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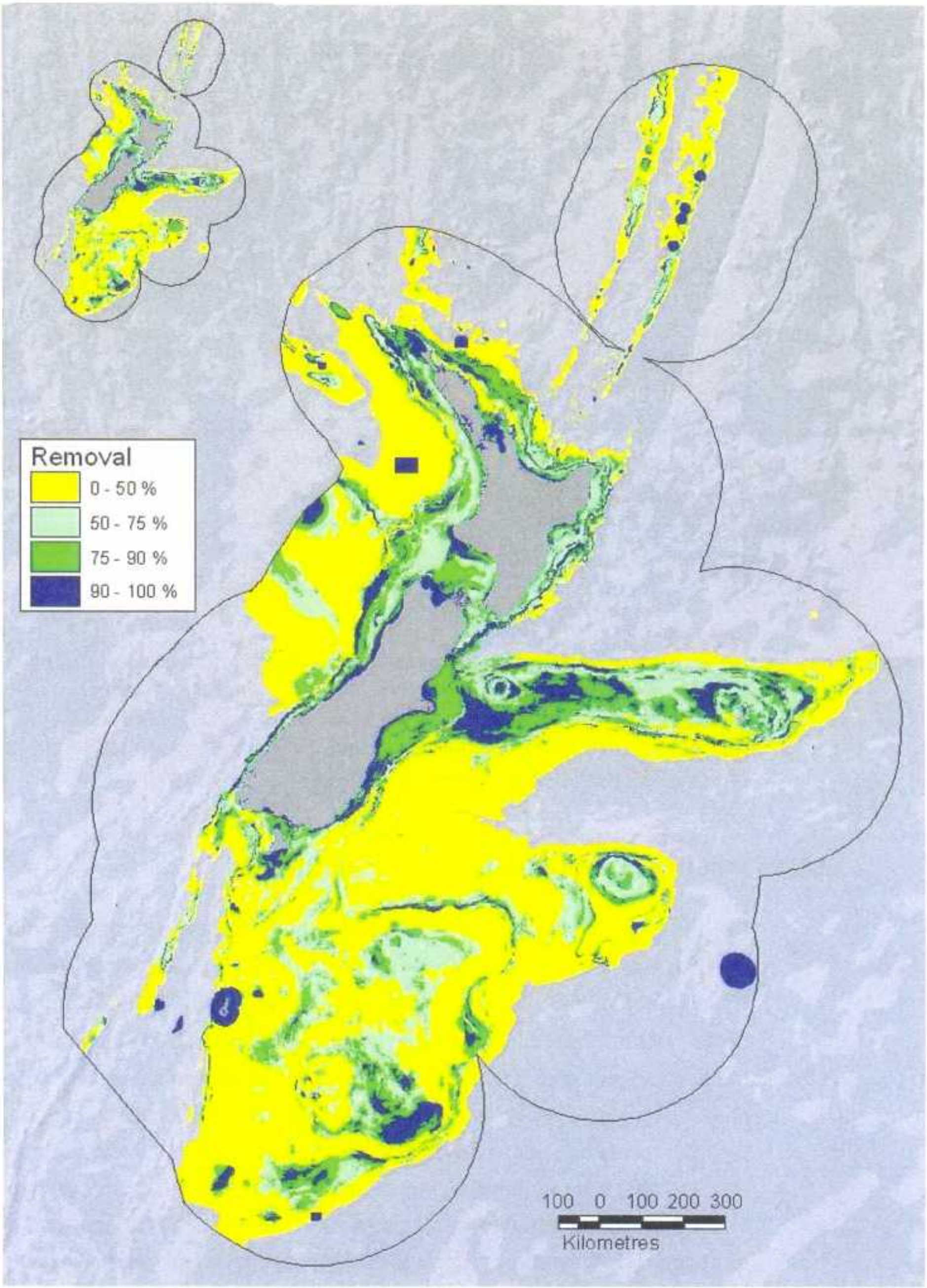

Figure 13: Relative conservation ranking of 1 km grid cells as calculated from an analysis using differential weighting of species, and in which cells located within existing reserves were retained until all non-reserve cells had been removed. Results from the weighted analysis are inset for comparison.

