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Analysis of potential threats from fishing to the objectives of a proposed Ross Sea region MPA

Delegations of New Zealand and the USA

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Abstract

We present an analysis of potential threats from fishing to the achievement of MPA objectives identified in the Ross Sea region MPA proposal submitted jointly by New Zealand and the USA. Ecosystem threats from fishing potentially undermine the requirements of Article II(3) paragraphs b and c. Fishing may also threaten science objectives, e.g. preventing establishment of scientific reference areas, or undermining ongoing efforts to understand environmental change un-confounded by human impacts. Where particular threats can be foreseen and located in space, MPA designation is one effective means of avoiding or mitigating ecosystem risks and promoting scientific objectives. Both threat-based objectives and scientific objectives were always implicit in the systematic process of MPA design used by New Zealand and the USA over several years; in this paper we make the underlying logic more explicit, drawing upon new and previously submitted material to identify threats to the MPA objectives, map those threats in space, and detail plausible mechanisms by which those threats can be expected to occur.

Introduction

In 2012 New Zealand and the USA jointly submitted a proposal for a Marine Protected Area in the Ross Sea region of the CCAMLR Area (CCAMLR XXXI/16Rev1). In discussions that followed some Members requested additional scientific information detailing the likely or potential threats from fishing to the achievement of the specific objectives of the MPA (i.e. a 'threats analysis', SC-CAMLR XXXI, paragraphs 5.33-5.37). This request echoed similar sentiments expressed at the MPA workshop in 2011 (SC-CAMLR-XXX/6 paragraph 3.41). The Scientific Committee agreed that analysis of the extent to which current or future activities may threaten the objectives of the MPA was a valid scientific question to inform the design and/or management of MPAs.

Consideration of ecosystem threats from fishing is implicit in the requirements of CCAMLR Article II(3); MPA designation is one effective means of achieving those requirements, consistent with CCAMLR Article IX and CM 91-04 paragraph 2. Identifying and seeking to mitigate specific ecosystem threats from fishing in particular locations was always implicit in the definition of MPA objectives and the process of MPA design by New Zealand and the USA (e.g. see SC-CAMLR-XXX/10 Table 1; SC-CAMLR-XXX/9 Figure 1) culminating in the updated proposal submitted to CAMLR-SM-II in Bremerhaven in 2013.

The purpose of this paper is (for those MPA objectives designed or intended to avoid or mitigate particular ecosystem threats from fishing) to make explicit the logic underlying the identification of MPA objectives and associated mapped priority features or areas for inclusion in the MPA, and to provide further scientific analysis detailing plausible mechanisms by which current or potential future fishing activities may threaten those objectives. MPA objectives defined to promote science or establish scientific reference areas are also discussed, to identify potential mechanisms by which fishing may threaten or undermine planned or existing research activities in the MPA, or prevent the establishment of effective reference areas.

Ross Sea region MPA objectives

CCAMLR XXXI/16Rev1 identified ten MPA objectives, and 27 associated mapped features or areas of priority for protection (Table 1, below), in the Ross Sea region, as follows:

i. to conserve ecological structure and function throughout the Ross Sea Region at all levels of biological organization, by protecting habitats that are important to native mammals, birds, fishes, and invertebrates;

ii. to provide a reference area in which fishing is limited, to better gauge the ecosystem effects of climate change and fishing, and to provide other opportunities for better understanding the Antarctic marine ecosystem; and

iii. to promote research and other scientific activities (including monitoring) focused on marine living resources."

iv. to protect a representative portion of benthic and pelagic marine environments;

v. to protect large-scale ecosystem processes responsible for the productivity and functional integrity of the ecosystem;

vi. to protect core distributions of trophically dominant pelagic prey species;

vii. to protect core foraging areas for land-based predators or those that may experience direct trophic competition from fisheries;

viii. to protect coastal locations of particular ecological importance;

ix. to protect areas of importance in the life cycle of Antarctic toothfish; and

x. to protect known rare or vulnerable benthic habitats."

Categories of MPA objectives

The MPA objectives fit into three main categories: *representativeness, mitigating ecosystem threats*, and *scientific reference areas*. The category of MPA objective has implications for the type and level of protection that is required within MPAs, and for the design of research and monitoring to evaluate MPA effectiveness (CCAMLR XXXI/Rev 1 Annex C paragraph 2).

Representativeness:

MPA Objective iv seeks to protect a minimum representative proportion of each benthic and pelagic bioregion. Bioregions (see WG-EMM-10/30 Figures 1 and 2) are defined with reference to environmental or physical habitat variables (e.g. depth, sea surface temperature) that are themselves unaffected by fishing activity; for this reason fishing cannot pose a 'threat' to the bioregions themselves; rather the bioregion is a proxy for the underlying biology and ecology that could be affected by fishing but for which particular threat mechanisms may be unknown. The commitment to protect a minimum representative portion of each bioregion therefore reflects precautionary management in data-poor areas or in habitats for which no specific threat mechanisms are identified (SC-CAMLR XXX/6, paragraph 4.8). Representativeness is not considered further in this paper.

Avoiding or mitigating ecosystem threats from fishing:

MPA objectives i and iv-x in CCAMLR-XXXI/16Rev1 are defined to avoid or mitigate ecosystem threats from fishing. Each of these objectives includes one or more associated mapped features or areas of particular priority for protection identified in the supporting material (SC-CCAMLR-XXX/9 and 10, and WS-MPA-11/25) and used to inform the design of the Ross Sea region MPA (as in WS-MPA-11/25). The level of protection sought for each feature (i.e. the proportion of the feature included in the MPA) is proportional to its perceived ecological importance and to the extent to which existing or potential future fishing activities in the location of the feature may be expected to exert an unacceptable ecosystem impact (see Table 1 below, updated from SC-CAMLR-XXX/10).

Article II(3) of the CAMLR Convention defines permissible limits of anthropogenic impacts on Antarctic marine ecosystems. Paragraph II(3)a effectively defines the limit of direct effects on the population of harvested stocks; these limits are operationalized in harvest decision rules that enable TACs to be calculated in accordance with the ecosystem role of the target species (i.e. as predator or as prey). Article II(3) also defines the limits of permissible effects on (non-harvested) associated and dependent species, and on overall ecosystem structure and function, requiring that ecological relationships be maintained (paragraph b), and ecosystem changes be reversible in 2-3 decades (paragraph c). Where ecological relationships between harvested and related species can be sufficiently disrupted to violate the requirements of paragraphs II(3)b-c, harvest and related activities may pose a threat to achievement of Article II, even at harvest levels lower than the limits defined in paragraph II(3)a.

Implicit in the designation of MPAs to avoid or mitigate ecosystem threats is the recognition that not all fish are of equal ecosystem importance: different fish of the same target stock, or even the same fish in different times or locations, will fill different ecological roles. For example a targeted fish in one location may provide essential prey to an air-breathing top predator, whereas in another location the same fish is inaccessible to predators. The objective of MPA designation for ecosystem threat mitigation is to identify those locations where ecological relationships may be particularly strong or particularly susceptible to disruption by fishing activities, and then design MPAs to reduce or eliminate fishing activities in those areas, displacing fishing effort instead into areas where the target fish stock is still available to the fishery but where ecosystem risks are lower. The level of protection required is highly dependent on the particular type and mechanism of plausible threat: where threats are potentially severe, unpredictable and/or irreversible, near 100% protection of the priority area or feature may be required to guarantee accordance with the terms of Article II(3); for other threats, protecting only a minor portion of the priority area or feature may be sufficient.

Scientific reference areas:

A separate but related objective of MPAs is to serve as scientific reference areas, providing opportunities to study marine ecosystems free from human interference (CM 91-04, paragraph 2(iii)), or to compare areas in which sustainable harvest is occurring with comparable areas in which no (or greatly reduced) fishing occurs, to better understand and distinguish between the effects of fishing and of other influences, including climate change. In locations where climatic or ecosystem research and monitoring is ongoing, MPA designation may help to protect the integrity of the research itself, by preventing localized harvest effects from generating bias or increased variability in data intended to monitor natural ecosystem or environmental variability and trends.

