BP	837
HYB	Black ghost shark	*Hydrolagus* sp. a	BP	1313
JAV	Javelin fish	*Lepidorhynchus denticulatus*	P	596
JDO	John dory	*Zeus faber*	BP	60
JGU	Spotted gurnard	*Pterygotrigla picta*	B	188
JMD	Horse mackerel	*Trachurus declivis*	P	115
JMM	Murphys mackerel	*Trachurus symmrtricus murphyi*	P	138
JMN	Golden mackerel	*Trachurus novaezelandiae*	P	60
KAH	Kahawai	*Arripis trutta*	P	38
KIN	Kingfish	*Seriola lalandi*	P	66
LCH	Long-nosed chimaera	*Harriotta raleighana*	BP	771
LDO	Lookdown dory	*Cyttus traverse*	BP	488
LEA	Leatherjacket	*Parika scaber*	BP	46
LIN	Ling	*Genypterus blacodes*	BP	475
LSO	Lemon sole	*Pelotretis flavilatus*	B(E)	111
MCA	Ridge scaled rattail	*Macrourus carinatus*	BP	1033
MDO	Mirror dory	*Zenopsis nebulosus*	BP	212
NNA	*Nezumia namatahi*	*Nezumia namatahi*	BP	1112
NSD	Northern spiny dogfish	*Squalus mitsukurii*	BP(E)	235
OPE	Orange perch	*Lepidoperca aurantia*	BP(E)	319
ORH	Orange roughy	*Hoplostethus atlanticus*	P	977
PCO	Ahuru	*Auchenoceros punctatus*	BP(E)	25

Code	Common name	Scientific name	Category	Average Depth
PDG	Prickly dogfish	*Oxynotus bruniensis*	B	472
PHO	Lighthouse fish	*Photichthys argenteus*	P	930
PIL	Pilchard	*Sardinops neopilchardus*	P	22
PLS	Plunkets shark	*Centroscymnus plunketi*	BP	820
POP	Porcupine fish	*Allomycterus jaculiferus*	BP(E)	104
PSK	Longnosed deepsea skate	*Bathyraja shuntovi*	BP(E)	1076
PSY	Psychrolutes	*Psychrolutes microporos*	B(E)	1004
RBM	Rays bream	*Brama brama*	P	377
RBT	Redbait	*Emmelichthys nitidus*	P	185
RCH	Widenosed chimaera	*Rhinochimaera pacifica*	BP	1040
RCO	Red cod	*Pseudophycis bachus*	BP	139
RIB	Ribaldo	*Mora moro*	BP	781
RMU	Red mullet	*Upeneichthys lineatus*	B	42
RUD	Rudderfish	*Centrolophus niger*	P	516
SBI	Bigscaled brown slickhead	*Alepocephalus sp.*	BP	1156
SBK	Spineback	*Notacanthus sexspinis*	BP	789
SBW	Southern blue whiting	*Micromesistius australis*	P(E) (sub spp.)	494
SCG	Scaly gurnard	*Lepidotrigla brachyoptera*	B	112
SCH	School shark	*Galeorhinus galeus*	BP	111
SCO	Swollenhead conger	*Bassanago bulbiceps*	B	666
SDO	Silver dory	*Cyttus novaezealandiae*	BP	229
SFL	Sand flounder	*Rhombosolea plebeia*	B(E)	27
SKI	Gemfish	*Rexea solandri*	P	250
SMC	Small-headed cod	*Lepidion microcephalus*	BP	939
SNA	Snapper	*Pagrus auratus*	BP	40
SND	Shovelnose spiny dogfish	*Deania calcea*	BP	874
SOR	Spiky oreo	*Neocyttus rhomboidalis*	P	825
SPD	Spiny dogfish	*Squalus acanthias*	BP	176
SPE	Sea perch	*Helicolenus spp.*	B(E)	361
SPO	Rig	*Mustelus lenticulatus*	BP(E)	66
SPZ	Spotted stargazer	*Genyagnus monopterygius*	B(E)	25
SRH	Silver roughy	*Hoplostethus mediterraneus*	BP	583
SSH	Slender smooth-hound	*Gollum attenuatus*	BP(E)	441
SSI	Silverside	*Argentina elongata*	P	422
SSM	Smallscaled brown slickhead	*Alepocephalus australis*	BP	1083
SSO	Smooth oreo	*Pseudocyttus maculatus*	P	995
STY	Spotty	*Notolabrus celidotus*	B(E)	24
SWA	Silver warehou	*Seriolella punctata*	P	243

Code	Common name	Scientific name	Category	Average Depth
TAR	Tarakihi	*Nemadactylus macropterus*	BP	125
TOP	Pale toadfish	*Ambophthalmos angustus*	B(E)	475
TRE	Trevally	*Pseudocaranx dentex*	P	37
TRS	*Trachyscorpia capensis*	*Trachyscorpia capensis*	B	907
TUB	*Tubbia tasmanica*	*Tubbia tasmanica*	P	883
VCO	Violet cod	*Antimora rostrata*	BP	1154
VNI	Blackspot rattail	*Ventrifossa nigromaculata*	BP	690
WAR	Common warehou	*Seriolella brama*	P	48
WHX	White rattail	*Trachyrincus aphyodes*	BP(E)	969
WIT	Witch	*Arnoglossus scapha*	B(E)	121
WOE	Warty oreo	*Allocyttus verrucosus*	P	1167
WRA	Longtailed stingray	*Dasyatis thetidis*	BP	19
WWA	White warehou	*Seriolella caerulea*	P	396
YBF	Yellow-belly flounder	*Rhombosolea leporine*	B(E)	21