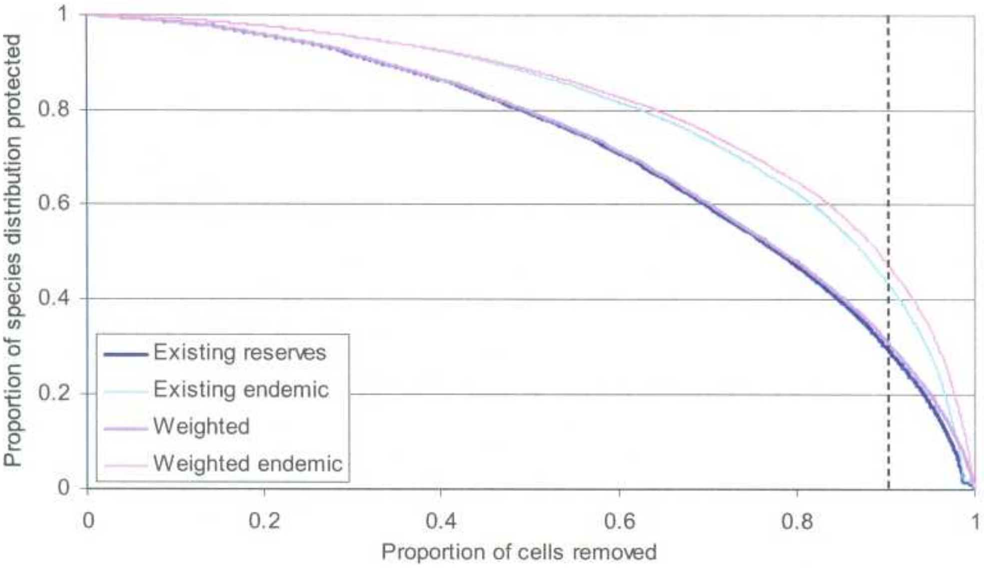

Figure 14: Comparison of the relationship between conservation protection and cell removal as calculated from the weighted analysis and an analysis in which cells located within existing reserves were retained until all other cells had been removed. Results are shown averaged both for all species, and 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.