In other instances well designed MPAs can be essential to the design of the research itself, by providing for effective comparisons between fished treatments and unfished or lightly fished 'controls' in comparable habitats. The level and type of protection required to achieve the MPA objective depends on the nature of the scientific question(s) being tested and the means by which data collection in the treatment/control areas will be achieved. In many instances fishing vessels themselves may be an essential component, not only to deliver the scientific 'treatment/control' design of the MPA, but also to collect data to monitor MPA effects and/or effectiveness. In these instances it may be useful to design and implement particular spatial and temporal constraints on the distribution of fishing effort inside the MPA and to customize data collection from fishing in these areas, to optimise their contribution to defined scientific research questions.

Sustainable fishing

While MPAs are defined primarily to achieve ecosystem protection or scientific objectives, it is also true that in some locations fishing may constitute a threat to sustainable fishing itself, i.e. because harvest activities in a particular location may negatively affect the target stock in ways that would not occur if the same stock were instead harvested at the same level elsewhere. For example fishing activities that disrupt spawning behaviour or over-harvest very young fish may have a detrimental effect on long-term fishery yields; displacing fishing effort to other areas could have corresponding positive effect on fisheries management. While the primary focus of the Ross Sea region MPA design process has been on managing ecosystem threats and pursuing scientific research objectives, the design process also considered potential threats from fishing to ongoing sustainable harvest. Where threats to sustainable fishing coincide with other MPA objectives these are identified below.

Organisation of this paper

To aid interpretation and for consistency with the design of research and monitoring under CCAMLR XXXI/Rev1 Annex C, MPA objectives are organized geographically into four ecologically defined regions, as follows: 1) the Ross Sea continental shelf; 2) the Ross Sea continental slope; 3) the Balleny Islands and proximity, and 4) the northern Ross Sea region and seamounts. Within each region, threats to specific objectives are identified that correspond to the three categories above (i.e. *mitigating ecosystem threats*, *establishing scientific reference areas*, and *eliminating threats to sustainable fishing*); the boundaries of mapped areas associated with the specific objectives are shown; the ecological mechanism(s) by which threats are likely to occur are identified; and scientific evidence supporting the nature and extent of the threats are cited.

Table 1 lists the objectives of the MPA and summarizes the level of protection sought and achieved for each priority feature or area, as a function of the level of potential threat from fishing. The right-hand column indicates the nature of plausible threats to each priority feature or area, classified as follows:

a. Direct impact by existing toothfish fishery

b. Plausible direct trophic interaction (competition for prey, or predation release) with existing toothfish fishery

c. Direct impact by potential future krill fishery

d. Plausible direct trophic interaction (competition for prey) with potential future krill fishery

Potential secondary ecosystem effects that are more distant (i.e. involving two or more trophic levels) may also be possible, but the likely mechanisms are more speculative; these are not identified in Table 1 but are discussed in the text. Note that this column refers to potential impacts *on the particular priority feature represented by the mapped boundary*; other impacts potentially occurring in the same location are evaluated separately where priority features overlap in space.

Note that objective i integrates multiple threat-based objectives (v-x) and objective iii applies at all locations inside the MPA; these objectives are not mapped individually so do not appear in Table 1. Note also that not all mapped priority areas are given equal treatment in the text; this paper focuses on those threat mechanisms that are considered most plausible, for which high levels of protection are sought, that occur over large areas, or that were otherwise important in the design of the proposed MPA. For example objective [v – b] (Polar Front) was identified as an area of enhanced foraging for flying seabirds, but flying seabirds are not impacted directly, and potential indirect impacts are mitigated by other objectives; objective [v – b] is not considered further. Similarly, bottom trawling is not permitted in the Ross Sea region and impact levels from bottom longline fisheries are estimated to be extremely low (SC-CAMLR-XXIX/Annex 8, Appendix E); benthic habitats (objective x) are not considered further in this paper.

In Table 1 and associated figures the mapped priority areas for protection are unchanged from WS-MPA-11/25 and have been available since September 2012 to all CCAMLR Members in Arc-GIS format (here: http://www.ccamlr.org/en/data/gis-shape-files-and-data-layers).
Also available is the custom GIS spatial planning software described in WG-EMM-12/56, to aid transparent evaluation of MPA scenarios. This software will reproduce the content of Table 1 for any user-proposed MPA boundary.

Table 1: Protection objectives and associated mapped areas or features of priority for protection (with boundaries as identified in WS-MPA-11/25), and levels of protection sought for each area , corresponding to the level of the potential threat from fishing to each objective. Protection levels achieved under the proposed Ross Sea region MPA, and the nature of plausible fishery interactions are also identified for each priority feature or area (see text).

Priority feature or area and figure where shown	Description and boundary of priority feature or area	Region	Protection sought	% of priority area inside MPA	Potenti al threat from fishing
Objective ii: scientific reference areas comparing fished vs lightly- or un-fished areas					
Figure 7	Iselin and Mawson Banks vs. Special Research Zone Fished vs. unfished northeast seamounts	slope north	fished vs. un-fished	N/A	N/A
Objective iv: representativeness of benthic and pelagic environments					
Benthic and pelagic bioregions	[Figures 1 and 2 of WG-EMM-10/30]	N/A	low (each bioregion)	N/A	N/A
Objective v : large-scale ecosystem processes/ areas					
a Fig 8	Ross Sea shelf front intersection with seasonal ice	slope	medium	67%	D
b	Polar Front*	north	low	70%	*
c Fig 8	Balleny Islands and proximity	Balleny Is	very high	100%	A,B,C,D
d .	Ross Sea polynya Marginal Ice Zone	shelf	medium	88%	D
e Fig 2	Eastern Ross Sea multi-year ice	slope	high	99%	D
Objective vi: trophically dominant pelagic prey species					
a Fig 5	Antarctic krill core distribution	slope	medium	55%	C
b Fig 5	Crystal krill core distribution	shelf	high	99%	C,D
c Fig 5	Antarctic silverfish core distribution	shelf	high	98%	B,D
Objective vii: spatially constrained top predator foraging distributions					
a Fig 2	Adélie penguin summer core foraging distribution	shelf	high	92%	D
b Fig 2	Emperor penguin summer core foraging distribution	shelf	high	94%	D
c Fig 1	Weddell seal summer core foraging distribution	shelf	very high	96%	B
d Fig 1	Type C killer whale core summer foraging distribution	shelf	very high	92%	B
Objective viii: coastal/localized areas of particular ecosystem importance					
a Fig 5	Southern Ross Sea shelf persistent winter polynya	shelf	high	100%	B,D
b Fig 5	Coastal polynyas	shelf	very high	94%	B,D
c Fig 5	Terra Nova Bay	shelf	very high	100%	A,B,C,D
d Fig 5	Victoria coast – coastal buffer and platelet ice formation zone	shelf	very high	100%	A,B,D
e Fig 5	Pennell Bank polynya	shelf	high	74%	B,D
Objective ix: D. mawsoni life cycle areas					
a Fig 3	Sub-adult toothfish settlement areas on the Ross Sea shelf	shelf	very high	100%	A,B
b Fig 3	Dispersal trenches for maturing toothfish	shelf	very high	99%	A,B
c Fig 3, 7	Adult feeding areas on the Ross Sea continental slope	slope	medium	48%	A
d Fig 3	*D. mawsoni* spawning areas west of Ross Gyre divergence	north	low	98%	A
e Fig 3, 7	*D. mawsoni* spawning areas east of Ross Gyre divergence	north	low	57%	A
*Objective x: rare or vulnerable benthic habitats**					
a .	Balleny Islands and adjacent seamounts	Balleny Is	high	100%	A*
b .	Admiralty Seamount	north	very high	100%	A*
c .	Cape Adare proximity continental slope	slope	high	100%	A*
d .	Southeast Ross Sea continental slope	slope	high	100%	A*
e .	Southern McMurdo Sound	shelf	very high	100%	A*

* note that in the absence of existing or potential threats objectives marked * and are not considered further in this paper

Results

1. The Ross Sea continental shelf

Multiple MPA objectives overlap on the Ross Sea shelf a shallow (c. 800 m) semi-enclosed sea with persistent polynyas, high productivity relative to elsewhere in the Southern Ocean, and abundant top predators. The MPA in this location is designed primarily: to eliminate possible threats to top predator populations in core foraging areas due to direct trophic competition with the existing toothfish fishery (objective [vii – c+d]) or with potential future pelagic fisheries (objective [vii – a+b]); to protect the integrity and continuity of existing research to monitor subadult toothfish (objective [ix – a]) and of other long-term data series indicative of natural ecosystem function and environmental change (objective iii); and to protect the structure and function of the intact and tightly coupled Ross Sea shelf pelagic ecosystem by preventing ecosystem effects of fishing on species or ecological features of particular importance for trophic energy flow (objective [v – a+d]; objective [vi – a-c]; objective [viii –a-e]). The most effective way to mitigate all of these threats while maintaining fishery yields is to eliminate commercial fishing on the Ross Sea shelf, and fish instead in the deeper waters of the Ross Sea slope or in the north. Because threats exist in both the benthic and pelagic environments, the shelf region is proposed as a full no-take MPA (except for scientific research). Identified potential threat mechanisms of particular importance are identified below.

