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Title Marine Protected Area planning by New Zealand and the United States in the Ross Sea region

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ABSTRACT

Since 2005, CCAMLR has progressed plans to implement Marine Protected Areas (MPAs) to achieve the aims of Article 2 of the Convention. CCAMLR has agreed a list of milestones for establishing a system of MPA in the Convention Area by 2012 (SC-CAMLR XXVIII, 3.28) and has encouraged Members to design and propose MPA scenarios on a regional basis. The 2011 CCAMLR MPA Workshop is intended to facilitate this process by reviewing MPA scenarios prepared and submitted by Members and providing a forum for discussing appropriate methods by which further MPA planning should proceed. This paper describes MPA planning processes undertaken by New Zealand and the United States, working in parallel and in collaboration with each other, to design MPA scenarios in the Ross Sea region. The paper presents separate MPA scenarios by New Zealand and by the United States consistent with their own planning processes and conservation objectives. It is the intention of both Members that these scenarios, following review by the MPA workshop and discussions with other Members, be used to inform the development of one or more formal MPA proposals for the Ross Sea region. The paper also presents a detailed description of tools and methods by which MPA planning was conducted by New Zealand and by the United States, to guide similar efforts by other CCAMLR Members.

SUMMARY OF FINDINGS AS RELATED TO NOMINATED AGENDA ITEMS

2 Describes MPA planning processes utilising both bioregionalisation and systematic conservation planning.

3 Presents draft MPA scenarios from New Zealand and from the United States, for review by the CCAMLR MPA workshop.

Marine Protected Area planning by New Zealand and the United States in the Ross Sea region

Sharp, B.R.[1], and Watters, G.M.[2]

Introduction

Since 2005, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) has progressed plans to implement Marine Protected Areas (MPAs). The 2005 CCAMLR MPA workshop stated clearly the purposes for which MPAs may be designated in the CCAMLR area to achieve the aims of Article II (SC-CAMLR XXIV, paragraph 3.54-3.55). In 2008 CCAMLR identified eleven areas within which MPA designation should be considered as a matter of high priority (SC-CAMLR XXVII, Figure 12), and encouraged Members to progress MPA planning at regional scales using fine-scale bioregionalisation and 'systematic conservation planning' (SC-CAMLR XXVII, paragraph 3.55).

CCAMLR endorsement of bioregionalisation and of the systematic conservation planning (SCP) approach implies a 2-phase process by which Members can proceed with MPA planning on a regional basis. Phase 1 involves assembling spatial biological and environmental information and summarising those data to most effectively approximate the ecological patterns deemed most relevant for the design of marine protection (e.g.,bioregionalisation, see Grant et al. 2006) and to identify areas of particular priority for inclusion in a network of MPAs. In Phase 2 the outputs of Phase 1 are analysed alongside additional data indicative of human activities and other management interests (e.g., fisheries) to identify spatial management solutions (i.e., MPA scenarios) that balance competing interests to achieve multiple conservation and management goals simultaneously (Margules & Pressey 2000). This 2-phase approach was successfully utilised in the South African Prince Edward Island MPA network design process (Lombard et al. 2007) and in the first high-seas MPA designation in the CCAMLR Area near the South Orkney Islands (SC-CCAMLR-XXVIII, paragraphs 3.16-3.19).

In 2009 CCAMLR agreed a list of milestones for establishing MPAs in the Convention Area (SC-CAMLR XXVIII, 3.28), encouraging completion of Phase 1 on a regional basis by 2010 and of Phase 2 during 2011, for presentation to the 2011 CCAMLR MPA Workshop. The terms of reference for the workshop (SC-CAMLR XXIX, 5.22) include

> *(ii) To share experience on different approaches for the selection of candidate marine sites for protection, including consideration...' and*
>
> *(iii) To review draft proposals for MPAs in the CAMLR Convention area, submitted for this purpose, such that Members developing proposals can incorporate feedback from the workshop and revise their proposals accordingly in advance of SC-CAMLR in 2011.*

This paper addresses the second term of reference (ii) by detailing the approaches taken by New Zealand and the United States to develop draft MPA scenarios for the Ross Sea region (RSR). By submitting these scenarios for review by the CCAMLR MPA Workshop, we are also addressing the third term of reference (iii). For the purposes of this work, the RSR is defined as the region south of 60°S and between 150°E and 150°W (or the combined areas of Subarea 88.1, SSRU 88.2A, and SSRU 88.2B).

New Zealand and the United States have been active contributors to the CCAMLR MPA planning process, and have declared their respective interests in progressing spatial marine protection in the Ross Sea region, which includes two of eleven areas identified by CCAMLR as priority areas for consideration in the development of a system of MPAs throughout the Southern Ocean. In 2009 New Zealand hosted a Ross Sea Region Bioregionalisation and Spatial Ecosystem Processes international expert workshop tasked with characterising environmental patterns and ecosystem processes in the RSR to inform MPA planning. In 2010 New Zealand presented the outputs of that workshop and subsequent analyses (Sharp et al. 2010), including separate benthic and pelagic bioregionalisations and 27 ecosystem process areas (used subsequently to define 'target areas', see below) of particular priority for protection within a system of MPAs (see SC-CAMLR XXIX, Annex 6, paragraphs 3.90-3.99). During the same period the International Marine Conservation Congress (IMCC) hosted an international Ross Sea workshop in the United States attended by scientists reporting on decades of research and monitoring in the RSR.A tremendous amount of spatial data and analyses were compiled in the report of the IMCC (IMCC 2009) and presented to CCAMLR (Ainley et al. 2010) with accompanying spatial modelling analyses (Ballard et al. 2010), also to inform MPA planning. WG-EMM agreed that a synthesis of the work included in Sharp et al. (2010), Ainley et al. (2010), and Ballard et al. (2010) 'would be expected to support the development of a comprehensive and effective spatial management plan to achieve CCAMLR objectives' (SC-CAMLR XXIX, annex 6, paragraph 3.85) and encouraged New Zealand and the United States to collaborate to the extent possible in the use of these outputs to inform MPA design (SC-CAMLR XXIX/Annex 6, paragraph 3.85).

The advice of WG-EMM indicates that collectively the outputs of Sharp et al. (2010) and Ainley et al. (2010)are adequate to support Phase 1 of the MPA planning process for the Ross Sea region, and that further spatial planning in Phase 2 should be undertaken collaboratively utilising outputs from both Member countries. Consistent with this advice, New Zealand and the United States have collaborated during the intersessional period while also engaging in parallel domestic consultation and MPA planning processes. Bilateral collaboration during the intersessional period has included:

- sharing available data and outputs from Sharp et al. (2010) and Ainley et al. (2010);
- discussing high-level conservation objectives to guide MPA planning in the Ross Sea region (consistent with SC-CAMLR XXIV paragraph 3.54);
- facilitating iterative scientific peer review of Phase 1 outputs, including 'target areas' of particular priority for protection, to correct errors or omissions prior to their utilisation in Phase 2; and
- iteratively reviewing draft MPA scenarios arising from internal planning processes by both Members while seeking changes or compromises to achieve to the greatest extent possible a single harmonised MPA scenario

This paper describes Phase 2 of the RSR MPA planning processes undertaken by New Zealand and by the United States, including domestic consultation and bilateral discussions. Outcomes from these processes include a New Zealand draft MPA scenario for the Ross Sea region, a U.S. draft MPA scenario for the Ross Sea region, and descriptions of the methods and tools by which each was produced, to potentially guide similar spatial planning efforts in other areas. The extent to which these two scenarios converged as a consequence of bilateral discussions, and the main remaining differences between them, are described in the Discussion section of this joint paper.

A New Zealand Ross Sea region MPA scenario

New Zealand supports the establishment of a system of marine protected areas (MPAs) in the Ross Sea region (RSR) and has actively contributed to marine science, analyses, and method development to support spatial management planning to meet this aim. The following section of this joint paper describes the New Zealand Ross Sea region MPA planning process undertaken to generate a draft MPA scenario for consideration by the CCAMLR MPA Workshop in Brest, France in September 2010.

The New Zealand scenario resulting from this process to date is shown in Figure 1. Consistent with the terms of reference for the CCAMLR MPA workshop (SC-CAMLR XXIX, paragraph 5.22 (iii)), this scenario is submitted as a draft, to be revised in accordance with advice arising from review by the workshop and in discussions with other CCAMLR Members.

The inputs, methods and tools by which the New Zealand scenario was developed are described below, with supplemental information in Annexes A-B. Description of the Systematic Conservation Planning method utilised by New Zealand is intended to contribute to workshop discussions of different approaches to the selection of candidate areas for protection (SC-CAMLR XXIX paragraph 5.22(ii).

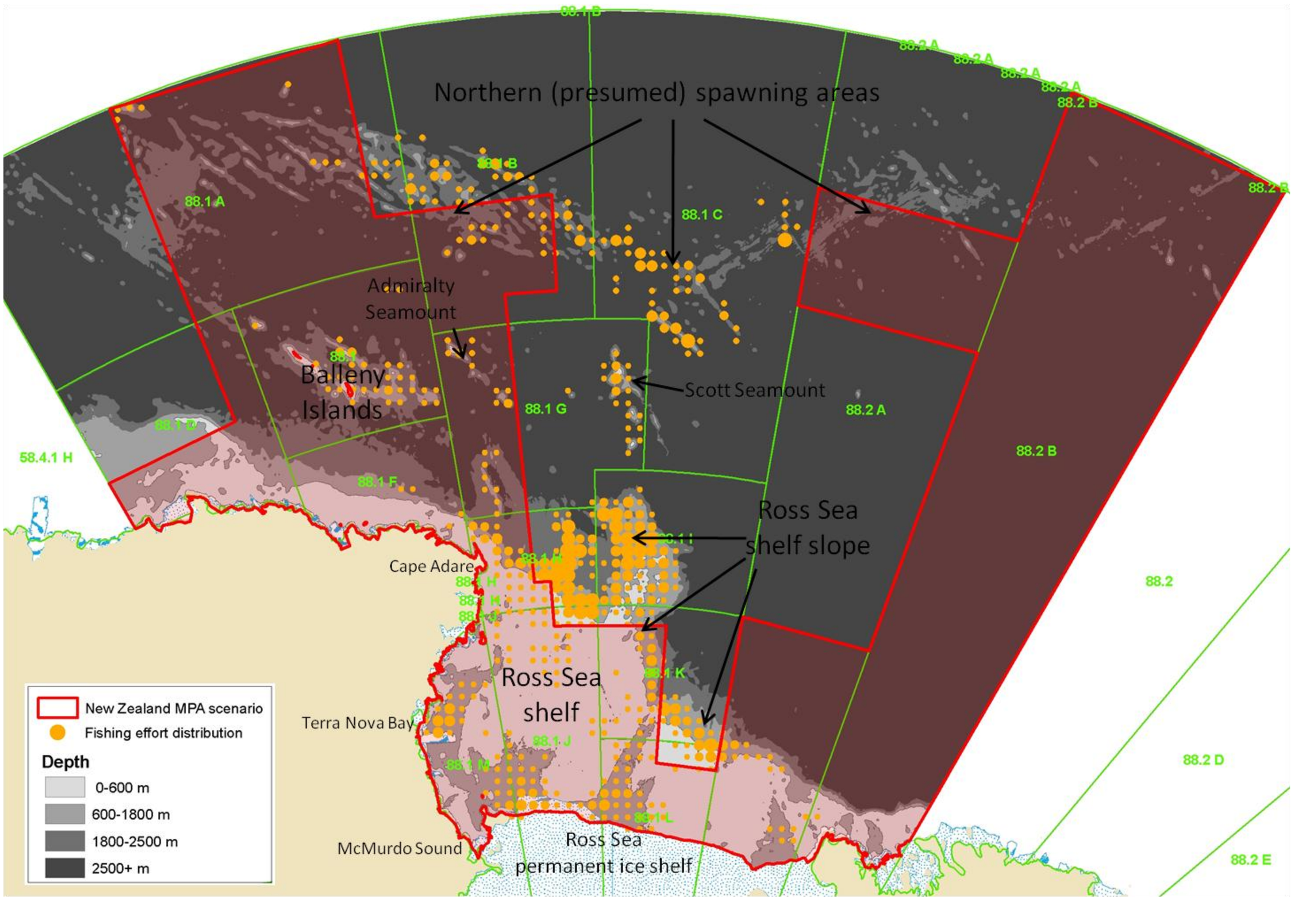

Figure 1: The New Zealand Ross Sea region MPA scenario. Areas for inclusion within a system of MPAs are shown in red. Note that protection also extends under the permanent ice on the Ross Sea shelf. SSRU boundaries are shown in green. The historical distribution of fishing effort (1998-2010) in the Subarea 88.1 and 88.2A-B toothfish fishery is also shown.

Methods (New Zealand)

Systematic Conservation Planning

Systematic conservation planning (SCP) is a transparent, objectives-driven spatial planning framework designed to identify optimal spatial management solutions to complex multi-stakeholder and multi-jurisdictional conservation planning problems (Margules and Pressey 2000). SCP is ideally suited to the needs of the CAMLR convention, which defines conservation as a balance between protection and rational use (harvest) of Antarctic marine living resources. SCP seeks wherever possible to identify 'win-win' solutions that meet protection objectives with minimal cost to rational use, and to identify those locations where protection and rational use objectives are potentially in conflict, such that trade-offs between competing management objectives become necessary. In the past decade a rich body of literature has developed to guide conservation practitioners seeking transparent and rigorous methods for the design of spatial management regimes (e.g. Knight et al. 2006; Groves et al. 2002; Tear et al. 2005, The Nature Conservancy and World Wildlife Fund 2006) from which there emerges a clear consensus regarding the common principles shared by successful applications of the SCP process. SCP practitioners emphasize the importance: i) of clearly stating conservation objectives not only as high-level principles but with explicit reference to particular areas or features, and performance metrics against which achievement will be assessed; ii) of maintaining a clear separation between the appropriate roles of science and of policy in the SCP process; iii) of actively engaging stakeholders throughout the SCP process; and iv) of establishing a rigorous process by which SCP practitioners bring science, management, and stakeholder considerations together to identify optimal spatial solutions, often assisted by the use of geographic information systems (GIS) and/or decision support tools (e.g. MARXAN, Ball and Possingham 2000).

In recent years the SCP framework has been increasingly applied to spatial planning in the marine environment (Ehler and Douvere 2009; Norse 2005; Young et al. 2007; Crowder and Norse 2008) such that the existence of successful case studies (e.g. see 27 examples reviewed in Leslie 2005) and the emergence of clearly articulated 'best practice' guidelines for marine spatial planning (Beck et al. 2003; Beck 2003) provide valuable guidance to managers undertaking to design systems of MPAs, with potential application for the CCAMLR MPA process.