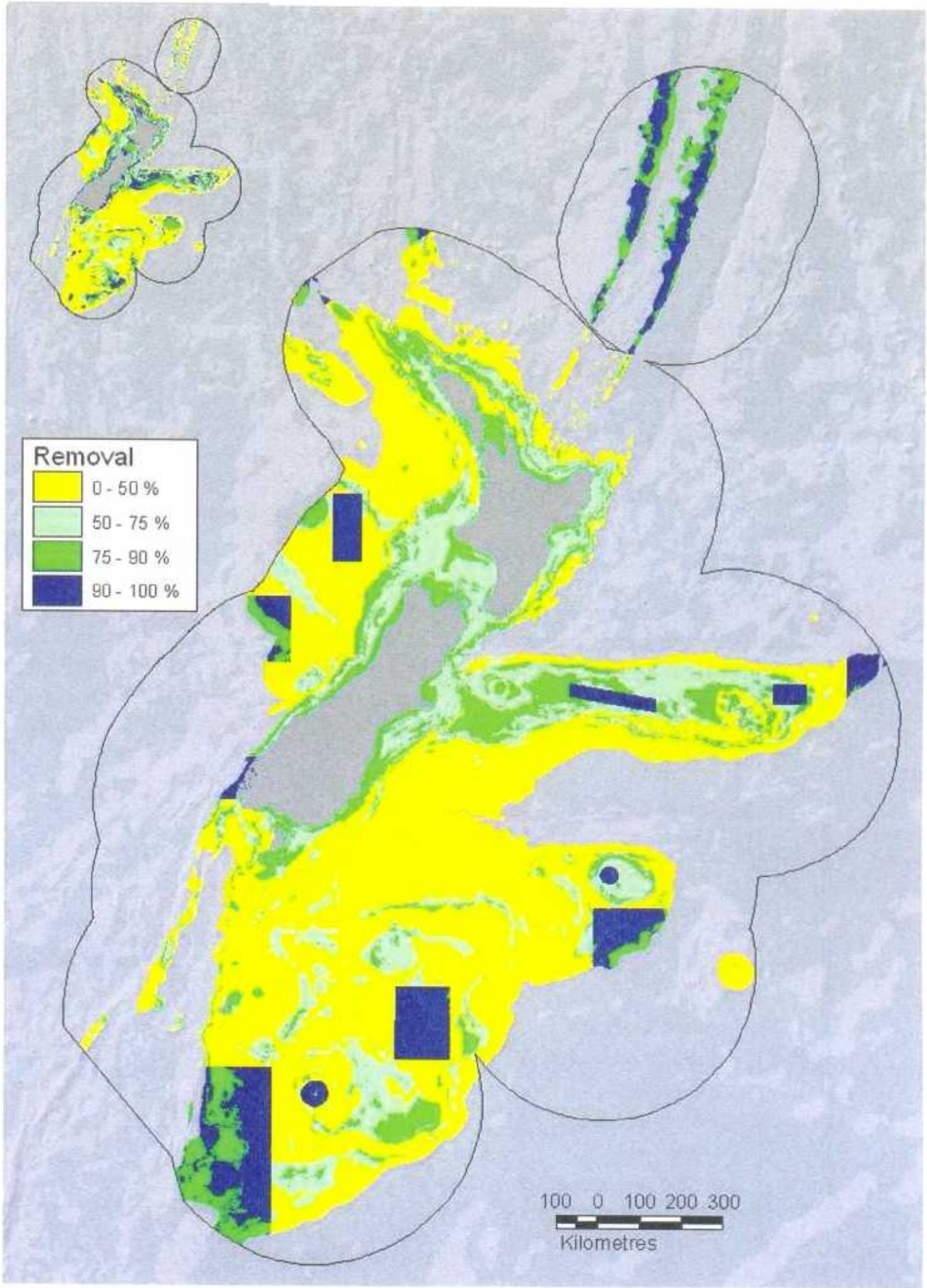

Figure 15: Relative conservation ranking of 1 km grid cells as calculated from an analysis using differential weighting of species, and in which cells located within the proposed Benthic Protection Areas were retained until all cells outside these proposed reserves had been removed. Results from the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

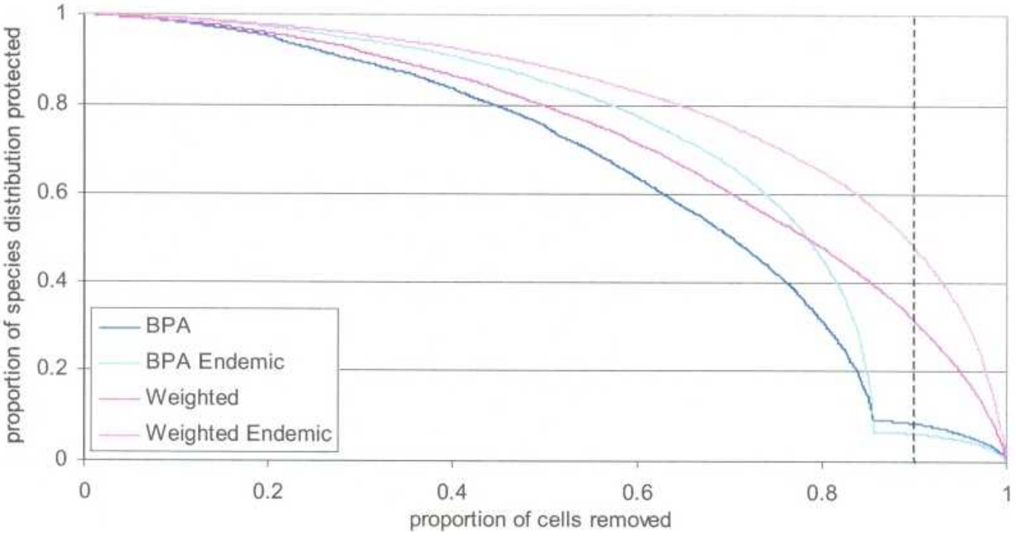

Figure 16: Comparison of the relationship between conservation protection and cell removal as calculated from the weighted analysis and an analysis in which cells located within Benthic Protection Areas proposed by the fishing industry were retained until all other cells had been removed. Results are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

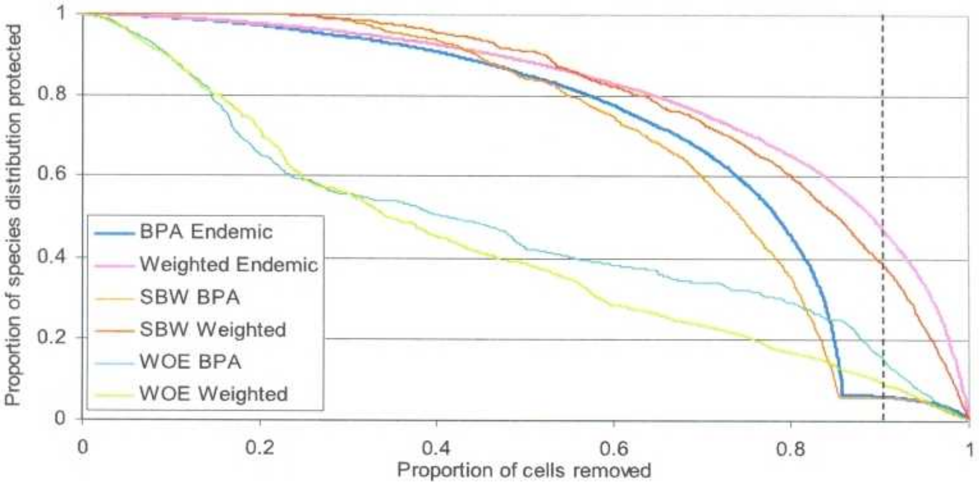

Figure 17: Comparison of the relationship between conservation protection and cell removal for two species, southern blue- whiting (SBW) and warty oreo (WOE) as calculated from the weighted analysis and an analysis in which cells located within Benthic Protection Areas were retained until all other cells 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

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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
CHID	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 brema*	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
THE	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	*Amoglossus 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