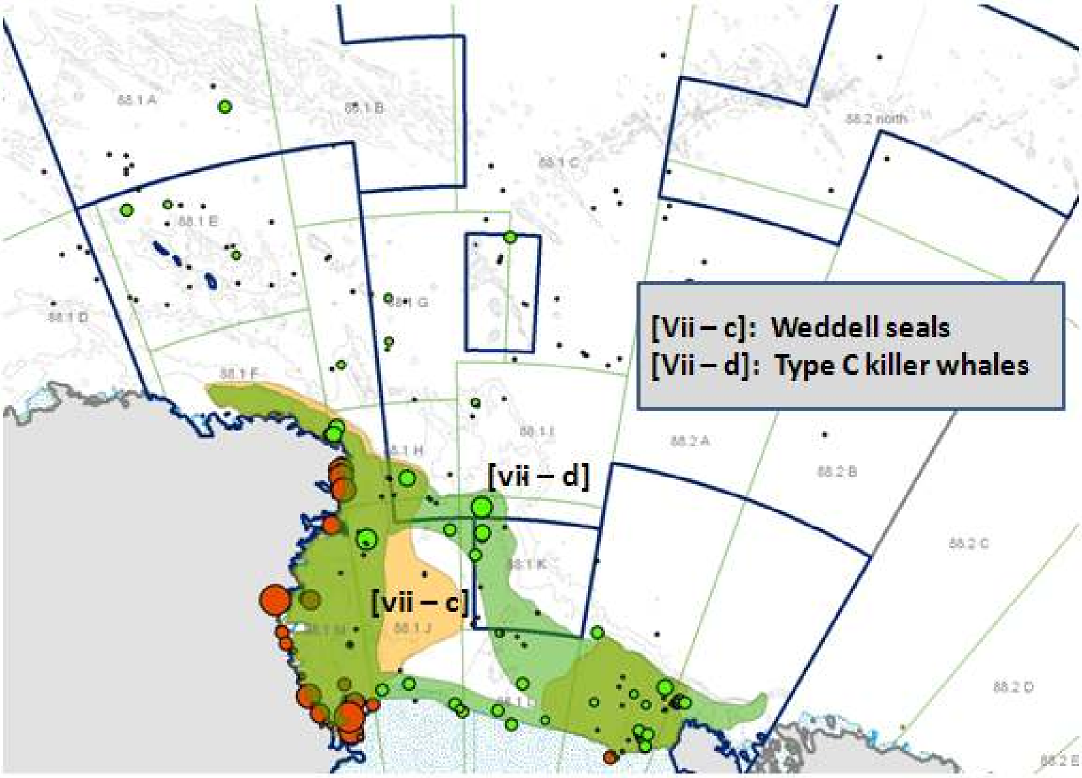

Figure 1: Core foraging areas for Weddell seals (objective [vii – c], orange, including breeding colony sizes) during the summer breeding, lactation, and post-weaning recovery phase; and for Type C killer whales (objective [vii – d], green, including at-sea sightings) during summer.

Objective [vii – d]: Type C killer whale core summer foraging distribution

Type C killer whales are the most abundant ecotype of killer whale over the Ross Sea shelf; they are specialist fish-eaters (Berzin & Vladimirov 1983; Pitman et al. 2007) and have been observed directly feeding on toothfish (Pitman & Ensor 2003; Ainley et al. 2009), utilising cracks and leads to hunt along and under fast ice edges near the Victoria Coast and in the marginal ice zone at the edge of the Ross Sea polynya (Ainley 1985; Andrews et al. 2008). The areas in which killer whales are thought to potentially interact with toothfish mapped in Figure 1.

Toothfish fishing in these locations generates two kinds of potential ecosystem risk, as well as threats to the ongoing fisheries science research program, and future fishery economic viability.

1) *Localized depletion could reduce toothfish availability for Type C killer whales in particular preferred foraging areas, with negative population consequences.* Based on stable isotope analyses (Krahn et al. 2008; Bury et al. 2008), diveable depths for killer whales (Baird et al. 2005) and total energy requirements in the context of a balanced Ross Sea trophic ecosystem model (Pinkerton et al. 2010a; Torres et al. 2013) it is not plausible that toothfish are the main prey item for Type C killer whales at the scale of the whole Ross Sea ecosystem and throughout the year. However it is likely based on behavioural observations; Ainley 2004; Ainley 2009), foraging efficiency considerations, and prey energetic analyses (Torres et al. 2013; , Eisert et al. 2013) that toothfish are an important prey item for Type C killer whales in summer months in at least some of the locations mapped in Figure 1.
2) *Prey-switching behaviour by killer whales responding to declining toothfish availability could have unpredictable ecosystem consequences.* The Ross Sea shelf ecosystem has been characterised as highly 'intact' (Halpern et al., 2008; Ainley 2009) with abundant top predator populations potentially exerting top-down ecosystem control on the abundance and distribution of their prey (Ainley 2004). Killer whales often exhibit highly specialized and selective foraging behaviour (Ford & Ellis 2006, Ford et al. 2010; Pitman & Durban 2011) and have sufficiently high per capita consumption rates to exert substantial top-down control on their prey; one consequence is that subsequent prey-switching behaviour may result in destabilizing top-down ecosystem impacts, including example possible serial population collapses of newly-targeted prey species (Springer et al. 2003, 2008) and trophic cascades (Pitman & Durban 2011; Estes et al. 1998).
3) *Learned depredation behaviour by killer whales taking toothfish from commercial vessels could undermine existing science-based management of the fishery, and reduce fishery profitability.* Killer whale depredation poses considerable challenges to fisheries management elsewhere in the CCAMLR Area (Ashford 1996; Roche et al. 2006; Moir Clark and Agnew 2010; Brandao & Butterworth 2005, Kock et al. 2006) and is a major problem for fisheries elsewhere in the world (Hamer et al. 2011, Dalla Rosa & Secchi 2007, Gilman et al. 2006; Visser 2000; Secchi and Vaske, 1998). Tag-based stock assessments rely on estimation of both total fish removals and post-release survival by tagged fish, both of which are compromised when killer whales take fish from longlines and remain present during hauling. Experience from other fisheries shows that once depredation behaviour begins it is almost impossible to stop; rather it is passed inter-generationally and may also spread between killer whale groups (Visser 2000, Yano & Dahlheim 1995). Once established, depredation may have a substantial negative impact on fisheries' economic viability. Furthermore, learned depredation behaviour may imply prey-switching away from natural prey sources, with possible destabilizing ecosystem consequences.

In the Ross Sea region to date depredation by killer whales has not been reported, and killer whales are observed to be largely indifferent to fishing vessels. However the risk of novel depredation behaviour by Type C killer whales in the Ross Sea may be high because: 1) they are already specialist fish-feeders and this is suggested as a risk factor (Guinet and Tixier, 2011); and 2) they occur in very large group sizes relative to Type B killer whales which are involved in depredation observed elsewhere (e.g. 10-150 individuals vs. 2-31 individuals; Pitman & Ensor 2003), such that novel depredation by even a single family group could have a significant impact on fisheries.