New Zealand officials sought throughout the Ross Sea region MPA planning process to achieve consistency with the recommendations of this body of literature, in particular with reference to best practice guidelines regarding the definition of target areas and protection targets (see Beck et al. 2003; Beck 2003; The Nature Conservancy 2009). New Zealand also maintained a procedural separation between its science process (Phase 1) and its planning process (Phase 2).

Use of Data and inputs from Phase 1 process

Within the SCP framework utilised by New Zealand, the Phase 2 MPA scenario planning process utilises scientific outputs from Phase 1, i.e. bioregionalisation and delineation of priority 'target areas' for protection. In this paper we draw freely from the data assembled in Ainley et al. (2010) and the methods and integrative analyses described in Sharp et al. (2010); these are referenced but not repeated in this paper except where changes have been made.

The outputs of Sharp et al. (2010) included a benthic and a pelagic bioregionalisation, both of which were utilised without adjustment in Phase 2; these maps are not reproduced here. The outputs of Sharp et al. (2010) also included 27 target areas of particular priority for protection, many of which have been adjusted in the intervening year. The updated target areas appear in this paper in Figures 2a-2f, but the particular choice of boundaries and the underlying data from which those boundaries were derived are as in Sharp et al. (2010) and are not repeated except where adjustments have been made.

Because the spatial delineation of target areas in Phase 1 strongly determines the outcome of Phase 2 (MPA scenario boundaries), and in recognition of the inherent difficulty of characterising complex, continuous, and dynamic ecological processes using discrete and static spatial data layers, great care was taken in defining target areas and making subsequent adjustments. Phase 1 is by nature an ongoing process as scientific understanding improves. However because Phase 1 is fundamentally a science process but Phase 2 is an integrated science/policy process, it was seen as important to maintain a separation between the two processes (e.g. Knight et al. 2006, Tear et al. 2005), to prevent science outputs from being manipulated to influence policy outcomes. Consequently in the course of the New Zealand RSR MPA planning process when potential errors or omissions were discovered with the Phase 1 outputs (i.e. target areas), suggestions for improvements were noted, but actual changes were only considered and approved under review by scientific experts divorced from the Phase 2 process, to ensure transparency and scientific integrity. Recommendations for adjustments to Phase 1 outputs were provided by the New Zealand Antarctic Working Group and by a panel of USA Antarctic scientists (see below), including the primary authors of Ainley et al. (2010). Resulting changes to Phase 1 outputs are described in Annex A

Terminology

Terminology is not always consistently applied in SCP literature. For clarity, consistent with the advice of SC-CAMLR XXIX, (paragraphs 5.15-5.16), we define our use of the following terms.

- *'Protection objective'* refers to a high-level statement of what kinds of areas we seek to protect within MPAs, to contribute to achieving the aims of Article II. Each protection objective will have a number of associated *target areas.* Note that *protection objective* refers to the objective *of the MPAs themselves,* and include primarily the protection of biodiversity and ecosystem processes, or the utility of MPAs for science, consistent with SC-CAMLR XXIV (paragraphs 3.54-3.55). The effects of MPA designation on other management objectives with which they may be in conflict, e.g. rational use, are represented as *costs* (below) against which protection objectives must be balanced.

- *'Target area'* refers to a spatially explicit area containing ecosystem processes or features worthy of protection within a system of MPAs, to achieve a *protection objective*. Every *target area* has a numerical *protection target* assigned.

- *'Protection target'* refers to a numerical proportion (0-100%) of the target area that we seek to include within the system of MPAs, reflecting the level of priority associated with that objective and the scale/precision at which the *target area* is drawn (i.e. with higher targets for smaller, well-defined areas).

- *'Cost'* refers to a spatially explicit representation of how MPA designation may negatively affect achievement of other management objectives (e.g. rational use). With respect to effects on fishery outcomes, *cost* is most easily represented as fishing *effort displacement* (e.g. with reference to historical fishing effort distribution) or foregone fishable resources (e.g with reference to a modelled fish distribution).

- *'Constraints'* refers to other management objectives or considerations that may impose limits on options for MPA designation, e.g. for ease of management or compliance purposes.

MPA Planning process

Within the SCP framework and consistent with the terminology above, the New Zealand RSR MPA planning process can be summarized by the following steps:

1. Define *protection objectives* for MPAs that will contribute to achievement of our overall management aims. Within CCAMLR the overall aims are defined in Article II; guidance for

the definition of corresponding protection objectives is provided in SC-CAMLR XXIV (paragraphs 3.54-3.55).

2. For each protection objective, identify *target areas,* the protection of which will contribute to achievement of the objective. Spatially explicit data layers representing these areas are the primary outputs of Phase 1, to be used as inputs to Phase 2 of the planning process.

3. For each target area, assign a numerical *protection target* reflecting the desired level of protection for that area.

4. Define spatially explicit representations of the *cost* of MPA designation to competing objectives such as rational use (e.g. fishing effort displacement).

5. Define additional *constraints* (if any) on MPA scenario design.

6. Develop and evaluate MPA scenarios that meet *protection targets* for each identified *target area* to the extent possible while minimising *cost,* and mindful of other *constraints*. Optimisation may be possible by iterative adjustment and evaluation against agreed performance metrics related to protection targets and cost, or by the use of a decision support tool such as MARXAN or Zonation.

7. Develop an associated management plan, research and monitoring plan, and legal framework for a proposal to implement the MPA scenario designed in Phase 2. This is a subsequent phase of work that is not described in this paper.

Step 1: Protection objectives

Following the 2005 CCAMLR MPA workshop (SC-CAMLR XXIV, Annex 7), the Scientific Committee provided advice to guide the designation of MPAs (SC-CAMLR XXIV, paragraph 3.54-3.55). Consistent with this advice, New Zealand identified eight high-level protection objectives to guide the design of an MPA scenario in the Ross Sea region. Protection objectives were defined as follows.

- *Objective 1: Protect a representative portion of benthic marine environments* [corresponds to 3.54 (iv)(a)] Representativeness targets were assigned with reference to each of the benthic bioregions in Figure 1 of Sharp et al. (2010).

- *Objective 2: Protect a representative portion of pelagic marine environments.* [corresponds to 3.54 (iv)(a)] Representativeness targets were assigned with reference to each of the pelagic bioregions in Figure 2 of Sharp et al. (2010).

- *Objective 3: Protect large-scale ecosystem processes responsible for the productivity and functional integrity of the Ross sea region ecosystem* [corresponds to 3.54 (i),(iii) and 3.55]. Enhanced ecosystem productivity and assimilation to higher trophic levels are influenced by ecosystem processes associated with bathymetric and/or oceanographic features (e.g. fronts, eddies and gyres) and dynamic ice behaviour. Five associated target areas were identified (Figure 2a).

- Objective 4: *Protect core distributions of trophically dominant pelagic prey species*. [corresponds to 3.54 (i)] Trophic ecosystem function in the Ross Sea region is dominated by two species of krill (*E. superba* and *E. crystallorophias*) and one species of notothenioid fish (*P. antarcticum*) which in turn support high populations of air-breathing top predators (cetaceans, pinnipeds, penguins, and flying seabirds). Three associated target areas were identified (Figure 2b).

- Objective 5: *Protect core foraging areas for top predators that are constrained to land based colonies, or that may experience direct trophic competition from fisheries*. [corresponds to 3.54 (i)] Top predators may be especially vulnerable to localized fishery effects during periods in which foraging is spatially constrained by the need to return to land-based colonies (i.e.. Adelie and emperor penguins, Weddell seals), or where the potential exists for direct competition with fisheries for available prey (i.e. Weddell seals, Type C killer whales with the existing toothfish fishery, Adelie and emperor penguins with a potential future krill fishery). Four associated target areas were identified (Figures 2c and 2d).

- *Objective 6: Protect areas of known importance in the life cycle of Antarctic toothfish.* [corresponds to 3.54 (i)]. Antarctic toothfish are an ecologically important species in the Ross Sea region and the target of a valuable fishery. Ongoing research into toothfish movements and demographic structure (Hanchet et al. 2008) has identified areas of particular importance in the life cycle migration of the Ross Sea region Antarctic toothfish stock. Four associated target areas were identified (Figure 2e).

- *Objective 7: Protect localized/coastal locations of particular ecological importance* [corresponds to 3.54 (i),(iii) and 3.55] Within localised areas of disproportionately high importance for the wider ecosystem (generally associated with polynya formation), correspondingly high protection targets are warranted. Five associated target areas were identified (Figure 2f).

- *Objective 8: Protect known rare or vulnerable benthic communities.* [corresponds to 3.54 (iv)(c)] Some benthic invertebrate communities may be vulnerable to damage by bottom fishing activities; others are of high conservation priority due to presumed rarity or known scientific significance. Five associated target areas were identified (Figure 2f).

Step 2: Target areas

In 2010 the Scientific Committee provided the following advice to guide bioregionalisation and identify areas of particular priority for protection (SC-CAMLR XXIX, paragraph 5.16)

(ii) *where biological and other spatial data are available, use appropriate datasets to locate areas containing ecosystem processes that may constitute conservation objectives in their own right and represent these areas as separate spatial overlays;*
(iii) *generate separate pelagic and benthic bioregionalisations;*
(iv) *for pelagic bioregionalisations, consider the selection of the following largescale environmental drivers: (a) depth, (b) water mass characteristics, and (c) dynamic ice behaviour.*

The bioregionalisations in Sharp et al. (2010) are consistent with the advice in (iii) and (iv). The identification of target areas is consistent with the advice in (ii) and in SC-CAMLR XXIX paragraph 5.33.

Target areas associated with each protection objective are listed in Table 1 and shown in Figures 2a – 2f. For the majority of these areas the spatial extent, selection rationale and use of spatial data underlying the delineation of area boundaries are as previously described in Sharp et al. (2010). Where areas have been added or modified subject to new scientific information and/or review; the changes are described in Annex A. For consistency, area numbers are retained as in Sharp et al. (2010).

All target areas were represented as spatial data layers in Arc GIS format to enable rapid comparison with available biological and fishery data at a range of scales and for use in a custom-designed MPA planning tool in ArcGIS (see below, and Annex B).

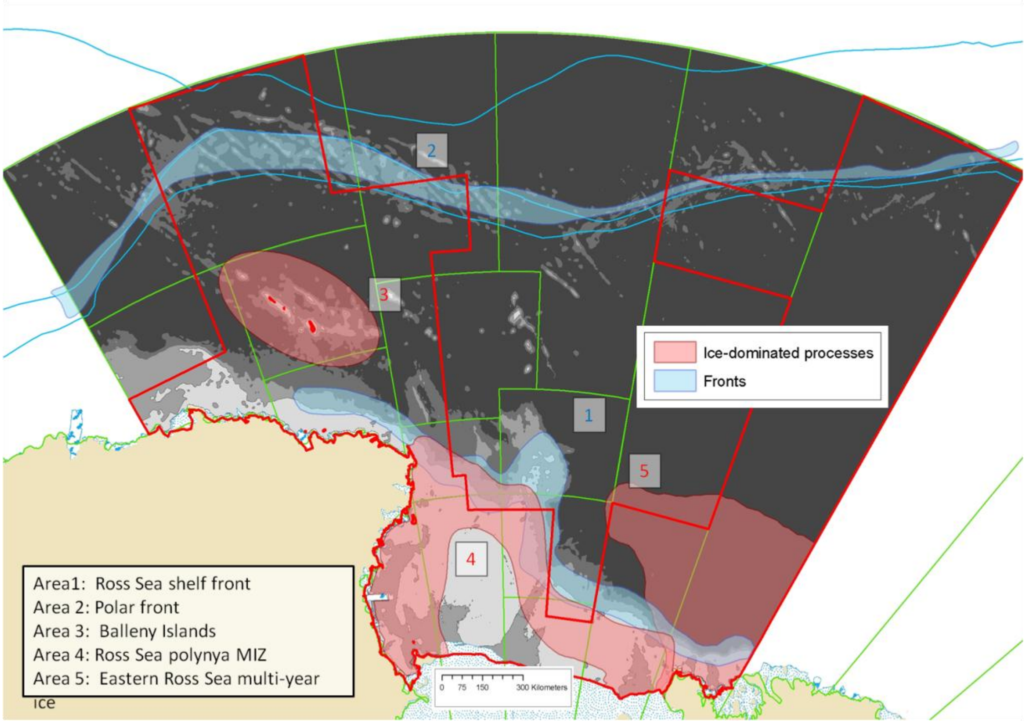

Figure 2a: Target areas for protection of large-scale ecosystem processes influencing productivity (Objective 3). Associated protection targets are high for Areas 4 and 5, reflecting their importance for shelf-associated top predator populations, and highest for the Balleny Islands and proximity (Area 3) reflecting its unique oceanographic and biological properties as well as high productivity.

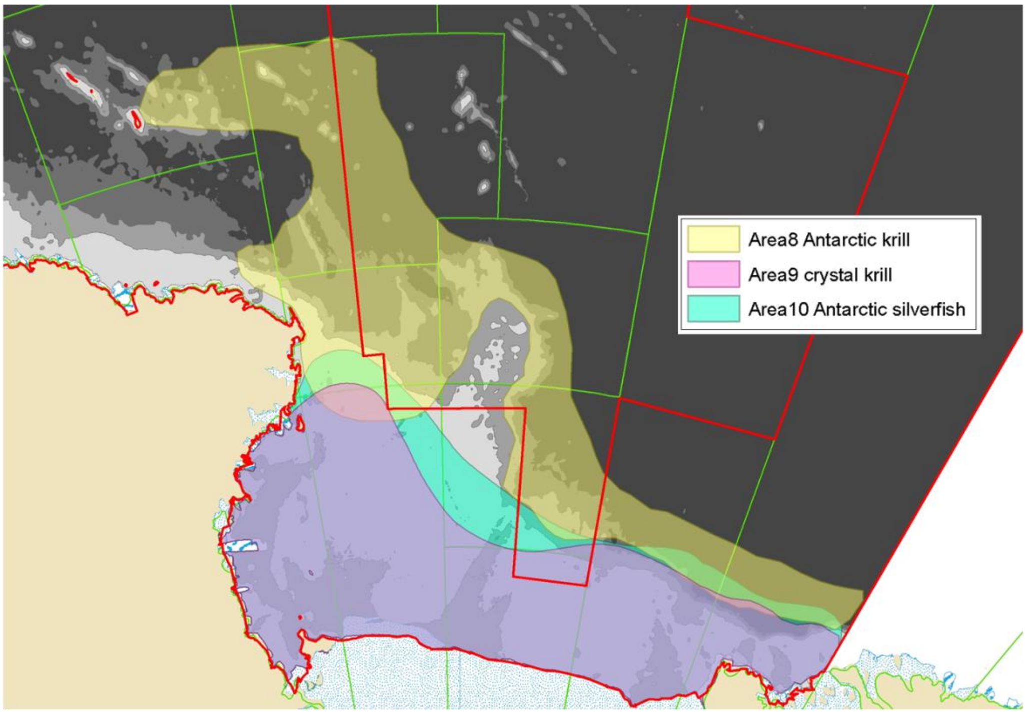

Figure 2b: Target areas for protection of trophically dominant pelagic prey species (Objective 4). Corresponding protection targets are higher for shelf-associated species than for Antarctic krill, to protect the relative functional intactness of the Ross Sea shelf ecosystem as characterised by high predator populations (Ainley et al. 2006) and possible top-down trophic ecosystem control (Ainley 2004).

