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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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.

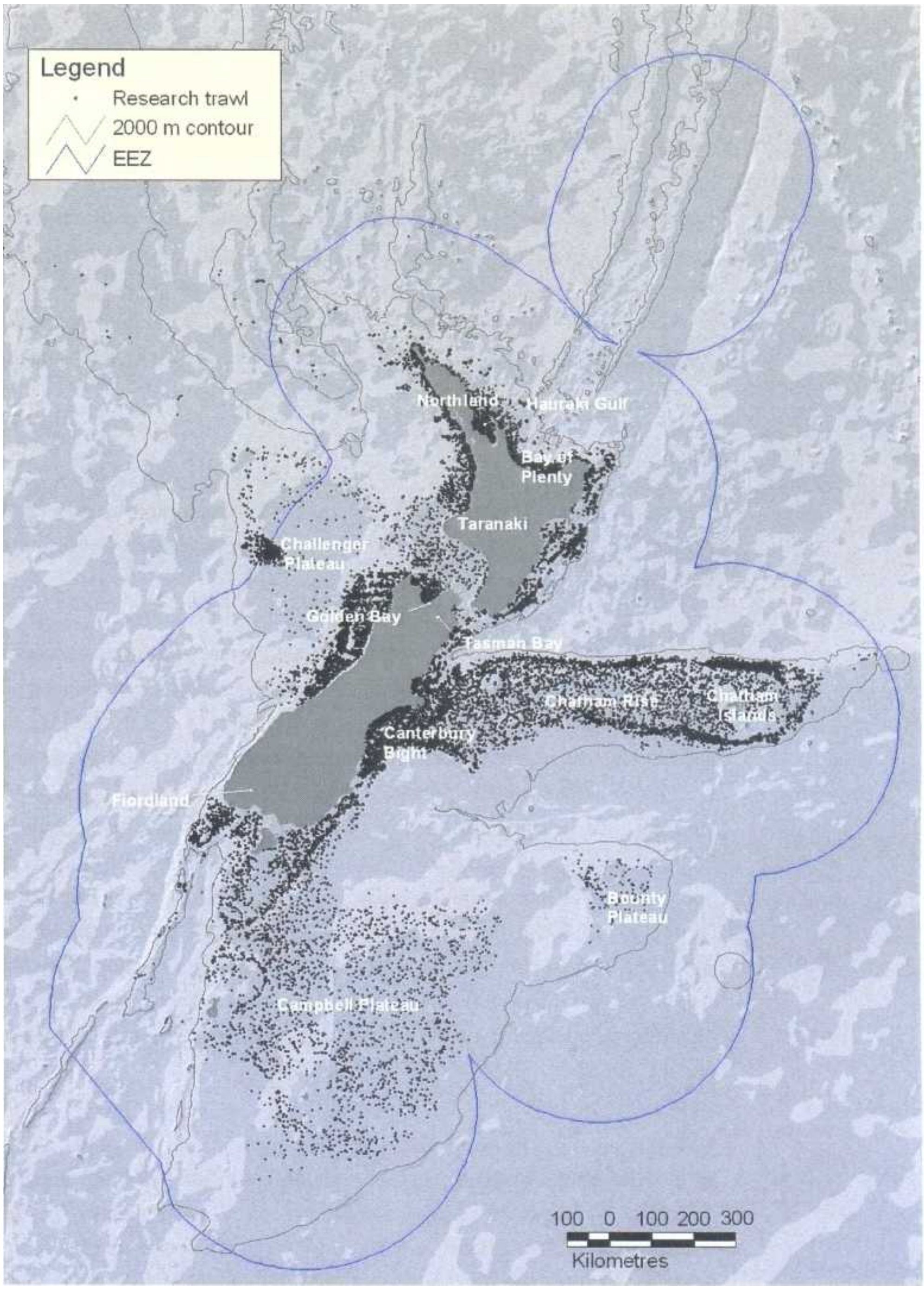

Figure 1: Locations of research trawl database (*fish_comm*) trawls used to construct predicted distribution maps for 122 fish species. The 2000 m contour defines approximately the maximum depth currently fished by bottom trawling.

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).