The most effective mitigation for all of these threats is to spatially segregate the commercial fishery from Type C killer whales; killer whales are commonly observed over the shallow waters of the Ross Sea shelf but only rarely over the deeper waters of the Ross Sea slope (depth 800+ m) or in the north.
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Objective [vii – c]: Weddell seal core foraging distribution

Weddell seals breed and wean their pups from colony locations in the western Ross Sea and at the Balleny Islands; and are known to prey on Antarctic toothfish during the summer breeding season (Calhaem & Christoffel 1969; Pinkerton et al. 2008; Ponganis & Stockard 2007; Ainley & Siniff 2009). Satellite telemetry (WG-EMM-10/11 Figure 36) reveals the spatial extent of foraging during the period in which Weddell seals are confined in the proximity of their colonies and immediately afterward during which breeding adults must regain condition. *Fishing in the area mapped in Figure 1 may negatively affect Weddell seals by reducing the local availability of toothfish, a potentially important prey item, during a critical life history stage in which breeding seals have greatly elevated energetic requirements.*

As with killer whales, stable isotope evidence (Burns et al. 1998, Zhao et al. 2004; Bury et al. 2008) and food web modelling (Pinkerton et al. 2008; Pinkerton et al. 2010a) suggest that that toothfish are not a major prey item for Weddell seals throughout their annual cycle. Nonetheless there are numerous direct observations of Weddell seals catching and eating toothfish at breeding colonies near McMurdo Sound (Davis et al. 1999, Davis et al. 2004; Calhaem & Christoffel 1969; Ross et al. 1982; Castellini et al. 1992; Kim et al. 2005; Ponganis & Stockard et al. 2007). New breathing holes in the ice are opportunistically exploited by seals to extend the range of their hunting, and toothfish CPUE through new drilled ice holes increases with distance away from existing breathing holes (Testa et al. 1985), suggesting that seal predation affects local toothfish abundance. Lactating females lose considerable body mass (>40%; Eisert & Oftedal 2009) and have greatly elevated energetic requirements during the breeding, lactating, and post-weaning recovery phase prior to delayed embryo implantation (Eisert et al. 2013; Oftedal & Eisert 2010). Heavy ice cover is correlated with reduced pup production in Erebus Bay, potentially due to effects on prey availability (Eisert & Oftedal 2009); it is likely that localized depletion by fisheries of toothfish close to Weddell seal breeding colonies could have similar detrimental effects on Weddell seal breeding success. Antarctic toothfish are likely to be the best available prey to Weddell seals in this period, such that a single average sized toothfish (energetically equivalent to more than 600 adult silverfish) is sufficient to meet elevated daily energetic requirements in this period (Eisert et al. 2013). On this basis toothfish fishing inside the areas indicated in Figure 1 may constitute a threat to Weddell seals; the proposed MPA effectively mitigates this threat.

Objective [vii – a+b]: Adélie and emperor penguin core summer foraging distributions

The potential threat mechanism by which fisheries may negatively affect breeding penguin colony populations is the same as for Weddell seals above, except that the threat arises from potential future pelagic fisheries (i.e. for silverfish or krill). Presumed foraging distributions in the summer period, during which breeding adults must forage and return to the colony to feed chicks, are shown in Figure 2. Penguins rely almost exclusively on silverfish and crystal krill at southern colonies (Smith et al. 2012) and also on Antarctic krill at more northern colonies near Cape Adare (Ainley 2002). Reproductive success is highly sensitive to prey availability and quality within obligate foraging distances (Whitehead et al. 2013, Ainley 2002). Satellite telemetry confirms that foraging distance increases through the season and as a function of proximity to other colonies, indicating that penguin predation is sufficient to locally deplete available prey (Ballance et al. 2009; Ainley et al. 2003). Penguins may be similarly vulnerable to localized prey competition during the post-summer moulting period, when they are confined to persistent pack ice in the eastern Ross Sea region (see below). On this basis fishing for penguin prey (krill or silverfish) within these areas may pose a threat to penguins.

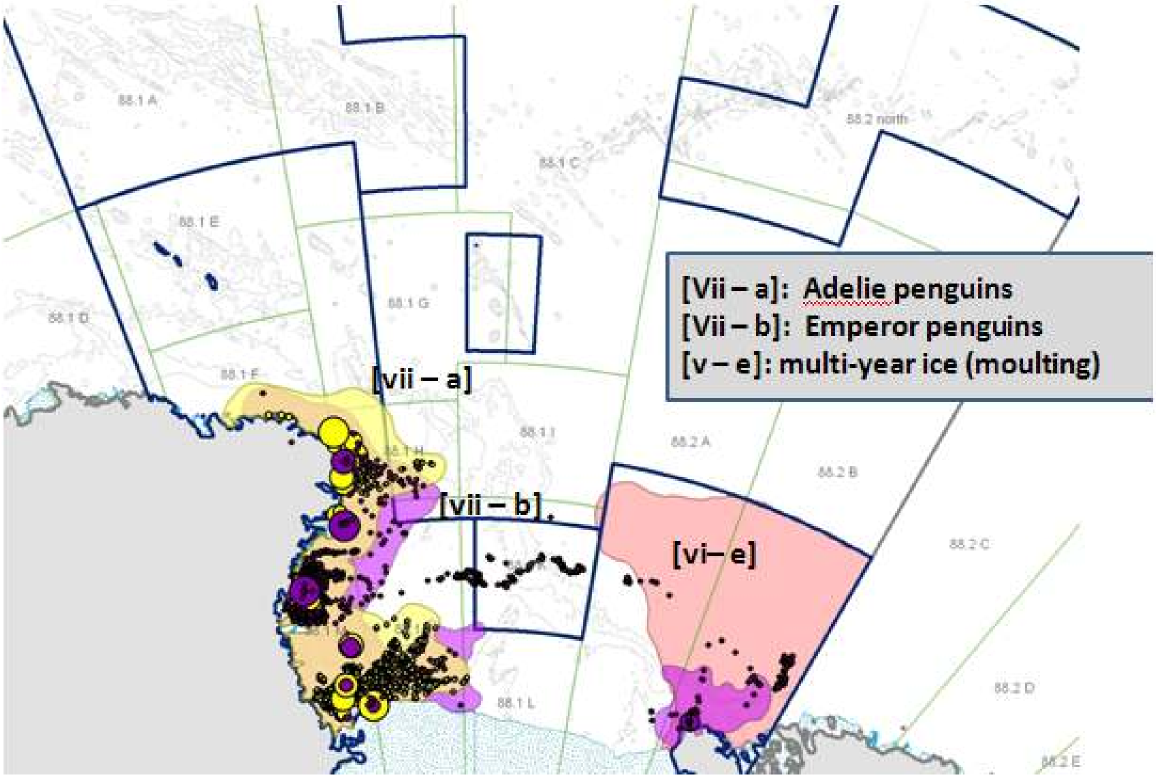


Figure 2: Core breeding (summer) foraging areas for Adélie penguins (objective [vii – a], yellow); and for Emperor penguins (objective [vii – b], purple) including colony sizes and summer foraging tracks. Persistent pack ice in the eastern Ross Sea (objective [v – e]) is seasonally important during moulting.

Objectives iii; [ix – a]: Sub-adult toothfish settlement areas in the southern Ross Sea shelf

In Hanchet et al. (2008) sub-adult toothfish (c. 5-10 years old and 60-100 cm) are thought to enter the Ross Sea region from the east and settle first in discrete deeper areas of the southern Ross Sea shelf, after which they appear to move westward eventually north to the deeper waters of the Ross Sea slope as they mature. An annual CCAMLR-sponsored scientific survey within defined strata on the southern Ross Sea shelf is designed to monitor the abundance of sub-adult toothfish as an index of recruitment variability, for use in the toothfish stock assessment, and as a potential 'early warning' of recruitment changes potentially affecting future yields. The first two years of this planned annual survey have been successfully completed (Hanchet et al. 2012, Parker et al. 2013). Locations of highest sub-adult toothfish abundance ([ix – a]) (including the core subadult survey strata) are shown in Figure 3. *Commercial fishing in these same locations just prior to the survey could be expected to generate increased noise and uncertainty in the survey index of abundance, undermining its effectiveness (e.g. Parker et al. 2013).*