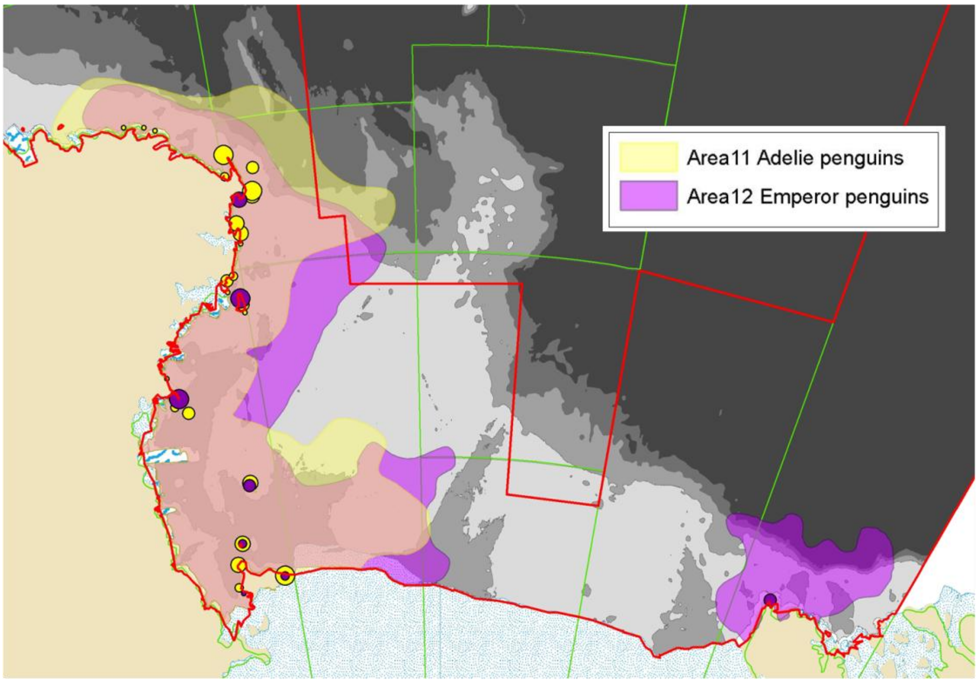

Figure 2c: Target areas for protection of spatially constrained top predator foraging distributions (Objective 5): Adelie and emperor penguins. Associated protection targets reflect the desire to prevent direct trophic competition with a potential future krill fishery, or other indirect ecosystem effects. Colony locations and relative population sizes are also shown.

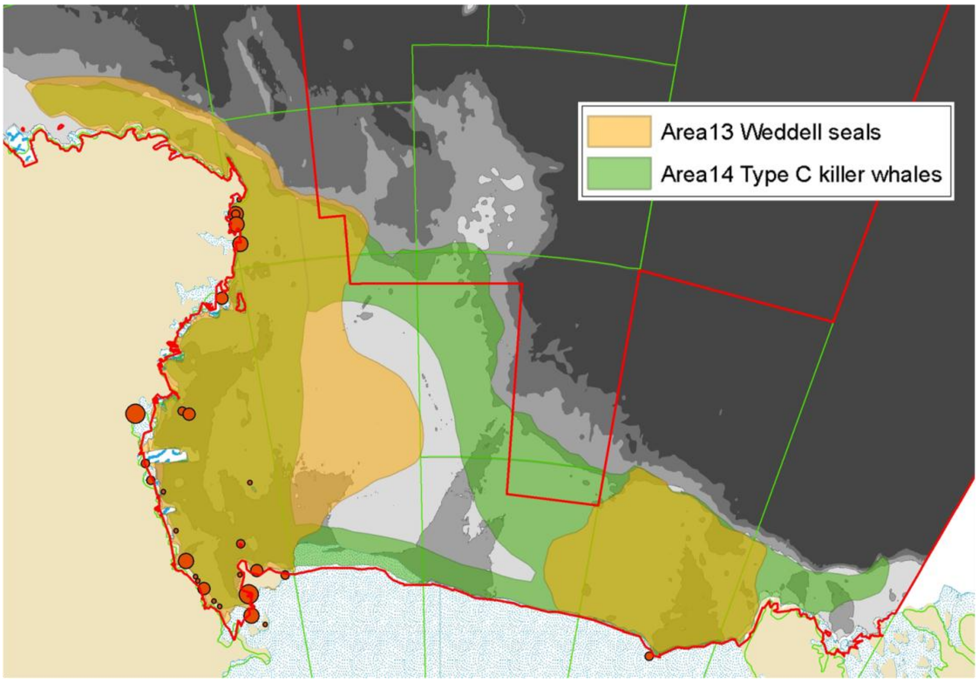

Figure 2d: Target areas for protection of spatially constrained top predator foraging distributions (Objective 5): Weddell seals and Type C killer whales. Corresponding protection targets are higher than for penguins, reflecting the (unknown) potential for direct trophic competition with the existing toothfish fishery and the clear utility of spatial management solutions to prevent fishery-predator interactions. Weddell seal colony locations and relative population sizes are also shown.

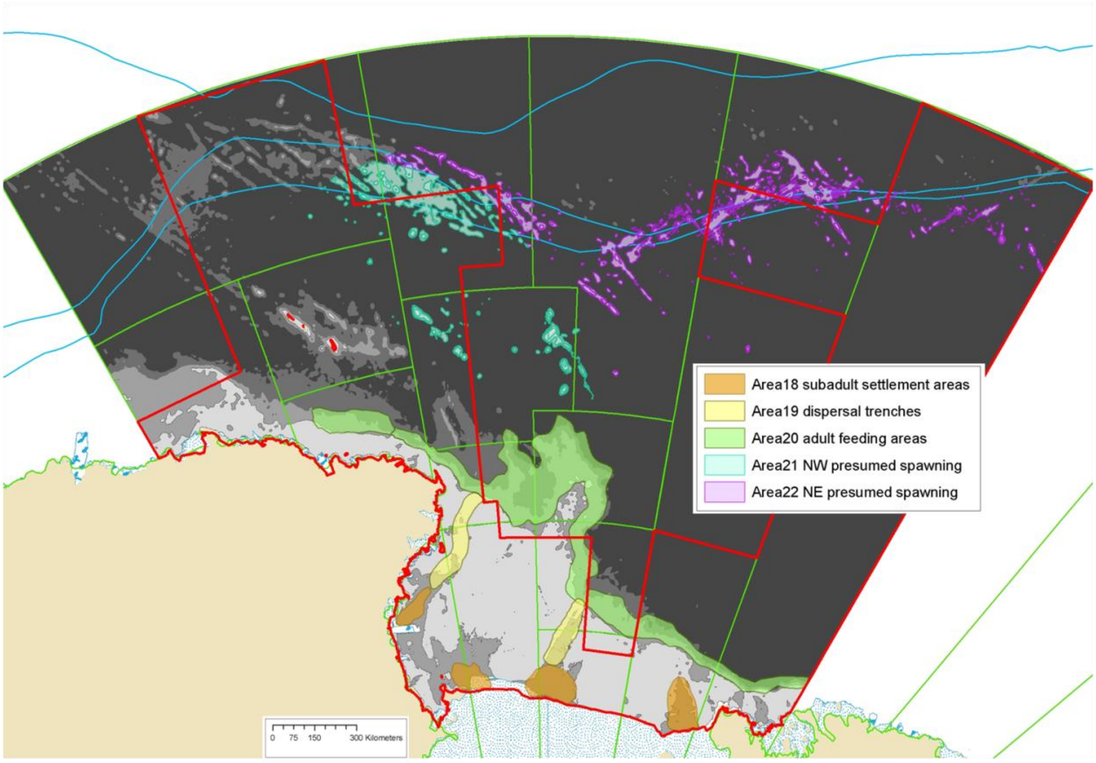

Figure 2e: Target areas for protection of *D. mawsoni* life cycle areas (Objective 6) from research described in Hanchet et al. (2008) and Hanchet et al. (2010). Protection targets are intended to displace fishing effort away from subadult and maturing toothfish in Areas 18-19 and into Areas 20-22 in which mature fish predominate, while still protecting a portion of the presumed spawning habitat in Areas 21-22.

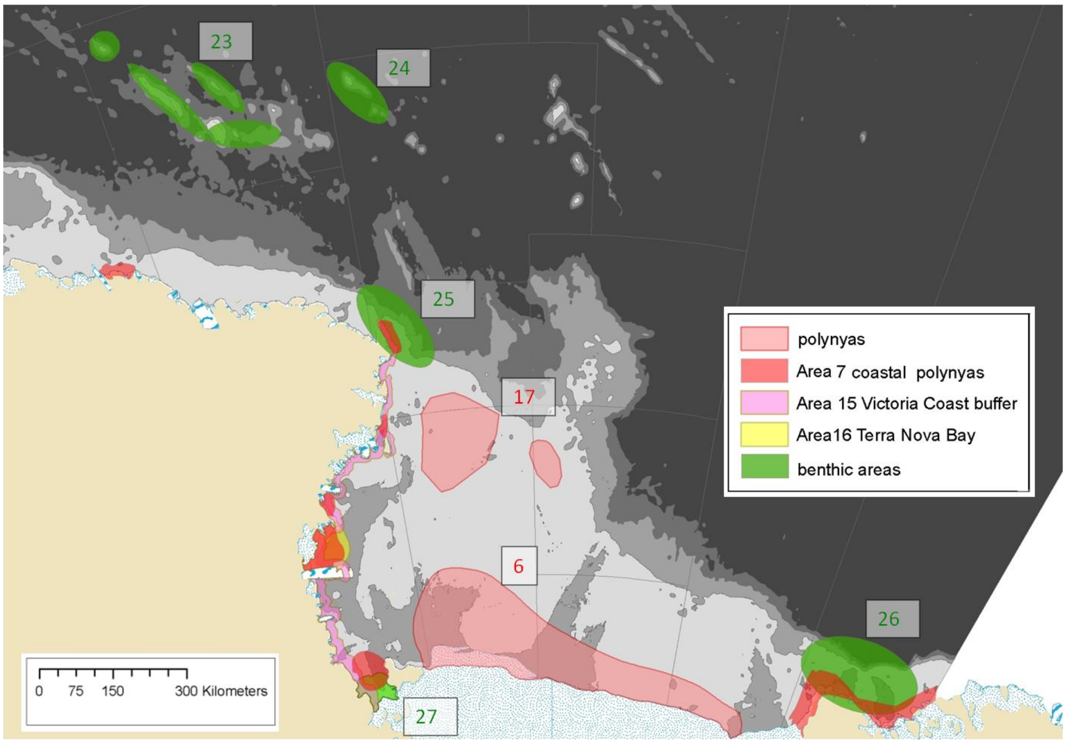

Figure 2f: Target areas for protection of small-scale/ localised ecosystem processes of particular importance (Objective 7) and rare or vulnerable benthic communities (Objective 8). Corresponding protection targets are very high, reflecting the known disproportionate ecosystem importance of processes occurring in these areas and also the high spatial precision with which the areas are delineated.

Step 3: Protection targets

Protection targets assigned to each target area indicate the percentage of that area that we seek to include within MPAs. Representativeness targets (i.e. protection targets assigned to each bioregion) and protection targets for the 27 target areas are shown in Table 1.

Protection targets were chosen to reflect the following considerations (as in SC-CAMLR XXIX/ Annex 6, paragraph 3.94):

- the relative ecological importance or role of the target area for the function of the wider Ross Sea regional ecosystem (i.e. a scientific assessment);

- the relative conservation priority assigned to species or processes occurring within the area (i.e. a values assessment); and

- the size or precision with which the area is defined (i.e. with higher targets possible for smaller, well-defined areas).

Assigning a range of protection targets for different target areas essentially acknowledges that not all areas are of equal importance in the ecosystem, or of equal value for conservation. There is a natural relationship between the size or precision with which a target area is defined and the corresponding appropriate protection target. E.g. doubling the size of a target area but reducing the corresponding protection target by half implies a commitment to protect the same amount of area, but provides greater flexibility as to which particular locations can be selected for protection to meet that commitment. Conversely, very high targets strongly constrain options for MPA scenarios, and are reserved for those target areas for which high ecological importance is scientifically demonstrable, and/or for small well-defined areas within which costs of protection are judged to be acceptable.

The following considerations informed the specific assignment of protection targets for areas associated with each objective.

- *Objectives 1-2: Representativeness:* The representativeness target sets a minimum level of protection that will be achieved for each bioregion in the absence of further location-specific indication of particular ecological value or conservation priority. Bioregionalisation is most applicable to data-poor settings (SC-CAMLR XXIX paragraph 5.33), and a commitment to 'representativeness' provides an effective mechanism to account for variable levels of available scientific information within the spatial planning domain. I.e. in regions where sufficient scientific information exists to define and locate target areas of particular priority for protection (SC-CAMLR XXIX paragraphs 5.22(ii)b and 5.28), these target areas will strongly drive MPA scenario outcomes, and the influence of the bioregionalisations will be generally weak (see UK 2009). In contrast, in data-poor regions MPA outcomes will be more strongly determined by representativeness alone, allowing correspondingly greater flexibility in the choice of areas to meet representativeness targets. Representativeness targets were set at 30%, consistent with emerging international best practice for marine ecoregional planning (Beck et al. 2003, The Nature Conservancy 2009) supported by species-area relationship considerations (Beck 2003; Tear et al. 2006).

- *Objective 3: Large-scale ecosystem processes/areas*: Frontal zones supporting higher productivity and actively targeted by top predators (Areas 1 and 2) warrant higher levels of protection (50%) than that assigned to representativeness alone. The Balleny Islands (Area 3; target = 100%) are the only islands at this latitude in this region, and generate a unique confluence of oceanographic conditions supporting high local productivity, focused top predator foraging (especially humpback whales) and unique for the region benthic, pelagic, and top predator assemblages (see New Zealand 2005 and references therein). The Ross Sea polynya MIZ (Area 4) is responsible for elevated productivity and trophic assimilation supporting extremely high top predator populations in the Ross Sea (Ainley et al. 2006), and Area 5 (eastern Ross Sea multi-year ice) provides essential post-breeding season habitats for some of those predators (targets = 75%).