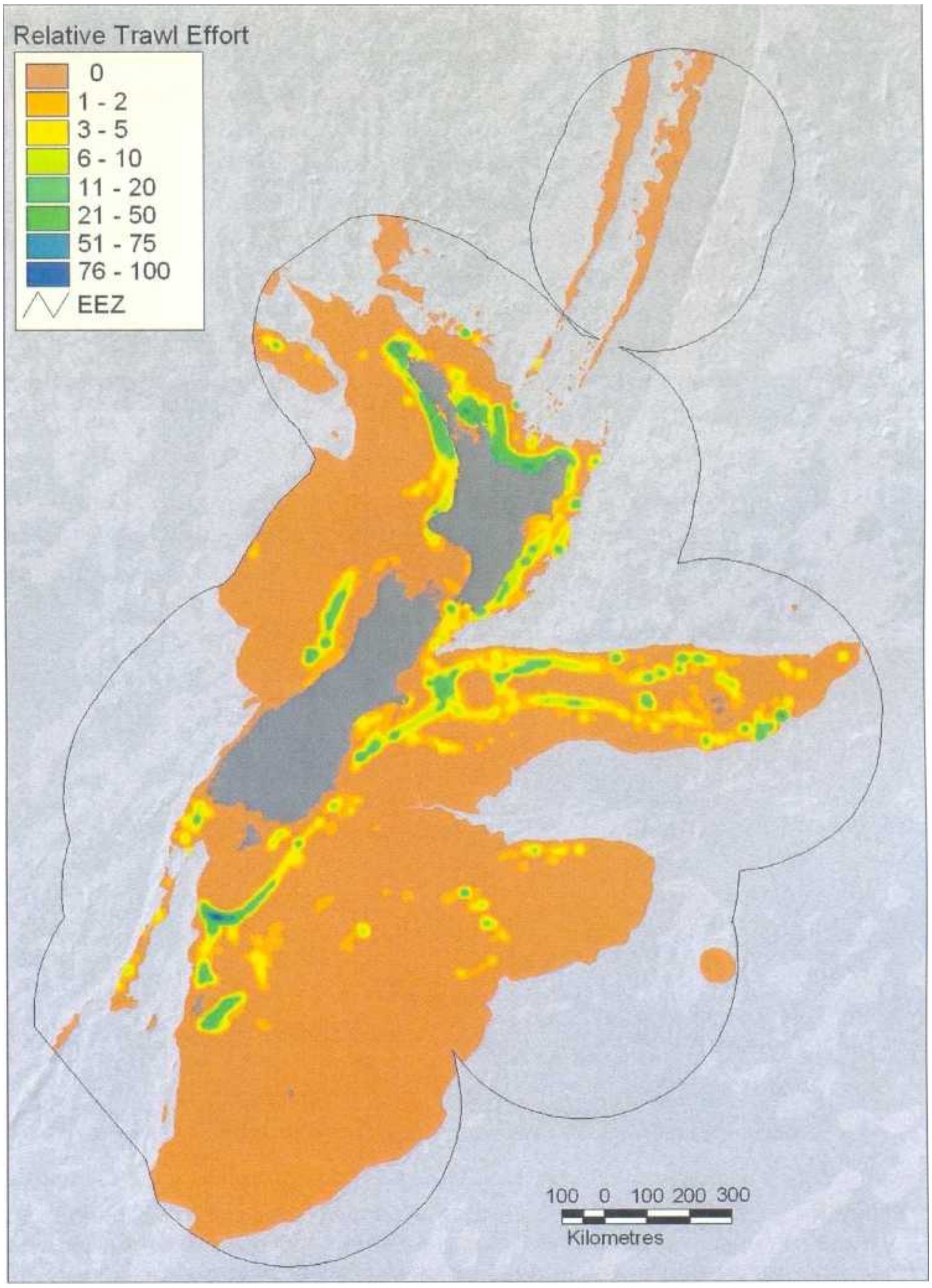

Figure 2: Spatial variation in commercial trawl effort across those parts of New Zealand's Exclusive Economic Zone with depths of less than 1950 m. See text for details.

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 resealed into a 0-100 range to produce a grid of relative trawl effort for use as a cost layer.