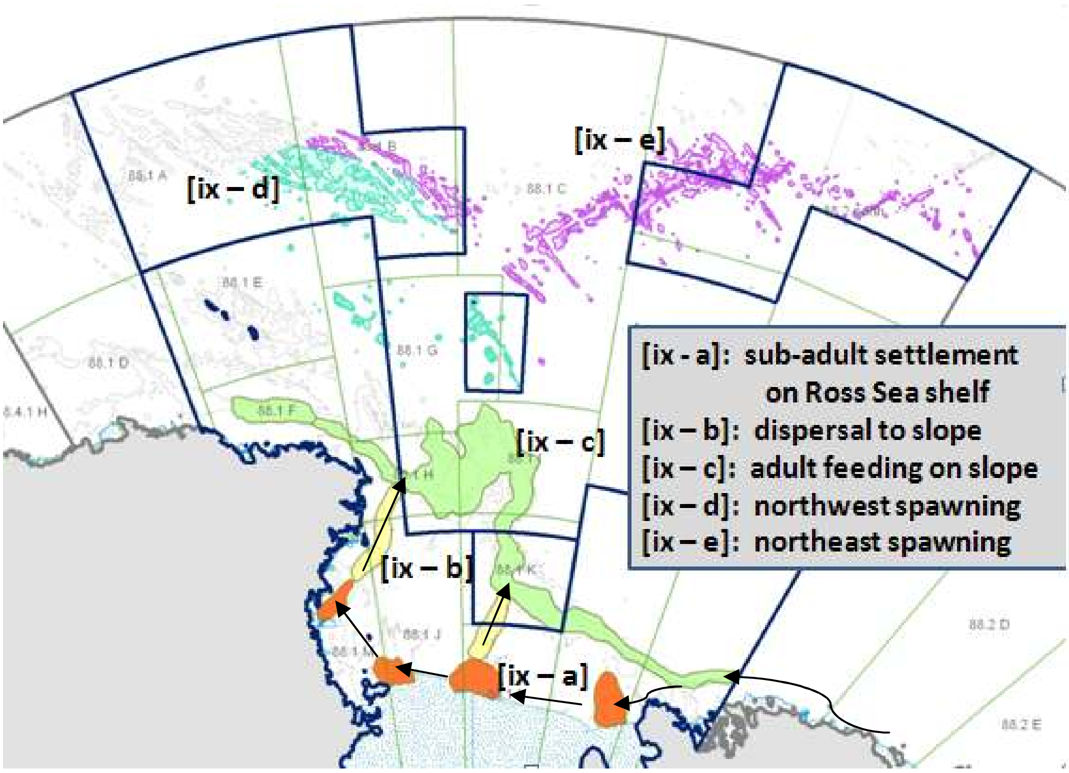
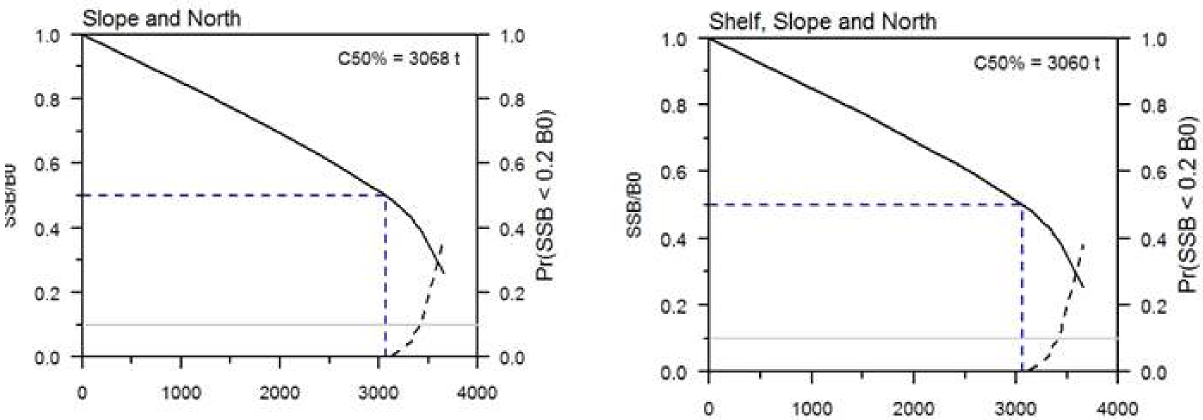


Figure 3: *D. Mawsoni* life cycle areas, following Hanchet et al. (2008), including: sub-adult settlement areas on the Ross Sea shelf (objective [ix – a], orange); dispersal trenches for maturing toothfish (objective [iv – b], yellow); adult feeding areas on the Ross Sea slope (objective [ix – c], green); and northern spawning areas to the west (objective [iv – d], turquoise) and east (objective [iv – e], purple]) of the Ross Gyre divergence.

Toothfish in these locations are also potentially available for top predators (see objective vii above), either in these locations or as they continue their anticipated life cycle movements west and north to locations nearer the Victoria Coast. These fish may be especially important if some killer whales over-winter in the Ross Sea polynya (area [viii – a]; Figure 5). Finally, commercial fishing on the Ross Sea shelf does not optimise potential fishery yields, because the dominant size mode of fish here are smaller than that which maximizes yield per recruit; (see Figure 4). *Designating an MPA in these locations therefore safeguards the integrity of an important fishery survey, prevents potential trophic competition with top predators, and has a neutral or minimally positive effect on potential fishery yield.*

Figure 4. Effects on projected fishery yields under CCAMLR decision rules for the Ross Sea toothfish fishery (modelled in WG-FSA-11/42) in which all commercial effort is displaced away from the Ross Sea shelf (left) vs. status quo management, under which some catch is taken from the shelf. Displacing effort away from the shelf has a neutral or marginally positive effect on yields, because many fish on the shelf are caught at a size lower than that which optimizes yield per recruit.



Objective iii, [vi – a-c]: Antarctic silverfish and crystal krill

The Ross Sea shelf ecosystem has been characterised as highly 'intact' (Halpern et al., 2008; Ainley, 2009) and potentially tightly coupled, such that impacts on key species may be expected to propagate through the food web (Pinkerton and Bradford-Grieve 2012). In contrast to the Antarctic-krill-centric ecosystem elsewhere in the Southern Ocean, in the Ross Sea Antarctic silverfish and to a lesser extent crystal krill are responsible for the vast majority of trophic energy flow between planktonic ecosystem components and abundant top predators (Smith et al. 2012; Pinkerton et al. 2010a). Spatial distributions for silverfish and crystal krill are shown in Figure 5, confined to the Ross Sea shelf. Both species may become locally depleted by predators, and silverfish are known to be cannibalistic at some times and locations, consistent with food limitation (Eastman, 1985; Pinkerton et al. 2013). In this context (i.e. evidence of top-down ecosystem control) *pelagic fisheries affecting these key species can be expected to exert secondary trophic other ecosystem components, including secondary effects on both higher and lower trophic levels, potentially undermining achievement of Article II(3)b-c.* Mixed trophic impact analysis (Ulanowicz & Puccia, 1990; Libralato et al., 2006) based on the mass-balanced Ross Sea trophic ecosystem model (Pinkerton et al., 2010a) reinforces this conclusion (Pinkerton & Bradford-Grieve 2012); silverfish are ranked third (after phytoplankton and mesozooplankton) in an index of trophic importance (Figure 6a). Because silverfish have high biomass and interact directly with a large number of ecosystem components from zooplankton to top predators, secondary trophic effects of any pelagic fishery affecting silverfish could be confounded with or indistinguishable from natural dynamics, undermining efforts to understand ecosystem function and environmental change unaffected by human impacts. Where ecosystem research and monitoring is ongoing in association with permanent bases in McMurdo Sound and Terra Nova Bay (e.g. Cameron & Siniff, 2004; Ainley 2002; Povero et al., 2001) long term time series data from these programmes, including CEMP monitoring, represent a substantial investment over many decades; MPA designation to protect key pelagic prey species in these locations protects this investment.

Objectives i; [v – a+d]; [viii – a-e]: ecological features and habitats of particular importance for trophic energy flow.

Figure 5 also depicts areas identified as priorities for protection because they contain features, habitats, or processes associated with high primary productivity or enhanced trophic energy flow to higher trophic levels. These include coastal polynyas [viii – a-e] and the Ross Sea polynya marginal ice zone [v – c]; *intense utilisation by top predators in these areas imply that fishing here may create increased risks of direct trophic competition with fisheries, or trophic cascades affecting food web structure.* These areas are almost wholly contained within the larger distributions for silverfish and crystal krill, and potential threat mechanisms are as discussed above.