- *Objective 4: Trophically dominant pelagic prey species:* Antarctic krill (Area 8) are a critical trophic link supporting pelagic food chains in areas not overlying the continental shelf, warranting elevated protection (50%). Crystal krill and especially silverfish (Areas 9-10, 75%) characterise the unique nature of the Ross Sea pelagic ecosystem distinct from *E. superba* dominated systems elsewhere in the CCAMLR Area (Pinkerton et al. 2010), and provide the crucial trophic link connecting extremely high productivity over the Ross Sea shelf with corresponding high top predator populations.

- *Objective 5: Spatially constrained top predator foraging distributions:* Marine spatial planning best practice guidelines (Beck et al. 2003, Beck 2003, The Nature Conservancy 2009) recommend that the definition of target areas for particular mobile species focus on life cycle stages in which they are likely to be most vulnerable; other distributions (i.e. outside of the vulnerable season, or for unconstrained species) are more appropriately approximated by mapping generic ecosystem processes driving productivity or trophic assimilation, affecting multiple species simultaneously (i.e. our target areas 1-10). Adelie and emperor penguins (Areas 11-12; target = 75%) occur in very high numbers in the Ross Sea and could conceivably be negatively affected by localised depletion of Antarctic krill near colonies on the Victoria Coast, should a Ross Sea krill fishery develop in future. Indirect trophic effects of the existing toothfish fishery (e.g. via trophic release of shared prey species such as silverfish) is unlikely, due to relatively low dietary overlap and (Pinkerton et al. 2010). In contrast, Weddell seals and Type C killer whales could conceivably encounter direct trophic competition from the toothfish fishery, warranting a higher protection target (90%) to prevent this interaction, although the actual importance of toothfish in the diet of these predators is unknown (e.g. Pinkerton et al. 2009).

- *Objective 6: D. mawsoni life cycle:* Because *D Mawsoni* is the target of the Ross Sea toothfish fishery the TAC for which is determined separately, assigning protection targets to areas indicative of different stages of the *D. mawsoni* life cycle provides a means of influencing fishery selectivity, i.e. controlling at what stage in their life cycle the fish will be vulnerable to capture. Scientists judged that displacing catch away from juvenile and pre-recruit fish (Areas 18-19; protection target = 100%) in favour of catching adult fish (Areas 20-22) may serve to minimise the risk of ecosystem effects of fishing as well as helping to deliver fishery outcomes and providing opportunities for science. At the same time it was thought that protecting some portion of the adult preferred feeding areas (Area 20) and the presumed spawning areas (Areas 21-22; target = 30%) may provide some benefit by helping to maintain the full range of size classes of larger fish, to counter potential genetic selectivity effects of the fishery on growth and maturity over time (e.g. Thompson 1998).

- *Objective 7: Coastal and localized ecosystem processes*: Polynyas (Areas 6, 7, 17) and coastal platelet ice formation (Area 16) are highly localized processes of known disproportionate ecosystem importance, warranting full protection where they occur (target =100%). Terra Nova Bay (Area 15, target = 100%) combines a range of ecosystem values including a known silverfish spawning area, and has a long history of science and ongoing environmental monitoring (see Italy 2010).

- *Objective 8: Rare or vulnerable benthic habitats*. Areas 23-27 (target = 100%) identify highly localized locations within which rare or vulnerable benthic communities have been observed directly or are thought to occur based on unique habitat characteristics. Some never-before-observed benthic communities on Admiralty seamount (Area 24) are of recognized global scientific significance (Bowden et al. 2011) prompting a recommendation by WG-EMM for inclusion in the VME (Vulnerable Marine Ecosystem) registry (WG-EMM-2011, paragraph 3.4).

Step 4: Cost to rational use (i.e. fishing effort displacement)

At Scientific Committee in 2010 it was noted that spatially explicit representations of the distribution of harvestable resources could be used in the design of a system of MPAs, to evaluate potential costs to rational use (SC-CAMLR XXIX, paragraph 5.34).

The only active fishery in the Ross Sea region is the exploratory longline fishery targeting Antarctic toothfish in Subarea 88.1. To represent the potential costs of MPA designation to the achievement of fishery outcomes, we summarized historical fishing effort data at the scale of 10 km x 10 km cells and represented total fishing effort as the cumulative sum of the length of longline deployed in each cell in the history of the fishery (1998-2010; note season ending 2011 is not included) in Arc GIS format. See Figure 3. We recognize that other representations of the potential value of particular locations for fishing (e.g. based on total catch or CPUE) may be equally valid and that all cost metrics based on fishery-dependent data include biases, being influenced to different degrees by restricted vessel access due to ice conditions, increasing knowledge and changing fisher behaviour over time as the fishery develops, and by changing management restrictions over time (e.g. the existing 550 m closure and 0 TAC areas). However in consultation with fishing industry stakeholders it was agreed that the Ross Sea fishery was sufficiently developed that patterns of historical fishing effort provide the most appropriate spatially resolved approximation of the value of different locations for rational use.

Fishing effort displacement associated with any MPA scenario is calculated as the cumulative total length of all longlines historically deployed inside the MPA, as a percentage of the cumulative total length in the fishery. Percent effort displacement is the metric by which cost to rational use is approximated in the SCP process. Other representations of effort displacement (e.g. based on total catch and total number of sets irrespective of length) were also examined, but it was found that outcomes were largely insensitive to these changes.

Effort displacement (using km of longline) associated with the New Zealand MPA scenario in Figure 1 is 20.6%. See also Table 2 in Discussion, below.

In considering cost to rational use arising from any MPA scenario it is important to recognize that the process by which TACs are set in exploratory fisheries is independent of potential MPA designation; i.e. fishing that is prevented from occurring inside a designated MPA will instead occur elsewhere, such that total catches are likely to remain unchanged. Consequently the calculated effort displacement provides an index of disruption to current fishing patterns and an indicator of potential foregone opportunity costs in future, but does not directly equate to an actual economic cost in terms of foregone catch. Note also that because SSRU boundaries and the partition of the TAC between SSRUs will need to be adjusted to accommodate new MPAs, the process of designating MPAs may simultaneously open new areas to fishing relative to the status quo, e.g. if TACs within the current 0 TAC SSRUs are revisited.

Table 1: Protection objectives, target areas, and protection targets used by New Zealand in Phase 2 of the Ross Sea region MPA planning process:			
Target Area	**Description**	**Boundary in Figure:**	**Protection target**
Protection Objective 1: representativeness of benthic environments			
17 benthic bioregions	[benthic bioregionalisation in Figure 1 of Sharp et al. 2010]		30%
Protection Objective 2: representativeness of pelagic environments			
18 pelagic bioregions	[pelagic bioregionalisation in Figure 2 of Sharp et al. 2010]		30%
Protection Objective 3: large-scale ecosystem processes/ areas			
Area 1	Ross Sea shelf front intersection with seasonal ice	Figure 2a	50%
Area 2	Polar Front	Figure 2a	50%
Area 3	Balleny Islands and proximity	Figure 2a	100%
Area 4	Ross Sea polynya Marginal Ice Zone	Figure 2a	75%
Area 5	Eastern Ross Sea multi-year ice	Figure 2a	75%
Protection Objective 4: trophically dominant pelagic prey species			
Area 8	Antarctic krill core distribution	Figure 2b	50%
Area 9	Crystal krill core distribution	Figure 2b	75%
Area 10	Antarctic silverfish core distribution	Figure 2b	75%
Protection Objective 5: spatially constrained top predator foraging distributions			
Area 11	Adelie penguin summer nesting season core foraging distribution	Figure 2c	75%
Area 12	Emperor penguin summer nesting season core foraging distribution	Figure 2c	75%
Area 13	Weddell seal summer pupping season core foraging distribution	Figure 2d	90%
Area 14	Type C killer whale summer preferred foraging distribution	Figure 2d	90%
Protection Objective 6: D. mawsoni life cycle areas			
Area 18	Subadult toothfish settlement areas on the Ross Sea shelf	Figure 2e	100%
Area 19	Dispersal trenches for maturing toothfish	Figure 2e	100%
Area 20	Adult feeding areas on the Ross Sea shelf slope	Figure 2e	30%
Area 21	Northern (presumed) D. mawsoni spawning areas west of Ross Gyre divergence	Figure 2e	30%
Area 22	Northern (presumed) D. mawsoni spawning areas east of Ross Gyre divergence	Figure 2e	30%
Protection Objective 7: coastal/localized areas of particular ecosystem importance			
Area 6	Southern Ross Sea shelf persistent winter polynya	Figure 2f	100%
Area 7	Coastal polynyas	Figure 2f	100%
Area 15	Terra Nova Bay	Figure 2f	100%
Area 16	Victoria coast – coastal buffer and platelet ice formation zone	Figure 2f	100%
Area 17	Pennell Bank polynya	Figure 2f	100%
Protection Objective 8: rare or vulnerable benthic habitats			
Area 23	Balleny Islands and adjacent seamounts	Figure 2f	100%
Area 24	Admiralty Seamount	Figure 2f	100%
Area 25	Cape Adare proximity continental slope	Figure 2f	100%
Area 26	Southeast Ross Sea continental slope	Figure 2f	100%
Area 27	Southern McMurdo Sound	Figure 2f	100%

[Note this figure contains potentially sensitive information so is not submitted in electronic form. The figure will be displayed at the CCAMLR MPA workshop in Brest. Comparable information at lower spatial resolution is contained within Figure 1, above]

Figure 3: Distribution of cumulative total fishing effort (km of longline deployed) in the Subarea 88.1 and 88.2 A-B toothfish fishery, 1998-2010, within 10x10 km cells.

Step 5: Constraints

The following additional MPA scenario design constraints were considered throughout the planning process and imposed in the final stages of MPA scenario planning.

- MPAs will be large and spatially contiguous without excessively complex boundary configurations
- All MPA boundaries will consist of straight lines oriented directly north-south or east-west, in order to avoid potential ambiguities arising from the use of different map projections
- All MPA boundary vertices will fall precisely on tenths of decimal degrees.

Step 6: MPA scenario development and evaluation

Different MPA scenarios were iteratively developed, evaluated, and adjusted over the course of several months informed by scientific review and consultations with domestic stakeholders, and discussions with the United States. This process was greatly aided by the use of a custom-designed MPA planning tool in ArcGIS, allowing rapid evaluation of user-defined MPA boundary scenarios against standard performance metrics (i.e. % protection for each target area and bioregion, and % displacement of fishing effort) and iterative adjustment to seek an optimal balance between protection and rational use. The New Zealand government approach was to seek an MPA scenario that met or exceeded the protection targets in Table 1 while minimising the associated fishing effort displacement, mindful of additional design constraints outlined in Step 5. The outcome of this process is the New Zealand MPA scenario shown in Figure 1 and further described in Results, below. The MPA planning tool is described in Annex B. Use of the MPA planning tool will be demonstrated at the CCAMLR MPA workshop in Brest; if possible the tool will be made available to interested Members wishing to utilise it for MPA planning in other areas.

Consultation with domestic stakeholders and MPA scenario evaluation process

New Zealand is a fishing Member of CCAMLR with a strong commitment to ecosystem protection and a credible record of science contributions supporting the sustainable utilisation of Antarctic marine living resources. The fishing industry, environmental NGOs, and Antarctic scientists within New Zealand all have a major stake in the outcomes of the RSR MPA planning process. Because these interests mirror a similar range of views held by CCAMLR Members, the New Zealand process of balancing competing objectives in MPA planning may provide a robust basis for a similar process within CCAMLR, to meet the aims of Article II.

In April and May 2011 New Zealand held three separate Ross Sea region stakeholder engagement and MPA planning workshops, attended by: i) government officials; ii) fishery and ecosystem scientists providing management advice to the Ross Sea region toothfish fishery; iii) representatives of the New Zealand Antarctic science community; iv) representatives of environmental NGOs; and v) fishing industry representatives. Stakeholders were invited to state their own objectives for the MPA planning process and propose MPA scenarios consistent with those objectives, and to participate in an iterative process of evaluating and adjusting MPA scenario boundaries to balance competing objectives in an open workshop setting, aided by the use of the MPA planning tool described in Annex B.

The MPA planning process described in steps 1-6, above, is listed sequentially but was iterative in its actual implementation, due to an absence of consensus with respect to protection objectives and protection targets in steps 1 and 3, which was not surprising given the range of stakeholder interests. Note however that in practice it is not necessary for all stakeholders to share the same protection objectives to find agreement, so long as the target areas associated with those objectives are spatially coincident. Protection targets in Table 1 represent the position adopted by New Zealand following the domestic MPA planning process.

The main strength of the MPA planning tool described in Annex B relative to optimisation tools such as MARXAN (Ball and Possingham 2000) is that the MPA planning tool enables rapid transparent evaluation of alternate MPA scenarios and negotiation of trade-offs between competing objectives *even in the absence of agreement about objectives, protection targets, and acceptable levels of cost.* This is because the input data layers (i.e. bioregionalisations, target areas, and fishing effort data), are science products divorced from the associated value judgments about which areas are most important to protect and how much is enough (i.e. protection targets) or how much accommodation should be made for acceptable fishery outcomes (acceptable cost). Ultimately these value judgments are inherent in the final decision about which MPA scenario is preferred, but instead of being required as inputs (as in spatial optimisation tools like MARXAN) in the New Zealand MPA planning tool these value judgments only affect the interpretation and use of tool outputs. By providing a forum for stakeholders to propose MPA scenarios consistent with their own protection objectives, but requiring that they express those objectives in terms of spatial distributions defined independently by scientific experts, the New Zealand sought to facilitate engagement from a diverse group of stakeholders while maintaining transparency and promoting adherence to scientific rigor.

The main weakness of the MPA planning tool is that without these value judgments (protection targets) coded explicitly as inputs, optimisation is not possible except by iterative adjustment of user-defined boundaries against pre-conceived targets. MPA scenarios were proposed, evaluated, and iteratively adjusted on the principle of *spatial interchangeability within target areas* and the commitment that *at a given level of protection achieved, the lowest cost spatial solution is preferred*. This principle provided an objective basis by which competing spatial solutions could be evaluated.