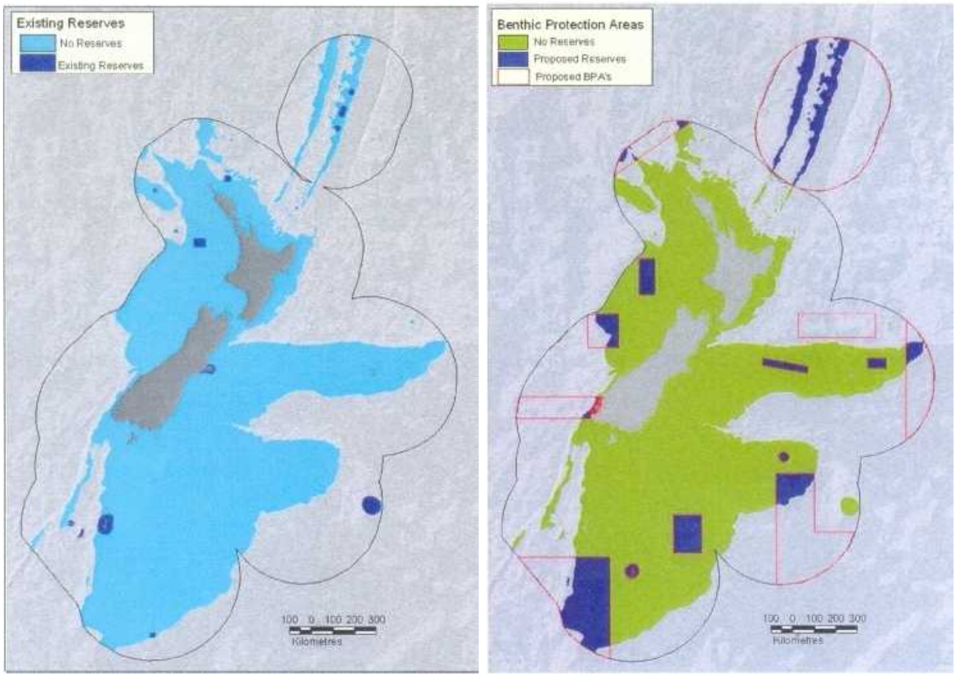

Figure 3: Existing and proposed reserve layers used in this analysis. a) Existing marine reserves, marine parks and seamount closures (most coastal marine parks and reserves are too small to be visible at this scale); b) Benthic Protection Areas proposed by the fishing industry. Note that only 27.7% 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.

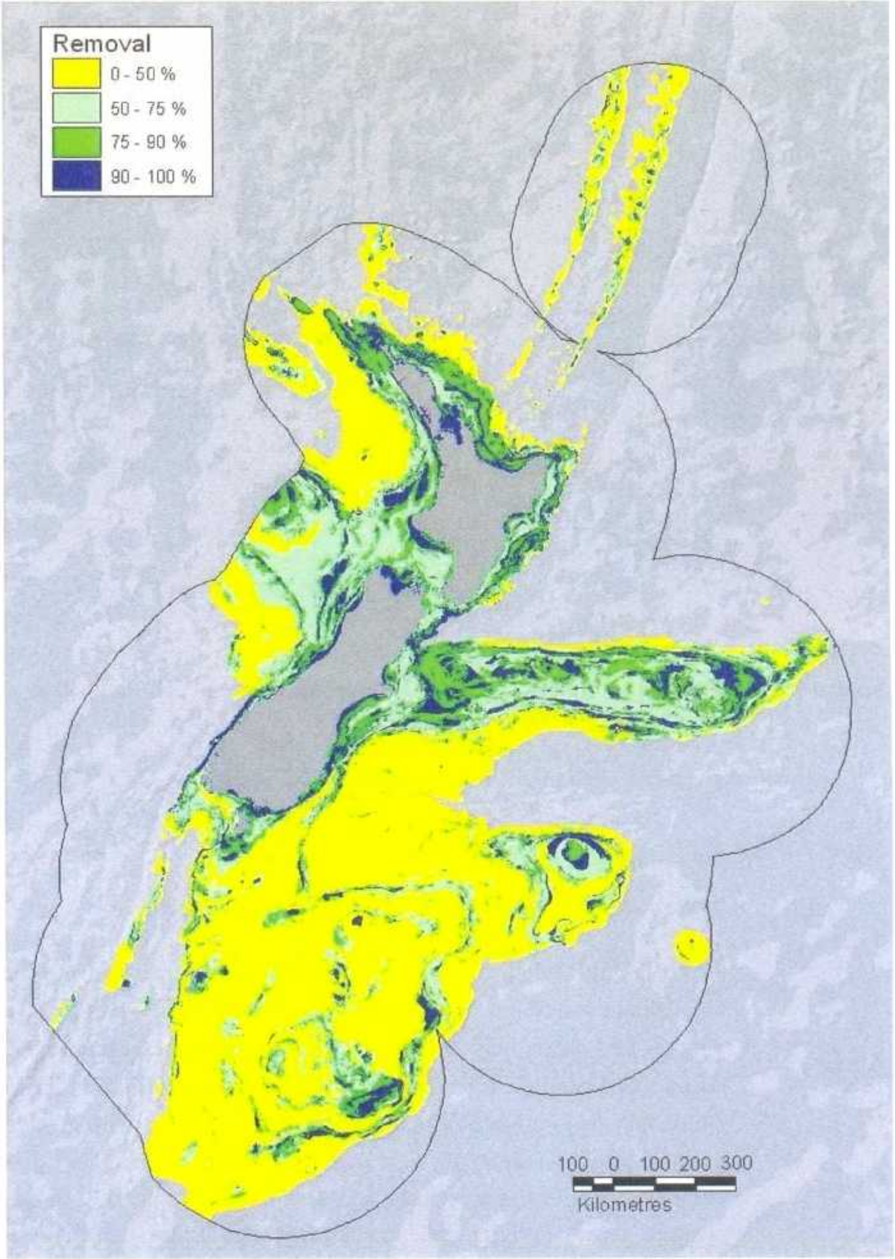

Figure 4: Relative conservation ranking of 1 km grid cells as calculated from the basic analysis. Rankings are shown for all cells occurring within New Zealand's Exclusive Economic Zone and having average depths less than 1950 m. Values indicate relative conservation value, so that, for example, cells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

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