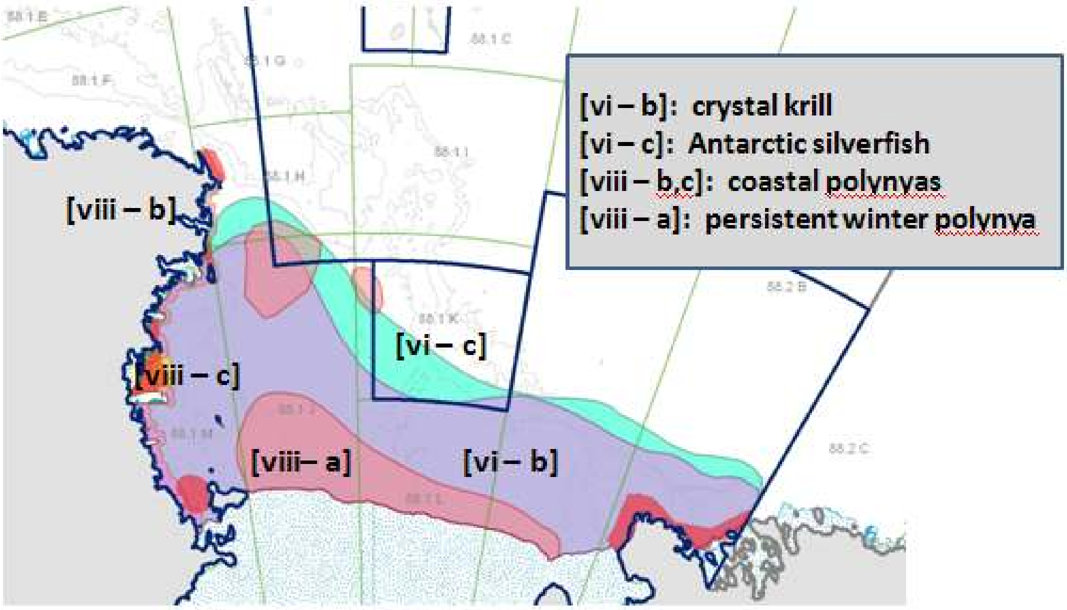


Figure 5: Priority areas for protection associated with Antarctic silverfish (objective [vi – c], turquoise); and crystal krill (objective [vi – b], purple) and with polynyas (red) including as the persistent winter Ross Sea polynya [viii – a], Terra Nova Bay [viii – c] and localized coastal polynyas [viii – b].

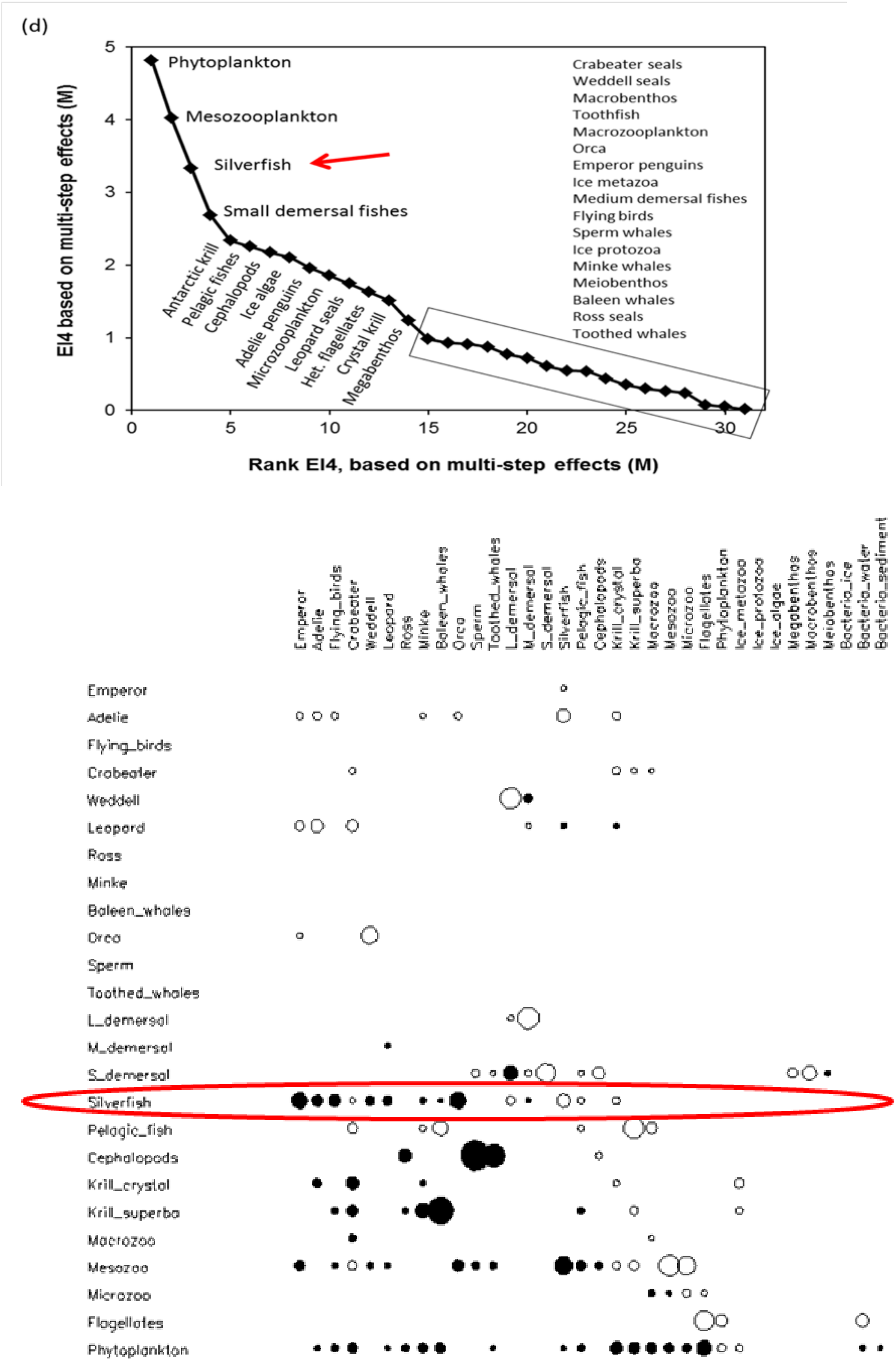


Figure 6: Results of a mixed trophic impact analysis for the Ross Sea based on the food-web model of Pinkerton et al. (2010a). Positive impacts are shown black and negative are white, with the diameter of the circle proportional to the magnitude of the effect. These results illustrate the ecosystem importance of Antarctic silverfish, with an aggregate trophic influence second only to phytoplankton and mesozooplankton (above). Changes in the abundance of silverfish can be expected to exert influence on a wide range of other ecosystem components at higher and lower trophic levels (below). Reproduced from Pinkerton and Bradford-Grieve (2012).

2. The Ross Sea continental slope

The Ross sea slope includes depths of 800-2500 m. Vertical mixing and a frontal zone make this area productive and preferentially utilized by foraging top predators. The slope supports the main feeding areas for adult Antarctic toothfish, including the main historical fishing grounds on Mawson and Iselin Banks (Stevenson et al. 2012). See Figure 7. The slope also supports elevated concentrations of Antarctic krill (O'Driscoll et al., 2011; Sala et al., 2002). The proposed MPA in this region is designed primarily to achieve science objectives, by enabling comparisons between lightly fished vs. more heavily fished locations, and to protect important pelagic prey (e.g. Antarctic krill) in key areas while still providing opportunity for future sustainable krill harvest consistent with Article II.

Objectives ii, iii, [ix – c]. scientific reference area to better gauge the ecosystem effects of climate change and fishing.