By exploring the optimum trade-offs that are possible at different levels of protection and cost (effort displacement), New Zealand sought to understand the shape of the marginal cost-benefit curve in different areas and identify areas in which the marginal cost of increased protection (in excess of targets) was low. To illustrate, where target areas coincide directly with areas of highest value for rational use (e.g. the summer ice-free Ross Sea shelf slope, pelagic bioregion 9) the marginal costs of additional protection are high, and further protection beyond a minimum target would not be favoured. In contrast, in areas of high conservation value and of lower interest for rational use (e.g. shallow areas of the Ross Sea shelf), the marginal cost of additional protection is low, and protection may be expanded to levels higher than the original protection target, *where sufficient scientific justification exists*. In this way it is possible to achieve relatively rapid stakeholder agreement in low-conflict areas. The New Zealand scenario reflects the outcome of this process, in which very high levels of protection (e.g. 90-95%, see below) are achieved for some target areas where costs are low and the scientific justification is clear. Discussions in areas where demands for ecosystem protection and rational use more directly coincide naturally proved more difficult, and required the New Zealand Government to select an appropriate inflection point on the cost-benefit trade-off curve.

Other considerations

Throughout the MPA planning process New Zealand also took into account the following additional considerations not adequately captured in the process of balancing protection targets against fishing effort displacement:

- The Ross Sea region fishery is spatially constrained by high ice cover that varies unpredictably between years; the pattern and sequence of the seasonal ice retreat is an important consideration in spatial management design.

- In an Olympic fishery it is important that the fishable (and ice-free) area be large enough to accommodate the expected number of vessels without forcing vessels into areas where health and safety will be compromised.

- MPA design should consider the likely effects on the availability of data to inform fishery management, particularly with respect to tag releases and recaptures by the licensed fleet. Tag returns strongly inform the current stock assessment (Dunn et al. 2009; Dunn et al. 2009b; Hanchet et al. 2010); MPAs that alter the current distribution of fishing effort will affect tag recapture rates perhaps in unpredictable ways.

- Properly designed MPAs may enable comparisons of fished vs. unfished contrasts to better study the effects of fishing, or monitoring of natural variability un-confounded by fishery impacts, providing valuable information to improve ecosystem understanding and management of the fishery (e.g. Hanchet et al. 2011).

Step 7: Implementation plan (Phase 3)

New Zealand plans to develop a management plan, science and monitoring plan, and legal framework for implementation of a system of MPAs in the Ross Sea region following review/ approval by the Scientific Committee of proposals arising from Phase 2.

Results (New Zealand)

The New Zealand RSR MPA scenario is shown in Figure 1.

Protection

Protection levels achieved for the 27 target areas are shown in Table 2 in Discussion (below). The New Zealand scenario meets and in some cases significantly exceeds protection targets for 26 of 27 target areas, and meets a 30% representativeness target for 16 of 17 benthic bioregions and 17 of 18 pelagic bioregions (protection for the remaining two bioregions is 29.2% and 28.1%, respectively). In particular:

- The New Zealand scenario includes 100% protection for all identified coastal or spatially constrained areas of particular ecosystem importance (Areas 6,7,15-17) and all identified rare or vulnerable benthic habitats (Areas 23-27).

- The New Zealand scenario achieves very high protection for distributions contributing to productivity and trophic assimilation over the Ross Sea shelf, as evidenced by high protection levels achieved for Area 4 (Ross Sea polynya MIZ) and Areas 9-10 (crystal krill and silverfish). In particular, including 95% of the distribution of Antarctic silverfish inside an MPA provides very strong protection for trophic flows supporting high top predator populations and the continued health and integrity of the Ross Sea shelf ecosystem.

- The New Zealand scenario achieves very high protection (>90%) for top predator distributions in locations and times when they are constrained in their foraging by fidelity to land-based colonies (Areas 11-13), by specialized foraging behaviours (Area 14) or by moulting requirements (Area 5). Killer whales in particular may exhibit sophisticated prey selectivity and the potential for complex prey-switching behaviour in response to changing prey availability, and can exert strong top-down ecosystem control. Killer whales are potentially implicated in the depletion of their secondary prey and subsequent trophic cascade effects in other marine systems around the world in which their primary prey availability has been affected (Pitman and Durban 2011 and references therein). Elsewhere in the CCAMLR Area killer whales thought to prey primarily on seals and penguins are known to actively target commercial fishing vessels to steal toothfish, with implications for fishery viability as well as potential ecosystem effects (Moir and Agnew 2010). By enforcing spatial segregation between fisheries and top predator populations, the New Zealand MPA scenario seeks to effectively eliminate risks of this nature in the Ross Sea region.

- The New Zealand scenario eliminates fishing on subadult and pre-recruit toothfish on the Ross Sea shelf where the risk of ecosystem effects is highest and where commercial fishing may confound the ability of environmental and fishery scientists to undertake monitoring independent of fishery impacts, including to detect changes in toothfish recruitment (see Hanchet et al. 2011). The New Zealand scenario shifts the current shelf-associated catch onto deeper and larger toothfish populations that are less strongly coupled with the Ross Sea shelf ecosystem (Stevens 2004; Stevens 2006; Pinkerton et al. 2010).

- On this basis the New Zealand MPA scenario would deliver clear and immediate ecosystem protection benefits to achieve the aims of Article II.

Effort displacement

Fishing effort displacement associated with the New Zealand scenario is shown in Figure 2. Expressed in terms of total km of line deployed, displacement is 20.6% with reference to all effort in the history of the fishery. Note however that because historically fishing has occurred in SSRUs that are now closed (i.e. depths < 550 m) or assigned 0 TACs, the actual level of displacement relative to the status quo fishable area is less than this figure, i.e. 6.6% of total historical effort is within areas that are currently closed.

New effort displacement under the New Zealand scenario arises primarily from the following closures:

- protection of deeper holes and troughs on the southern Ross Sea shelf (area 18, Figure 2e), within which the toothfish fishery currently operates primarily targeting smaller and pre-recruit fish (Hanchet et al. 2010). Displacement of this fishing effort protects pre-recruit toothfish (Area 18), to prevent potential direct trophic competition with toothfish predators (Areas 13-14), to protect the only winter ice-free portion of the entire Ross Sea region (Area 6), and maintain a high level of protection for keystone species that dominate the trophic function of the intact Ross Sea shelf ecosystem (Areas 9-10).

- protection of a portion of the Ross Sea shelf slope near Cape Adare. Displacement in this area protects the confluence of multiple target areas relating to ecosystem productivity (Areas 1,4), constrained predator foraging (Areas 11-14), coastal polynyas (Area 7) and vulnerable benthic habitats (Area 25)

- protection of a lightly fished portion of the Ross Sea slope in Subarea 88.1K. Displacement in this area achieves the protection target for Area 1 and representativeness targets for benthic bioregion 4 and pelagic bioregions 9 and 14 on the Ross Sea shelf slope.

- protection of currently fished topographic features in Subarea 88.1B, to protect a portion of the presumed *D. mawsoni* spawning area west of the Ross Gyre divergence (Area 21).

At the same time the New Zealand scenario would open new areas to fishing that have not previously been fished, i.e. in the north of Subarea 88.2. Opening this area to fishing will allow redistribution in space of fishing effort displaced by closure of the Ross Sea shelf without associated increased vessel crowding. Redistribution of effort will require reallocation of the existing TAC between the northern, slope and shelf SSRUs, and the redesign of existing small scale research units in Subarea 88.1.

New Zealand has assessed that effort displacement associated with this MPA scenario is justified to meet the high levels of protection for important ecosystem processes and areas described above. The proposed level of displacement is consistent with the aims of Article II because:

- The redistribution of effort will not prevent vessels from catching the TAC.

- The redistribution of effort is not anticipated to greatly exacerbate problems of vessel crowding.

- The redistribution of effort is not anticipated to substantially reduce the quality of information acquired from tag releases and recaptures, used to inform the stock assessment.

Retrospective validation using MARXAN

New Zealand recognizes that a range of possible MPA scenarios could be justified by defining different protection targets, e.g. to reflect different conservation objectives. However the MPA planning process by which the New Zealand scenario was derived proceeded on the basis that for a particular set of target areas and protection targets, there may exist a single preferred MPA scenario, optimised to minimise cost to rational use. One drawback of the MPA planning tool developed by New Zealand for this process is that by relying on user-defined MPA boundaries in the absence of predetermined objectives or targets, there is no automated optimisation function possible, as in decision support tools such as MARXAN. However, by iteratively testing and evaluating alternate boundary configurations in an open workshop setting, officials were confident of achieving the optimum cost-benefit trade-off for a given set of protection targets, while simultaneously incorporating constraints as defined in step 5 (e.g. the desire for contiguous areas with straight-line boundaries) and other considerations described in step 6 (e.g. utility for science or operational limitations imposed by ice), which are difficult to incorporate into algorithmic cost-benefit optimisation as used by decision support tools.

To test to what extent the New Zealand scenario achieved this aim, and for comparison with the methods of the UK (2009) and Lombard et al. (2007) a retrospective validation of the New Zealand scenario was undertaken using MARXAN. To achieve this we used the actual protection levels achieved with respect to the 27 target areas (in Table 2) and input these as protection targets back into MARXAN, along with a 30% representativeness target for each of the 17 benthic bioregions and 18 pelagic bioregions in Sharp et al. (2010). Analyses were performed using standard MARXAN procedures to optimise protection of these 62 features versus a cost layer using cumulative total toothfish catch (tons) at a grid size of 30 x 30 km^2. An alternate cost layer using fishable area instead of actual effort distributions was also used (results not shown). 4982 planning units were included in the grid. One boundary parameter was included in all scenario runs to increase 'clumping' of solutions; prior sensitivity analysis suggested the use of p=0.001 for this boundary parameter. Analyses were performed with and without weighting assigned to the target features. Differences were minimal, and only un-weighted results are presented here.

Of interest, the scientist running the MARXAN analysis was provided with the requisite data layers and protection targets as inputs but was not shown the corresponding MPA scenario boundaries, to avoid bias.

The output of the MARXAN analysis described above is shown in Figure 4. The New Zealand MPA scenario shows a high degree of convergence with the optimised (cost-minimisation) solution achieving the same level of protection. Where the MARXAN solution differs this is largely attributable to its tendency to avoid protecting areas abutting the outer boundary of the planning domain (an inherent bias arising from the boundary minimisation function) and its willingness to protect or exclude from protection individual cells based on the patchiness of the cost layer, as opposed to the subjective process' adherence to a principle of only protecting large and continuous areas with simple boundary configurations.

It was concluded that the iterative user-driven MPA planning tool and methodology was successful at identifying an optimal spatial design to achieve the desired level of protection while minimising cost to rational use, and that the New Zealand MPA scenario represents an appropriate balance between ecosystem protection and rational use, consistent with Article II.

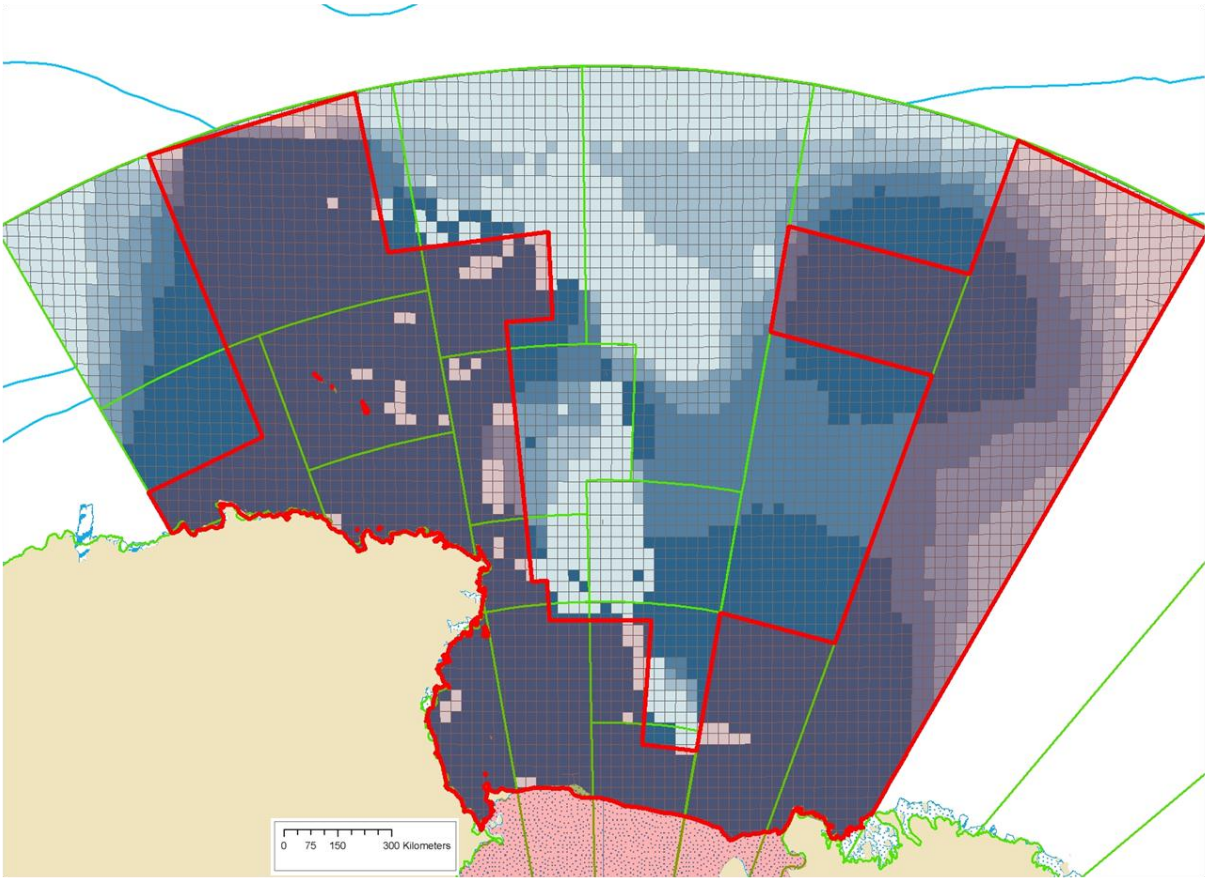

Figure 4: MARXAN output retrospectively applied to test the choice of MPA boundaries in the New Zealand scenario. Protection levels achieved by the New Zealand scenario for the 27 target areas (in Table 2, below) were used to define input protection targets, to test to what extent the New Zealand scenario constitutes an optimised cost-benefit solution at these protection levels. Representativeness target = 30%. Cost was represented as total cumulative historical toothfish catch (tons, 1998-2010). The New Zealand scenario is shown in red. The frequency of inclusion in the MARXAN-derived MPA solution for each cell is shown in blue (darker areas being most selected).