The proposed Special Research Zone (SRZ) in SSRU 88.1K establishes a zone in which the exploratory fishery for Antarctic toothfish would enable scientific research to better understand the ecosystem effects of fishing distinct from climate change. The SRZ overlays a portion of the Ross Sea slope that supports Antarctic toothfish with similar size composition to the established traditional fishing grounds on Mawson and Iselin Banks, outside the MPA (New Zealand 2013). This design effectively establishes an ecosystem-scale experiment. Total historical removals in the SRZ have been lower than those for Mawson and Iselin Banks despite the presence of an apparently comparable biomass, and future exploitation rates will be considerably lower under the MPA proposal (see Mormede & Dunn 2013), while maintaining sufficient fishing to provide a platform for data collection. *While spatially controlled fishing effort is necessary to achieve these science objectives, spatially uncontrolled fishing threatens achievement of these objectives by undermining the proposed heavily vs. lightly fished contrast.*

The SRZ reference area will enable research to examine the following known or potential effects of fishing:

- The most likely foreseeable ecosystem effect of the toothfish fishery is increased abundance of toothfish prey (e.g. rattails and icefish) in fished areas (Pinkerton et al. 2010a; Pinkerton & Bradford-Grieve 2012); monitoring bycatch and toothfish stomach contents inside vs. outside the SRZ could greatly improve our understanding of demersal fish food web interactions (Pinkerton et al. 2010b).
- The size composition of exploited populations changes over time; monitoring changing size compositions inside vs outside the SRZ will help scientists to better estimate exploitation rates, gear selectivity, and fish movements between areas.
- If the ecosystem role of larger older fish is qualitatively different than that of smaller younger fish then maintaining a portion of the stock with the original composition helps to prevent unforeseen ecosystem changes in that location (Francis et al. 2007)
- Fishing can affect the exploited population's 'intrinsic' biological and demographic parameters (e.g. growth rate, age at maturity) either as a selective evolutionary force or by inducing a plastic response to reduced intraspecific competition as fish density declines (Allendorf & Hard 2009; Haugen & Vøllestad, 2001; Conover & Munch, 2002; Conover, 2000, 2007; Edeline et al. 2007, 2009; Berkeley et al. 2004)

- If predators are found to interact with toothfish on the slope (e.g., Weddell seals during winter) then monitoring habitat utilisation or foraging success inside vs outside the SRZ may indicate to what extent toothfish are important prey outside of core areas and whether fisheries removals affect these predators.

The ability to detect and study these effects will be heavily dependent on patterns of toothfish movement and mixing rates between adjacent areas, which is a high priority research question and the subject of new modelling efforts (see Mormede & Dunn 2013). Tag recaptures to date from this area have been low and include an unusually large proportion of fish that have moved between SSRUs between the time of their release and recapture. Maintaining the toothfish tagging programme in this area is important to provide empirical estimates of movement and mixing rates (New Zealand 2013).

Besides providing a platform from which to collect data to inform the above comparisons, the purpose of ongoing fishing at levels proposed inside the SRZ is to maintain the integrity and continuity of the toothfish tagging programme, which inform the stock assessment and underpins the science-based management of the fishery. Tagging and recapturing toothfish in this zone is necessary to maintain a stable index of abundance for this portion of the stock and to continue to improve our understanding of toothfish life cycle movements. The increased tagging rate inside the SRZ compensates somewhat for reduced catch and scanning rates in this zone, to minimise expected changes to bias in the stock assessment. New Zealand (2013) discusses future research designs in the SRZ that may further optimise the collection of data in this zone to answer priority research questions. In addition, Ross Sea toothfish spatial population model currently in development (Mormede & Dunn 2013) may inform simulations to examine the consequences of spatial management designs for tag-based stock assessments, and to design tagging programmes to reduce stock assessment bias arising from toothfish movement and spatially unrepresentative fishing effort patterns.

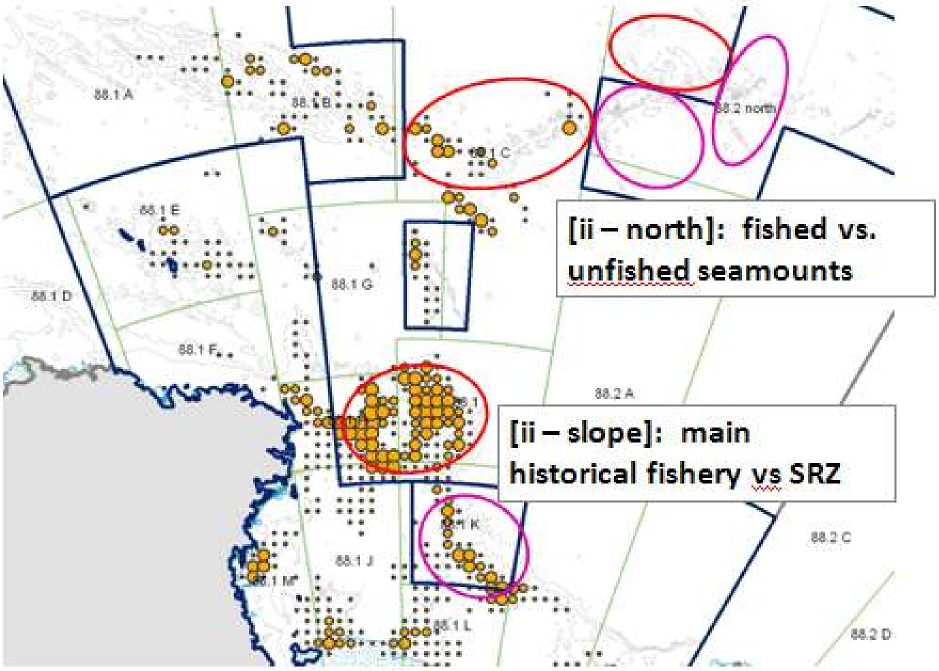


Figure 7: Proposed scientific reference areas (Objective ii) comparing fished vs. lightly- or un-fished locations on the Ross Sea slope and northern seamounts. Circles indicate total toothfish removals (tons) in the history of the fishery (1998-2013; note the absence of circles in the north of 88.2 AB indicating that this area has never been open for commercial fishing).

Objective [v – e]: eastern Ross Sea persistent pack ice

Persistent pack ice in the eastern Ross Sea overlying and north of the Ross Sea slope (see Figure 5) provides essential moulting habitat for large numbers of Emperor penguins (Ainley et al. 2006) and crabeater seals (Ainley 1985) which feed on Antarctic krill during the late summer moulting period. *Krill fishing here during the time when krill predators are spatially constrained in close proximity to pack ice could result in localized depletion, with corresponding threats for predator populations similar to those associated with fishing near breeding colonies.*

Objectives [vi – a] and [v – a]: Antarctic krill, and top predator foraging on the Ross Sea slope front

The MPA design in this region also achieves moderate levels of protection for areas of highest abundance of Antarctic krill [vi – a], and for the productive summer ice-free portion of the Ross Sea slope front [v – a], which is preferred by top predators (Ainley *et al*. 1984; Gilbert & Erikson 1977; Ichii *et al*. 1998; Karnovsky *et al*. 2007). The intention was to fully protect those areas where krill and other pelagic prey are likely to be most important (i.e. in close proximity to land-based predator colonies or moulting habitat; see Figure 7) while ensuring that other areas of high krill abundance remain outside the MPA to allow future sustainable harvest consistent with Article II.

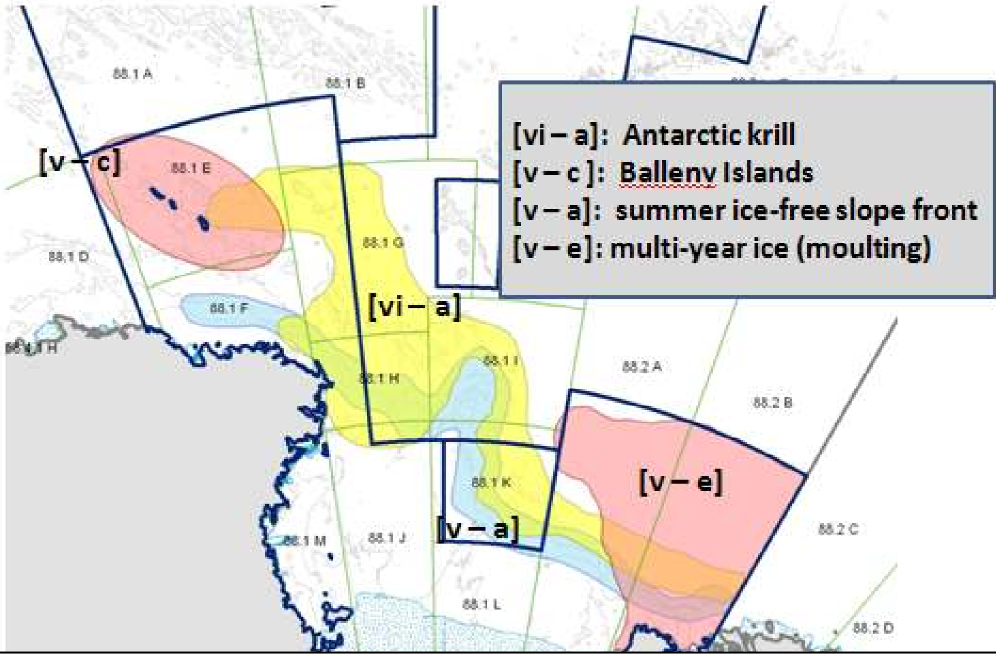


Figure 8: Priority areas for ecosystem protection on the Ross Sea slope and Balleny Islands: Antarctic krill (objective [vi – a], yellow); the summer ice-free continental slope front (objective [v – a], blue) is a focus for top predators; pack ice in the eastern Ross Sea (objective [v – e], red) is important for moulting penguins and seals; the Balleny Islands (objective [v – c], red) are an ecosystem hotspot: this priority area is drawn to encompass multiple objectives (analogous to objectives v, vi, vii, and ix on the Ross Sea shelf.)

3. The Balleny Islands and vicinity

The Balleny Islands and surrounding waters constitute a regionally unique ecological hotspot. Complex oceanographic conditions arising from intersecting water masses, a recurrent deep-water polynya (Martin et al. 1992, Arrigo & Van Dijken 2003) and transient wind-driven polynyas make this an area of elevated biological productivity, including abundant adult and larval Antarctic krill (Voronina 1995, Timonin 1987, Voronina & Maslennikov 1993, Azzali & Kalinowski 2000) and possibly also Antarctic silverfish (apparent in acoustic surveys but unconfirmed by physical sampling; S. Gauthier, NIWA, unpublished). These prey resources in proximity to land support breeding and transient populations of colony-based top predators including the only known chinstrap penguin breeding colony within 4000 km (Macdonald et al. 2002), as well as abundant whales. Humpback whales from East Australia are known to migrate almost exclusively to this area to feed. These whale populations are currently recovering at a rate of 8-10% per annum; in contrast Pacific humpback populations that presumably migrate to areas east of the Ross Sea region are scarcely recovering (Constantine et al. 2013). The differences in these observed population trends may illustrate the high ecosystem importance of the Balleny Islands pelagic environment as an ecological hotspot on a circumpolar scale. In the demersal environment the Balleny Islands and surrounding seamounts provide unique volcanic substrate habitats with a diverse fish assemblage including species not found elsewhere in the Ross Sea region (Balushkin 1976). Some of the smallest Antarctic toothfish observed in the Ross Sea region (< 60 cm) were found here.

Because of this diversity, the spatial boundary associated with objective [v – c] (Figure 8) essentially encompasses multiple protection objectives corresponding to objectives [vi - a+c], [vii - a-d], [ix – a], [viii – b], and [x – a] elsewhere. In the absence of specific spatial data, a single distribution was used, drawn sufficiently large to encompass the presumed foraging radius of colony-based predators and the observed effect of the islands generating transient polynyas affecting biological productivity. *Corresponding threat mechanisms to objectives in this area are as identified above for objectives v, vi, vii, and [ix – a] on the Ross Sea shelf.* Because these include threats in both the pelagic and demersal environments, this area is proposed as part of the general (no-take) protection zone.

4. Northern Ross Sea region and seamounts

The northern Ross Sea region includes seamounts and underwater features of the Pacific-Antarctic Ridge; it is an overlap zone for fish at both the northern and southern extremes of their distributions, as well as an area of significant endemism. These features also support mature Antarctic toothfish and a productive portion of the regional fishery. MPA objectives in this area seek to prevent disruption of toothfish spawning behaviour, to deliver science outcomes to better understand toothfish spawning and life cycle dynamics, and to achieve representativeness.

Toothfish recovered from sperm whale stomachs (Yukhov 1971) and gonad maturity indices from toothfish captured by the fishery (Parker & Marriott 2012) suggest that Antarctic toothfish migrate to northern seamounts to spawn (Hanchet et al. 2008); it is possible that spawning is also more widespread and occurs on the continental slope (Petrov 2011, Parker & Grimes 2010). Spawning likely occurs in winter but spawning fish have not been sampled directly. Simulations using oceanic circulation models (Dunn et al. 2012) suggest that eggs and larvae released east of the Ross Gyre divergence are carried to the east and eventually back to the Antarctic continent in Subarea 88.2, where juvenile fish (< 60 cm) have been observed. Eggs and larvae released west of the divergence may be carried to the Balleny Islands and perhaps to the Antarctic coast west of the Ross Sea or in Subarea 58.4.1 (Ashford et al. 2012). Because of this oceanographic discontinuity, protection objectives for spawning toothfish are evaluated separately with reference to spatial distributions west [ix – c] and east [ix – d] of the divergence (Figure 3).

Objective [ix – d]: Protection of spawning toothfish west of Ross Sea divergence

Seasonal protection in the northwest Ross Sea region seeks to eliminate the threat that commercial fishing may disrupt spawning behaviour. Because spawning occurs in winter, a seasonal closure is adequate for this purpose (i.e. in the Spawning Protection Zone in SM-XXXII-XX). Therefore this objective does not constrain the existing (summer) fishery; instead the proposal would re-open currently closed areas in the northwest Ross Sea region (SSRU 88.1 A). See Figure 3.

Objectives ii,iii, [ix – e] scientific reference area and protection for spawning fish

Protection proposed in the north of SSSRUs 88.2A and B prevents disruption of winter spawning behaviour as above, but includes additional (year-round) protection to achieve science objectives (ii and iii). By establishing a no-take reference area in historically closed areas (Subareas 88.2 AB) in close proximity to known productive fishing grounds in Subarea 88.1C, this MPA design will enable comparisons of fished vs unfished seamounts in comparable habitats. See Figure 7. By monitoring changes to fish populations in these areas over time (as for objective ii and [ix – c] on the slope, above) it may be possible to better understand fish movements related to spawning behaviour and the effects of fishing in these locations. If fish mix between northern areas in the course of their ontogenetic movements then no contrast in the open vs. closed areas would be expected; however if fish are actually resident in the north over many years or if they exhibit site fidelity in their spawning migration (as in Atlantic cod: Robichaud & Rose, 2001; North Sea plaice: Hunter et al., 2003) then well-designed research utilising the open vs. closed contrast may be able to detect changes to the fished population over time and improve our understanding of life cycle movements. Residence time on northern seamounts may be sex-dependent (Mormede et al. 2011). This dynamic would be important to include in developing a monitoring program in this area, and would also influence the parameterisation of the SPM (Mormede & Dunn 2013). The degree of movement both within and between areas will significantly affect the outcome of any MPA design in this area, and should be considered in the design of monitoring plans.

Proposing full protection of a portion of the northern seamounts also delivers representativeness with respect to northern bioregions that do not exist elsewhere (see Figures 1 and 2 of WG-EMM-10/30).

Discussion

Spatially explicit analyses of existing or potential threats from fishing to the achievement of MPA objectives can greatly facilitate transparent and rigorous dialog to inform the design and/or management of MPAs. Where objectives are agreed (as in CM 91-04 paragraph 2) and mechanisms potentially threatening those objectives can be shown to exist in particular locations, and where MPAs provide an effective means of avoiding or mitigating potential threats consistent with Article IX, then part of the rationale guiding MPA design arises logically from the locations at which objectives may be threatened and the extent of the protection required to mitigate them. In this way the policy decision to establish MPAs can be strongly informed by scientific analyses.

The objectives of the proposed Ross Sea region MPA are consistent with CM 91-04, and were defined to protect against specific foreseeable or potential threats to the marine ecosystems of the Ross Sea region, as in Article II(3) paragraphs b and c, and to achieve scientific outcomes. We believe that designating the proposed MPA is the most effective way of mitigating these threats and improving scientific understanding of the Ross Sea region, while providing for ongoing sustainable harvest consistent with Article II. Furthermore we expect that other CCAMLR Members undertaking MPA planning in the Ross Sea region committed to a similar set of objectives and drawing upon the same extensive scientific knowledge base would logically arrive at a similar MPA proposal.

This paper is intended to facilitate rigorous scientific consideration and discussion of these issues, to support the adoption of a Ross Sea region Marine Protected Area at CAMLR-SM-II in Bremerhaven.

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