An MPA scenario developed by the United States

The United States supports the establishment of a marine protected area (MPA) in the Ross Sea region (RSR), with science playing a key role in establishing the boundaries and regulations that will determine human activities therein. For the purposes of this work, the RSR is defined as the region south of 60°S and between 150°E and 150°W (or the combined areas of Subarea 88.1, SSRU 88.2A, and SSRU 88.2B). The following section of this joint paper shares the U.S. experience with “approaches to the selection of candidate marine sites for protection” as per the Terms of Reference for the CCAMLR MPA Workshop (SC-CAMLR-XXIX, paragraph 5.22). The text summarizes scientific work that has led both to a set of U.S. policy aims and to a scenario that identifies potential boundaries for an MPA in the RSR. Further to the Terms of Reference for the CCAMLR MPA Workshop, all Members are encouraged to provide feedback on the work presented here (SC-CAMLR-XXIX, paragraph 5.22).

U.S. policy aims and potential boundaries for an MPA scenario

Following consultations with scientists from the United States and discussions with New Zealand colleagues who work within the CCAMLR community, the United States developed its own policy aims for establishing an MPA in the RSR. These aims provide a domestic focus for implementing the conservation objectives set forth in Article II of the Convention and may define the foundation of policy positions put forward during future negotiations to establish such an MPA. By establishing an MPA in the RSR, the U.S. aims to:

1. conserve ecological structure and function – at all levels of biological organization – by prohibiting fishing in habitats that are important to native mammals, birds, fishes, and invertebrates throughout the Ross Sea region;
2. maintain a reference area in which there is no fishing to better gauge the ecosystem effects of climate change; and
3. promote research and other scientific activities (e.g., monitoring) focused on marine living resources.

Figure 5 illustrates the potential boundaries of a no-take MPA in the RSR. This scenario is a direct result of the domestic consultations and bilateral discussions that have occurred thus far, and the United States considers these potential boundaries to be consistent with Article II and the policy aims articulated above. The boundaries were designed to be relatively simple and to define a large, contiguous MPA. The scenario has several noteworthy aspects.

1. The scenario should not be considered a formal proposal at this time, but the potential boundaries of the no-take MPA do encompass areas that the United States is ultimately interested in protecting. All Members are invited to comment on the scenario illustrated in Figure 5.
2. The main fishing grounds for Antarctic toothfish (*Dissostichus mawsoni*) around Mawson and Iselin Banks are not within the MPA. Consistent with the conservation objectives set forth in Article II, the United States considers that it is important to balance spatial protection and sustainable harvest.
3. The boundaries of the MPA do, however, bisect a complex of bioregions and ecosystem process areas (used to define “target areas” in the planning method utilized by New Zealand) that overlay longline fishing grounds southeast of Mawson and Iselin Banks (see Figure 7). This bisection may provide an opportunity for well-planned research and monitoring efforts to contrast a reference area with a fished area and thereby distinguish changes caused by fishing from those caused by climate change.
4. The MPA would provide substantial protection to important habitats for native mammals, birds, fishes, and invertebrates. The MPA would also protect all known VME risk areas and an appreciable amount of the habitat within which Antarctic toothfish with the highest gonadosomatic ratios have been caught.

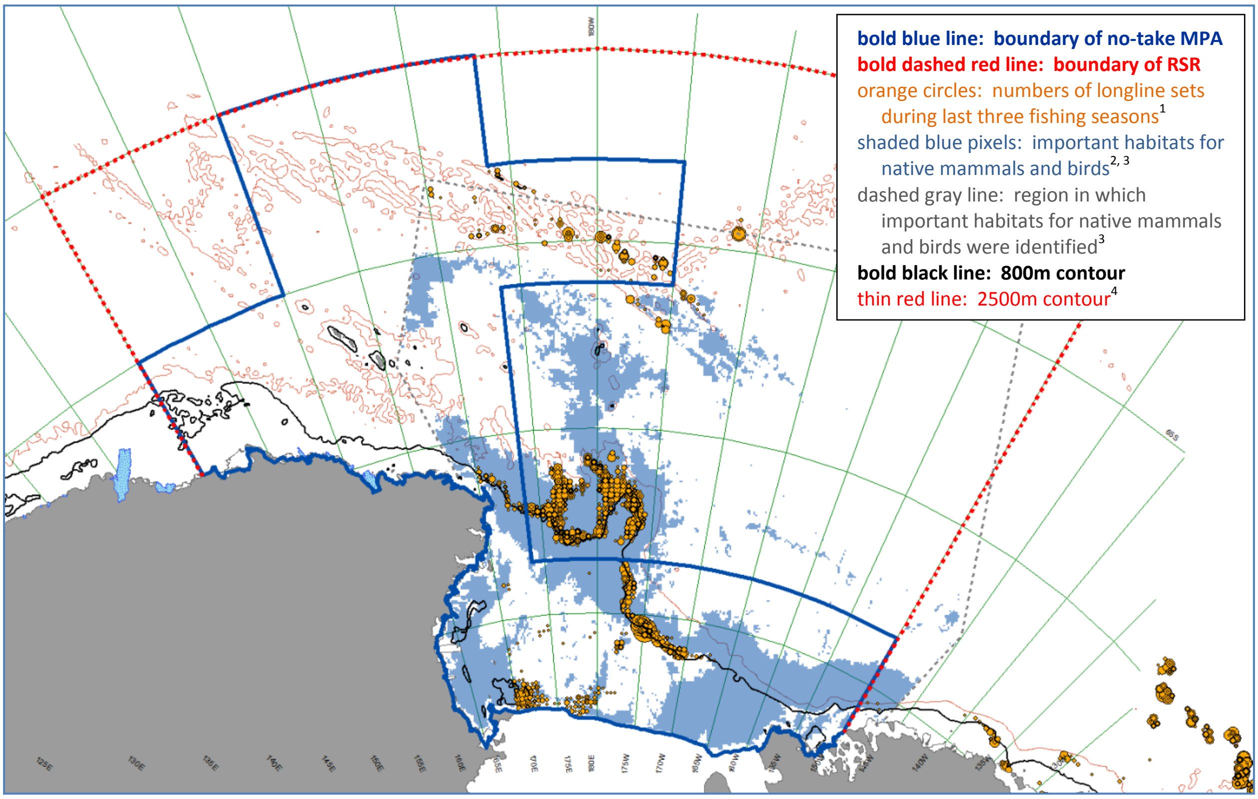

Figure 5. A scenario defining an MPA in the RSR; commercial fishing would be prohibited inside the polygon defined by the bold blue line. [1]Data for the 2010/11 season are preliminary. [2]Inferred from the top 25% of zonation scores that summarize the patterns of occurrence of several native mammals and birds; see the main text. [3]Ballard et al. (2010). [4]Approximate limit of depths fishable by the longline fishery (see Hanchet et al. 2010).

The United States is working to establish an MPA in the RSR following a two-year plan. Science is instrumental in all phases of this plan. The work plan continues to evolve; the current version is summarized here.

Milestone	Start date[1]	Roles of science
Consult with U.S. scientists	April 2011	• Identify "ecological objectives" that might promote a healthy ecosystem • Define performance metrics that quantify the degrees to which alternative MPAs achieve the ecological objectives • Use ecological objectives and performance metrics to prioritize specific smaller areas for protection
Discuss issues with colleagues from New Zealand	May 2011	• Summarize scientific work to date and exchange data, GIS layers, etc. • Debate scientific justifications for and evaluate relative performances of alternative MPA scenarios

Define U.S. policy aims	June 2011	• Compare results from domestic consultations with those from bilateral discussions to increase scope of scientific reasoning • Advise on degrees to which draft policy aims might achieve the ecological objectives identified from consultations with U.S. scientists and address other relevant issues identified from comparison above
Consult with all Members of CCAMLR	August 2011	• Share experience on "approaches to the selection of candidate marine sites for protection"(SC-CAMLR-XXIX, paragraph 5.22) • Receive recommendations to further progress work on an MPA for the RSR (SC-CAMLR-XXIX, paragraph 5.23)
Propose boundaries of MPA to SC-CAMLR[2]	September 2011	• Consider recommendations from the CCAMLR MPA Workshop and revise scenario illustrated in Figure 5 to account for new scientific perspectives as appropriate • Debate scientific justifications for and evaluate relative performances of alternative scenarios • Merge revised version of scenario in Figure 5 with alternative scenarios, if possible, to develop a unified proposal for consideration and further debate by SC-CAMLR[2]
Develop draft management plan for proposed MPA	January 2012	• Draft a research and monitoring strategy for the proposed MPA in consultation with scientists outside of the Scientific Committee and its working groups
Further consultation with all Members of CCAMLR (starting at WG-EMM but progressing to SC-CAMLR and CCAMLR)	July 2012	• Debate scientific justifications for and evaluate relative performances of the formally proposed MPA(s)
Negotiate a Conservation Measure	October 2012	• Provide relevant scientific facts and text during drafting (e.g., latitude and longitude coordinates of agreed MPA) • Provide a research and monitoring strategy to accompany the Conservation Measure

[1]In most cases, the column titled "start date" indicates when a particular phase of work was or might be initiated; most of the work phases listed here will continue throughout the period during which an MPA for the RSR will be proposed and negotiated.
[2]The U.S. and New Zealand have indicated a mutual desire to develop, if possible, a joint proposal for an MPA in the RSR. However, before proceeding with further work to develop a joint proposal, both Members have agreed to consider views expressed at the CCAMLR MPA Workshop.

Note that before the work plan outlined above was established, scientists from the U.S. and other Members of CCAMLR contributed a substantial body of interdisciplinary work, developed through decades of research, to form the scientific foundation for most issues considered here (e.g., the work summarized by Ainley et al. 2010 and Ballard et al. 2010).

Consultations with U.S. scientists

A small workshop was held from 13-15 April, 2011 at the Southwest Fisheries Science Center in La Jolla, California. The workshop was facilitated by G. Watters and attended by U.S. scientists with experience and expertise relevant to the ecology and management of the RSR. Two elements of work were addressed at the workshop: 1) a review of information presented by Sharp et al. (2010), and 2) an "interview" intended to elicit an increased understanding of U.S. scientists' perspective on an MPA in the RSR. The text that follows summarizes results from the interview. This summary reflects the perspective of G. Watters; it was not adopted or agreed by participants at the workshop. Moreover, the ecological objectives discussed at the workshop and the results of the workshop do not directly reflect U.S. Government policy.

The interview was undertaken to provide the United States with a science-based approach to identifying MPA boundaries that might be simultaneously agreeable to all Members of CCAMLR. Several participants at the workshop in La Jolla support protection of the entire Ross Sea shelf and slope. However, given that the continental slope is an important fishing ground for Antarctic toothfish and adoption of MPAs is a consensus activity within CCAMLR, it is unlikely that the entire shelf and slope will become a no-take MPA. Thus, participants at the workshop were asked to 1) specify a small set of "ecological objectives" that, if achieved, might promote a healthy ecosystem in the RSR; 2) define spatially-explicit performance metrics that could be used to assess how well an MPA might achieve these objectives; and 3) prioritize the protection of smaller areas within the RSR consistent with their ecological objectives. Participants at the workshop focused on the region south of 70°S. U.S. scientists generally have the most experience with this region, and most of the data available for consideration at the workshop originated from it.

Participants at the La Jolla workshop specified five ecological objectives that explicitly consider multiple species and address the concept of habitat, themes which ultimately became key elements in the set of U.S. policy aims. The participants' top two priority objectives related to protecting habitats for 1) native mammals and birds and 2) benthic communities. Large, robust predator populations and diverse benthic communities rich with climax species were considered to be indicative of a healthy ecosystem. Participants at the workshop suggested several performance metrics for the first priority objective, all of which were based on zonation scores reported by Ballard et al. (2010). These scores summarize occurrence patterns for nine species of native mammals and birds. After the workshop, G. Watters used the top 25% of the zonation scores to balance bias-variance tradeoffs in assessing the importance of any given habitat (pixel on a map). Participants at the workshop suggested using the area of seabed at depths < 800m as a performance metric for the second priority objective. Both zonation scores and seabed areas at depths < 800m were considered during development of the scenario illustrated in Figure 5. In general, boundaries that encompassed relatively more of the habitats identified by these two metrics were preferred, but this preference was tempered by considerations such as potential overlap with the longline fishery and whether other results (e.g., species richness of predators, the participants' third performance metric) suggested that habitats were important for a few rather than many species.

After listing their ecological objectives and defining relevant performance metrics, participants at the La Jolla workshop were asked to draw boundaries that demarcate small areas which, in their view, should be considered priorities for protection. These priority areas are illustrated in Figure 6, and the relative performance of each is indicated below.

Priority area	Sum of top 25% of zonation scores within priority area	% of seabed south of 70°S and <800m within priority area	Sum of longline sets during last three seasons within priority area
10%	35.1	18.0	438
20%	40.8	18.2	1212
30%	29.9	6.4	8
40%	14.3	24.2	252
50%	12.8	28.8	190
60%	16.4	0.0	503
70%	10.1	1.6	6
80%	4.2	0.0	0
90%	0.7	0.0	0

The participants prioritized areas consistent with the prioritization of their ecological objectives. The first three priority areas provided the best performance relative to their first objective, and the fourth and fifth priority areas provided the best performance relative to their second objective. The participants also prioritized areas consistent with the desire, held by some at the workshop, to protect the entire shelf and slope. The first six priority areas overlapped nearly all fishing effort that has occurred south of 70°S during the past three fishing seasons, and, of these six, only the third priority area had minimal overlap with the recent distribution of fishing effort.

Nearly equivalent levels of protection can be gained from alternative configurations of the participants' priority areas, but some of these alternatives would substantially change the overlap with the recent distribution of fishing effort. For example, an MPA composed of priority areas 3-5 and 7-9 would, in total, protect a similar amount of important predator habitat as would an MPA composed of priority areas 1 and 2. However, the former configuration would have substantially less overlap with recent fishing effort. Small areas were generally more "exchangeable" with respect to protecting habitats than to reducing overlap with the fishery because the important habitats are more widely distributed than recent fishing effort. Although the potential MPA ultimately developed by the United States was not designed to have coincident boundaries with any combination of the priority areas identified at the workshop, the concept of exchangeability was considered in an effort balance spatial protection and sustainable harvest while developing the scenario depicted in Figure 5.

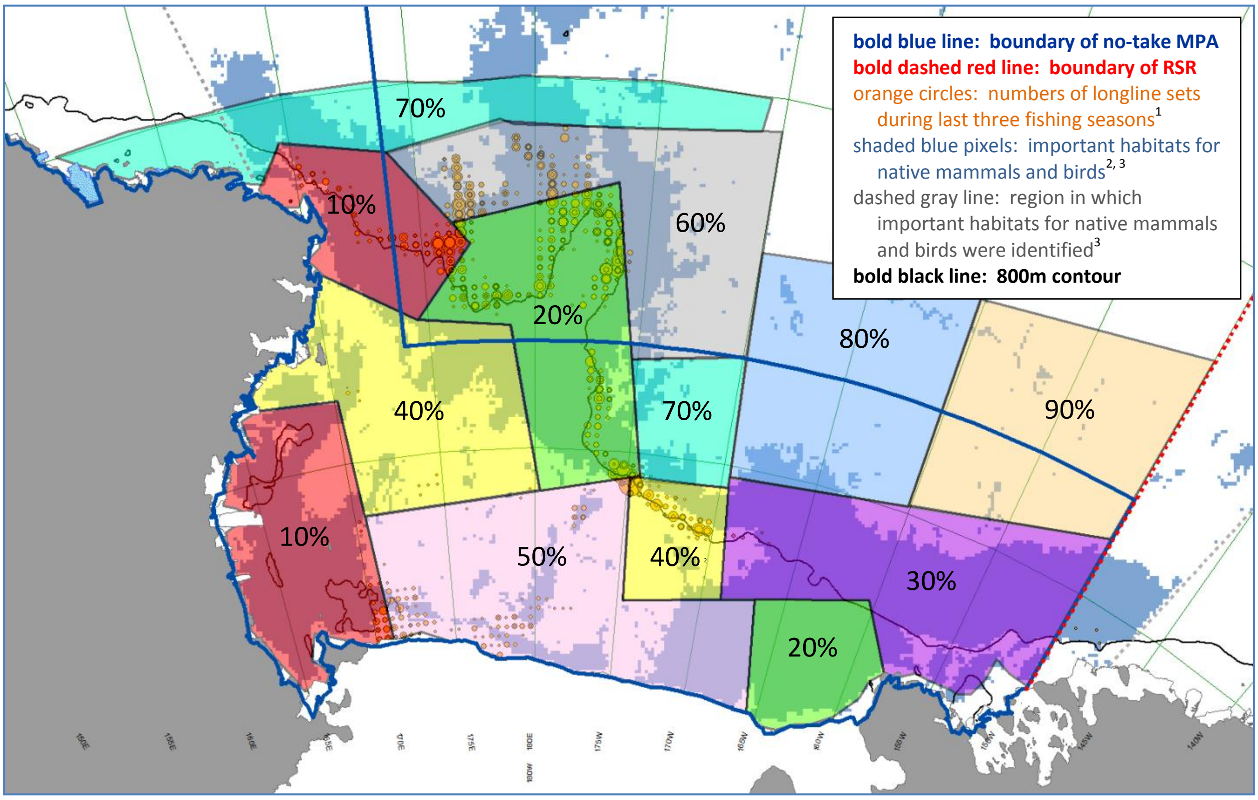

Figure 6. A prioritized sequence of smaller areas identified for protection by U.S. scientists (transparently colored polygons, some of which are not contiguous, each with a surface area of about 10% of the region south of 70°S) overlaid onto the scenario illustrated in Figure 5. 10% = 1st priority for protection; 20% = 2nd priority; 30% = 3rd priority; etc. [1]Data for the 2010/11 season are preliminary. [2]Inferred from the top 25% of zonation scores that summarize the patterns of occurrence of several native mammals and birds; see the main text. [3]Ballard et al. (2010).

Discussions with New Zealand

Detailed discussions with colleagues from New Zealand began in May 2011, during a separate meeting at the Southwest Fisheries Science Center in La Jolla; these discussions helped expand the scope of U.S. scientific thinking in two ways. First, the bioregionalization results provided by Sharp et al. (2010 and revisions made thereafter) demonstrate that the region north of 70°S is ecologically heterogeneous and includes several unique bioregions that do not occur farther south. The Commission has agreed that MPAs may need to provide comprehensive and representative coverage of such heterogeneity and uniqueness (e.g., CCAMLR-XXIV, paragraph 4.14), and, therefore, it seemed that an MPA limited to protecting areas south of 70°S would be insufficient to further the objectives in Article II of the Convention.

The scope of U.S. thinking was also expanded by considering the seamounts north of 70°S. These environments are thought to include important spawning habitats for Antarctic toothfish (Hanchet 2010). The Commission has agreed that utilizing MPAs to protect specific life-history stages may help to further its management objectives (e.g., CCAMLR-XXIV, paragraph 4.14). Since most toothfish captured south of 70°S have had very low gonadosomatic ratios (Hanchet 2010), an MPA limited to the region south of 70°S would presumably provide relatively little protection to spawning fish. The spatial extent of toothfish spawning habitat throughout the seamounts north of 70°S is unknown, and it was difficult to develop boundaries for an MPA in this area. Drawing the boundaries of an MPA designed to protect toothfish spawning habitat required consideration of the tradeoff between protecting areas where fish with relatively high gonadosomatic ratios have been observed in catches taken by the fishery versus protecting areas that have not been explored by the fishery but are plausible spawning areas based on bathymetry and oceanographic circulation patterns. The scenario illustrated in Figure 5 was developed by favoring the former side of this tradeoff. Taken together, the expanded scope of thought provided by bilateral discussions with New Zealand highlighted the importance of protecting areas north of 70°S despite the relative lack of data from this region.

Discussions with New Zealand also provided information used to develop an hypothesis about why the most important fishing grounds for Antarctic toothfish occur over the central portion of the continental slope and helped crystallize one view of how this area, which is also important habitat for native mammals and birds (Figure 5), might be partitioned by an MPA. Most longline sets in the RSR have been made in an area marked by the simultaneous presence and absence of several pelagic and benthic bioregions and "ecosystem process areas" (Figure 7). This complex of bioregions is not found elsewhere within the RSR, and it seems reasonable to hypothesize that the physical properties of this complex lead to enhanced production and explain why the area is important both to the fishery and to native mammals and birds. Sea ice is not persistent within this complex, but persistent sea ice bounds the complex to the west and the east. The complex includes two pelagic bioregions that are characterized by "vigorous shelf flow and front interactions" with "warmer water at depth" and "elevated productivity targeted by top predators" (Sharp et al. 2010) but which are largely absent to the west and the east, where the persistent sea ice occurs. The continental slope in this complex is relatively wide and is marked by the fragmentation of a benthic bioregion that Sharp et al. (2010) characterized as "rough" with "high current" and which forms an otherwise uninterrupted, continuous band to the west and the east. The complex's wide slope is linked to the continental shelf via two trenches that may act as ontogenetic migration corridors for Antarctic toothfish (note, however, that only one such corridor, the "Terra Nova trench" was originally included in the presentation by Sharp et al. 2010), and VME risk areas have been identified near the northwestern edge of each trench. The two trenches, with their attendant VME risk areas and neighboring bioregions appear to define two comparable units within the complex. The comparability of these units can form the basis for partitioning the complex. A no-take MPA that bisects the complex might provide the best opportunity to contrast a "treatment" (the unit with fishing) with a "control" (the unit inside the MPA) and facilitate the study of how fishing may impact the marine ecosystem in the RSR beyond the impacts of climate change alone. Conversely, since the complex of bioregions and ecosystem process areas between about 170°E and 170°W does not occur elsewhere within the RSR, an MPA that either mostly excludes the complex or mostly includes the complex would seem to provide no such opportunity. These arguments further link the scenario illustrated in Figure 5 to the U.S. policy aims.

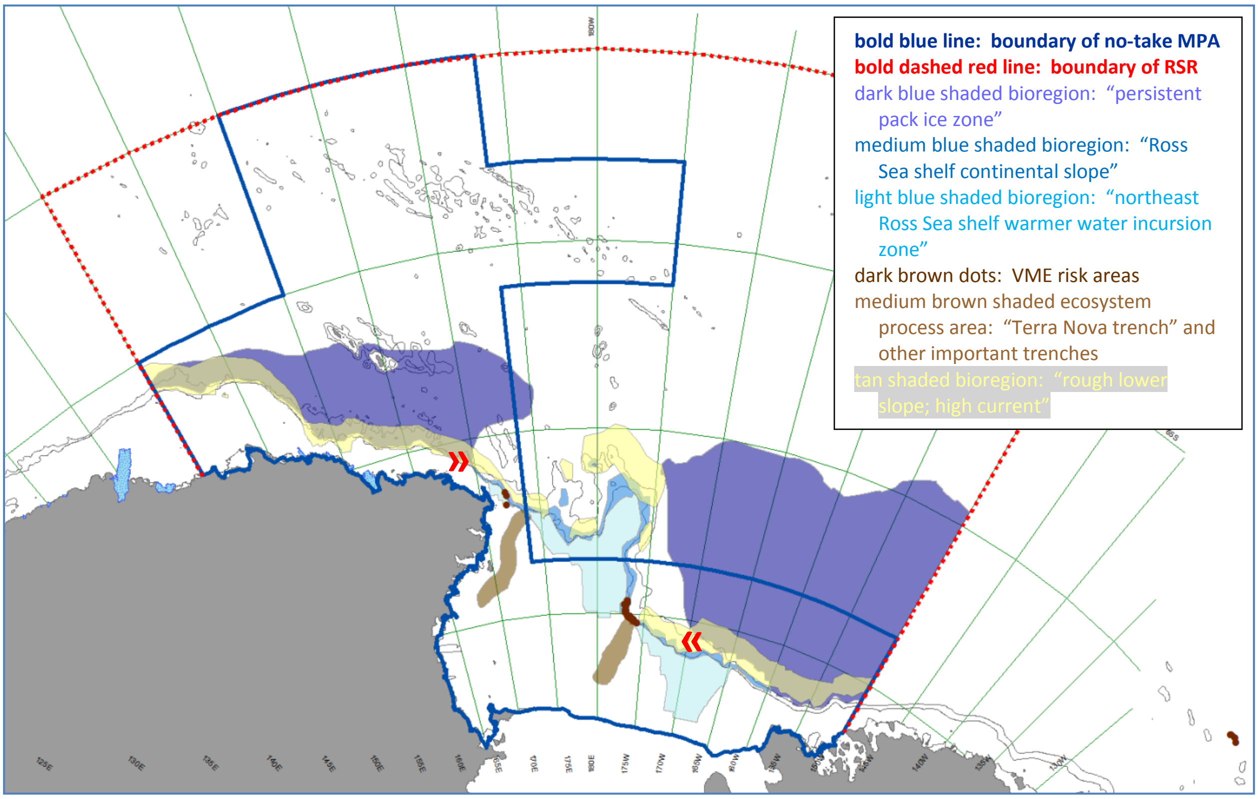

Figure 7. Bioregions and “ecosystem process areas” that, by their presence or absence define a unique complex along the continental slope of the RSR, overlaid onto the scenario illustrated in Figure 5. Blue shades indicate pelagic bioregions, and brown shades indicate benthic bioregions and ecosystem process areas. All bioregions and ecosystem process areas except the VME risk areas were identified and named by Sharp et al. (2010 and revisions thereafter). Locations of VME risk areas were provided by the CCAMLR Secretariat (2011). On the slope, longline fishing effort has primarily been distributed between 170°E and 170°W (between the red double-angle indicators).

Discussion

The collaboration between New Zealand and the United States was productive. The scientific rigor of domestic processes undertaken by both Members was improved; colleagues from New Zealand benefitted from review of the Phase 1 inputs to their SCP approach, while colleagues from the United States broadened their perspective on spatial processes occurring north of 70°S and surrounding the central portion of the continental slope. More importantly, the scenarios developed by both Members describe potential MPAs that would provide considerable levels of ecosystem protection. The table below summarizes each scenario's proportional coverage of the ecosystem process areas (used to define 'target areas' in the New Zealand section of this paper) presented by Sharp et al. (2010, with revisions presented in Annex A).

Area or cost metric	Description	% coverage in New Zealand scenario	% coverage in U.S. scenario
Area 1	Ross Sea shelf front intersection with seasonal ice	59	66
Area 2	Polar Front	48	65
Area 3	Balleny Islands and proximity	100	100
Area 4	Ross Sea polynya marginal ice zone	88	87
Area 5	Eastern Ross Sea multi-year ice	89	55
Area 8	Antarctic krill core distribution	51	54
Area 9	Crystal krill core distribution	97	99
Area 10	Antarctic silverfish core distribution	95	97
Area 11	Adélie penguin summer nesting season core foraging distribution	95	92
Area 12	Emperor penguin summer nesting season core foraging distribution	97	94
Area 13	Weddell seal summer pupping season core foraging distribution	99	96
Area 14	Type-C killer whale summer preferred foraging distribution	91	92
Area 18	Subadult toothfish settlement areas on the Ross Sea shelf	100	100
Area 19	Dispersal trenches for maturing toothfish	100	99
Area 20	Adult feeding areas on the Ross Sea shelf slope	40	48
Area 21	Northern (presumed) *D. mawsoni* spawning areas west of Ross Gyre divergence	46	85
Area 22	Northern (presumed) *D. mawsoni* spawning areas east of Ross Gyre divergence	26	29
Area 6	Southern Ross Sea shelf persistent winter polynya	100	100
Area 7	Coastal polynyas	100	100
Area 15	Terra Nova Bay	100	100
Area 16	Victoria coast – coastal buffer and platelet ice formation zone	100	100
Area 17	Pennell Bank polynya	93	70
Area 23	Balleny Islands and adjacent seamounts	100	100
Area 24	Admiralty Seamount	100	100
Area 25	Cape Adare proximity continental slope	100	100
Area 26	Southeast Ross Sea continental slope	100	100
Area 27	Southern McMurdo Sound	100	100
length	Total km of longline deployed, 1998-2010	21	36
catch	Total tons of toothfish catch, 1998-2010	15	31

Both scenarios would provide near total protection for some unique and important ecosystem process areas within the RSR (e.g., on the continental shelf). Both scenarios include a representative proportion of all benthic and pelagic bioregions. The lowest levels of protection provided by both scenarios are for bioregions and ecosystem process (target) areas with circumpolar distributions (e.g., the polar front). In general, both MPA scenarios would provide substantive levels of protection because they are well sited and large in size. A small MPA would not be able to provide the comprehensive protection indicated by either scenario considered here.

The difference between the two scenarios was most pronounced over the northern seamounts, the southeastern section of the continental slope, and an area of continental slope in the far west (SSRU 88.1D) (Figure 8). The New Zealand scenario covers less of the historical fishing grounds for Antarctic toothfish than the U.S. scenario and avoids those areas in which historical fishing effort has been most concentrated (see table above). To provide fresh perspective and enrich the ongoing debate, New Zealand and the United States collectively invite other Members to provide their views on the scenarios presented here.

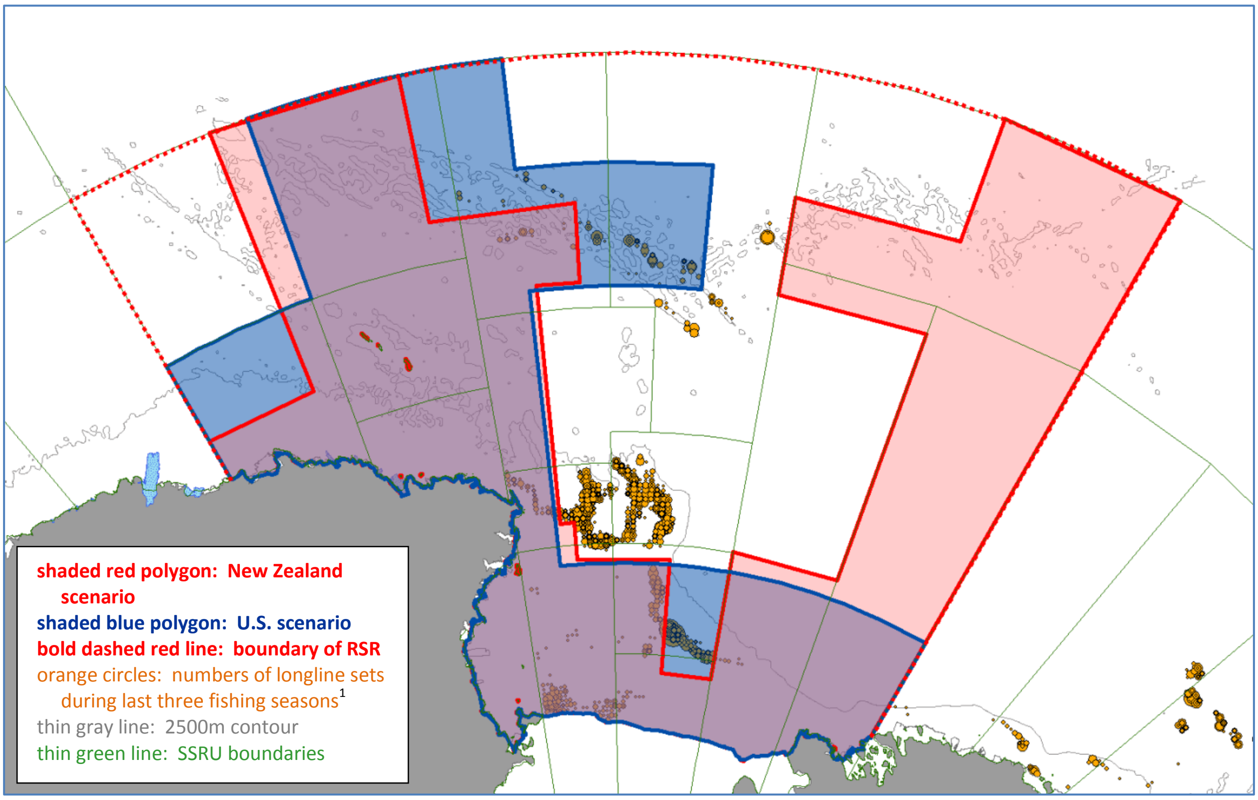

Figure 8. A comparison of the MPA scenarios developed by New Zealand and the United States. [1]Data for the 2010/11 season are preliminary.

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Annex A: Modifications to Phase 1 outputs: target areas

Target areas used in the systematic conservation planning process are listed in Table 1 and shown in Figures 2a-2f. For the majority of these areas the spatial extent, selection rationale and scientific justification for the delineation of area boundaries are as previously described in Sharp et al. (2010). Where areas have been added or modified subject to new scientific information and/or scientific review; the changes are described below. For consistency, area numbers are retained as in Sharp et al. (2010).

Objective 1: Protect a representative portion of benthic marine environments. No changes were made to the benthic bioregions as appear in Figure 1 of Sharp et al. (2010).

Objective 2: Protect a representative portion of pelagic marine environments. No changes were made to the pelagic bioregions as appear in Figure 2 of Sharp et al. (2010).

Objective 3: Protect large-scale ecosystem processes responsible for the productivity and functional integrity of the Ross sea region ecosystem.

- *Area 1: Ross Sea shelf front intersection with seasonal ice.* This area was extended east and west along the continental shelf break (800 m contour) following peer review by the principal authors of Ainley et al. (2010).

- Area 2: Polar Front. No change

- Area 3: Balleny Islands and proximity. No change.

- *Area 4: Ross Sea polynya Marginal Ice Zone* This area was adjusted to reflect the retreat of the Marginal Ice Zone westward to the Victoria Coast throughout the summer

- *Area 5: Eastern Ross Sea multi-year ice*. This area was adjusted to include only areas under persistent (multi-year) ice, to better reflect the importance of this area for moulting emperor penguins and crabeater seals, using satellite tracking data shown in Ainley et al. (2010), Figures 34 and 43.

Objective 4: Protect core distributions of trophically dominant pelagic prey species (krill and silverfish).

- *Area 8: Antarctic krill core distribution*: This area was expanded to include the full presumed core distribution of Antarctic krill in the Ross Sea region rather than merely the northeast Ross Sea aggregation. The distribution was drawn to reflect krill densities observed in survey transects (Ainley et al. (2010), Figures 25-26; O'Driscoll et al. 2009), from spatial distribution modelling described in the 2006 CCAMLR Bioregionalisation report (SC-CAMLR-XXVI/7, Figure 2), and extrapolated to reflect the apparent habitat affinity with the Ross Sea shelf front

- *Area 9: Crystal krill core distribution.* This area was amended slightly consistent with data in Ainley et al. (2010), Figures 25-26.

- *Area 10: Antarctic silverfish core distribution*. This area was defined consistent with data in Ainley et al. (2010), Figures 25-26 and O'Driscoll et al. (2009).

Objective 5: Protect core foraging areas for top predators that are constrained to land based colonies, or that may experience direct trophic competition from fisheries.

- Area 11: Adelie penguin summer nesting season core foraging distribution. No change.

- Area 12: Emperor penguin summer nesting season core foraging distribution. No change.

- *Area 13: Weddell seal summer pupping season core foraging distribution*. This area was adjusted slightly in the western Ross Sea to reflect a foraging distance in the proximity of northern colonies comparable to that observed for satellite tracked seals at McMurdo Sound, and to include the outlying colony at Cape Colbeck, consistent with data in Ainley et al. (2010) Figure 35.

- *Area 14: Type C killer whale summer preferred foraging distribution*. This area was adjusted to correspond to the union of the Ross Sea polynya edge marginal ice zone (Area 4) with the previously defined Area 14, consistent with sightings data in Ainley et al. (2010) Figure 32.

Objective 6: Protect areas of known importance in the life cycle of Antarctic toothfish.

- Area 18: Subadult (pre-recruit) toothfish settlement areas on the southern and western Ross Sea shelf: These areas were adjusted slightly to better reflect updated bathymetric data.

- Area 19: (Presumed) dispersal trenches connecting pre-recruit settlement areas with preferred adult feeding areas. An additional area was added in the eastern Ross Sea.

- *Area 20: Preferred adult feeding areas on the Ross Sea shelf slope.* As with Area 1, this area was extended east and west along the continental shelf break (800 m contour) following scientific peer review.

- *Areas 21-22: Northern (presumed) spawning areas*: The original Area 21 definition in Sharp et al. (2010) was drawn to reflect only locations where Antarctic toothfish with maturing gonads had been observed directly, and was consequently heavily biased by its reliance on fishery-dependent data. Subsequent scientific review recommended that presumed spawning locations be extended to include the full extent of the Pacific-Antarctic Ridge within which *D. mawsoni* are thought to predominate (i.e. excluding SSRU 88.1A in which toothfish are predominantly *D. eleginoides*) and restricted to depths of 1800—2500 m. This presumed distribution for probable spawning habitat is based on widely observed high gonadosomatic ratios in northern areas (Parker and Grimes 2010) and the use of larval dispersal simulations using oceanographic circulation models compared with length-frequency distributions of observed fish consistent with a hypothetical life cycle (Hanchet et al. 2008). On this basis the area was split to reflect the boundary between: i) a western presumed spawning distribution (Area 21), in which eggs and larvae would be expected to be carried by the Ross Gyre south and west to the Balleny Islands and the Antarctic continental shelf in SSRUs 88.1D and F; vs. ii) an eastern distribution (Area 22) in which eggs and larvae are expected to be carried eastward and eventually deposited on the Antarctic continental shelf in the region of Subarea 88.2 C-D. (Hanchet et al. 2008) Larval dispersal simulations supporting these area definitions will be shown at the CCAMLR MPA workshop in Brest.

  It is likely that only the eastern distribution (Area 22) is of relevance to recruitment into the Ross Sea stock; toothfish larvae spawned in Area 21 may ultimately settle in the western Ross Sea region (e.g. SSRU 88.1D) or move westward into Subarea 58.4.1. A commitment to protect presumed spawning habitat for D. *mawsoni* should be expected to include a portion of both of these distributions. Note also that the original Area 22 from Sharp et al. (2010)

was defined to reflect benthic habitat values (Objective 8), but the revised Areas 21-22 defined to reflect presumed spawning locations effectively replace the original Area 22, ensuring protection of spawning areas and benthic values simultaneously.

Objective 7: Protect localized/coastal locations of particular ecological importance

- Area 6: Southern Ross Sea shelf persistent winter polynya. No change.

- *Area 7: Coastal polynyas.* Cape Colbeck polynya extended eastward.

- Area 15: Terra Nova Bay. No change.

- Area 16: Victoria Land coast/ persistent ice tongues and proximity. No change

- [previous Area 17 removed]. The original Area 17 from Sharp et al. (2010) was defined to encompass a localised area of presumed high importance for *Macrourids* (rattails) as evidenced by a localised hotspot of anomalously high rattail CPUE as bycatch in the toothfish fishery. Re-analysis as additional bycatch data became available revealed that the original location was not as spatially constrained or as anomalous as had been thought; instead, relatively high rattail bycatch extends over a much larger area of the Ross Sea slope in SSRUs I and K. The localised area was therefore eliminated as an input to the planning process; care was taken to include areas of higher rattail bycatch in the proposed MPA boundaries when seeking representative closures of Ross Sea slope bioregions.

- *[New] Area 17: Pennell Bank polynya*. New area added following peer review comments from the authors of Ainley et al. (2010).

Objective 8: Protect known rare or vulnerable benthic habitats.

- Area 23: Balleny Islands and associated seamounts. No change.

- Area 24: Admiralty seamount. No change.

- Area 25: Cape Adare proximity continental slope. No change

- Area 26: Southeast Ross Sea continental slope. No change

- Area 27: Southern McMurdo Sound. No change

Annex B New Zealand MPA Planning tool in ArcGIS

In 2010 (SC-CAMLR XXIX, paragraph 5.20):

> *The Scientific Committee noted that it was important to create a transparent process by which multiple objectives for spatial protection could be considered in balance with rational use. It agreed that the discussions would best proceed with a focus on individual MPA proposals, rather than at a broad overarching scale. This is due to the expectation that different MPAs could have a different combination of objectives as agreed by CCAMLR-XXIV, paragraph 4.14, i.e. protection of ecosystem processes, habitats and biodiversity, and protection of species, including population and life-history stages. In the development of MPA proposals there is a need to clearly identify how achievement of the objectives will be assessed, while taking account of uncertainty.*

The attractiveness but inherent difficulty of achieving a transparent and repeatable method by which to design and propose MPA scenarios has been the subject of considerable discussion within CCAMLR much of it focused around the use of decision support tools such as MARXAN (e.g. SC-CAMLR XXIX/Annex 6, paragraphs 3.111-3.114). New Zealand officials considered that the MPA scenario planning process should, to the extent possible:

- be transparent with respect to conservation objectives and target areas (i.e. what are we trying to protect and where is it located).
- provide a mechanism for utilising spatial representations of the 'costs' (to rational use) of protecting different areas
- allow transparent and repeatable evaluation of alternate MPA scenarios with respect to protection objectives and costs, using simple quantitative performance metrics
- be easily understood by users and stakeholders
- facilitate engagement by a wide range of stakeholders without the need for agreement about objectives and targets, or about the appropriate trade-off between protection objectives and rational use
- enable spatial planners and stakeholders to rapidly evaluate and iteratively adjust the boundaries of draft MPA scenarios, preferably in an open stakeholder setting
- be sufficiently flexible to allow consideration of additional MPA design constraints that are not easily represented in spatially resolved digital formats (e.g. the need for simple straight-line boundaries)

Decision support tools such as MARXAN perform well with respect to i), ii), and iii) but less well with respect to iv) through vii). In particular the need to agree and define objectives and protection targets as inputs requires a level of consensus about conservation priorities and appropriate trade-offs against rational use that is difficult to achieve in a multi-stakeholder setting, and the objective function by which MARXAN negotiates spatial-trade-offs between multiple objectives can be a complex 'black box' from the standpoint of non-expert stakeholders.

For these reasons New Zealand developed a custom-designed MPA planning tool for use in ArcGIS. The tool utilises the following inputs:

- spatial data layers representing target areas for protection (binary polygons)
- spatial data layers representing environment classifications or bioregionalisations (classified polygons)
- spatial data layers representing an index of spatially resolved value for rational use, e.g. using fishery data or modelled target fish distributions (points or raster)

Use of the tool is as follows:

1. The user selects from the available spatially resolved fishery data one or more representations of value for rational use (e.g. numbers of historical sets, length of lines deployed, total historical catch, modelled target species abundance, etc.)
2. The user defines the boundaries of an MPA, either as rectangular coordinates, by drawing a single- or multi-part polygon on-screen in Arc GIS, or by importing an existing polygon shapefile.
3. The tool clips the boundaries of the user-defined MPA to match the coastline or outer extent of the planning domain, and saves the MPA as a shapefile for later use.
4. The tool automatically calculates: i) the proportion of each target area included within that MPA; ii) the proportion of each bioregion included in that MPA; and iii) the proportion of fishing effort displaced by that MPA, and exports these performance metrics to a spreadsheet
5. The user iteratively repeats steps 2-4, adding (or subtracting) new MPAs to (or from) the MPA scenario and tracking the contribution of individual MPAs to overall performance metrics (% protection or % displacement) via manipulation of spreadsheet columns.

Processing time for each new MPA or boundary adjustment is approximately 3-5 minutes, enabling comparative evaluation and iterative adjustment of MPA scenarios in real time in a workshop setting.

Use of the MPA planning tool will be demonstrated at the CCAMLR MPA workshop in Brest. If possible the MPA planning tool may be made available to interested Members wishing to utilise it elsewhere in the CCAMLR area. A user manual is also available on request.