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Title **THE ROSS SEA ANTARCTIC TOOTHFISH FISHERY: REVIEW OF THE 3-YEAR EXPERIMENT AND DEVELOPMENT OF MEDIUM-TERM RESEARCH OBJECTIVES AND AN OPERATIONAL FRAMEWORK FOR THE FISHERY**

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ABSTRACT

The aim of this paper is to review the recent management of the Ross Sea toothfish fishery (including the 3-year experiment), to identify key operational and research objectives for the fishery over the next 5–7 years in relation to Article II of the Convention, and to develop an operational framework to achieve those objectives. The paper focuses primarily on Antarctic toothfish, as catches of Patagonian toothfish are negligible, and covers Subareas 88.1 and 88.2.

We begin by summarising the operational management and conduct of the fishery up to the 2004–05 fishing year (prior to the start of the 3-year experiment). This includes the reasons why the 3-year experiment was initiated and the key objectives of the experiment. We then go on to summarise the operational changes which formed the framework of the 3-year experiment, and to review the success and/or any problems associated with each of those changes.

Next we identify key operational and research objectives for the fishery over the next 5–7 years in relation to Article II of the Convention. As part of this process we identify uncertainties in our current knowledge which need to be addressed to fulfil the requirements of Article II. These include, for example, uncertainty in the biological parameters and stock assessment of Antarctic toothfish, uncertainty in its ecological relationships with predators and prey, and uncertainty over other ecosystem effects of fishing. Finally, we provide recommendations on the development of an operational framework for the fishery.

SUMMARY OF FINDINGS AS RELATED TO NOMINATED AGENDA ITEMS

Agenda Item	Findings
5.1	We review the 3-year experiment and develop medium-term research objectives and an operational framework for the fishery.

The Ross Sea Antarctic toothfish fishery: review of the 3-year experiment and development of medium-term research objectives and an operational framework for the fishery.

Delegation of New Zealand

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The aim of this paper is to review the recent management of the Ross Sea toothfish fishery (including the 3-year experiment), to identify key operational and research objectives for the fishery over the next 5–7 years in relation to Article II of the Convention, and to develop an operational framework to achieve those objectives. The paper focuses primarily on Antarctic toothfish, as catches of Patagonian toothfish are negligible, and covers Subareas 88.1 and 88.2.

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1. INTRODUCTION

The exploratory toothfish longline fishery in the Ross Sea region was started in 1996/97. The fishery initially developed slowly, but there was a doubling of effort, in terms of numbers of vessels and sets, in 2000/01 and again in 2003/04. The catch limit was reached for the first time in 2004/05 which also coincided with the year of the first independent assessments of Antarctic toothfish based on tag-recapture data.

In response to difficulties experienced in the day-to-day management of the fishery by the Secretariat and in the prosecution of the fishery by fishers, and to improve the usefulness of the information coming from the fishery a number of changes in the management of the fishery were proposed at the 2005 CCAMLR meeting. These changes, which included amalgamation of catch limits across Small Scale Research Units (SSRUs), the introduction of open/closed SSRUs, the removal of the requirement for prescribed geographical separations and minimum and maximum hook numbers for research sets, and research allocations for closed SSRUs, were agreed on the basis that they would form the basis of an experiment which would run for a period of three years until the end of the 2007/08 season. The Scientific Committee considered that after this time it would be better understood how to gain the information necessary to establish catch limits in other areas of the Ross Sea (SC-CAMLR XXIV para. 4.163)

As the experiment has now come to the end of its three year period, it is timely to review the effect that the experiment has had on the fishery with respect to the fishing activity, the day-to-day management of the fishery, and the effect on reducing uncertainties in the stock assessment. We review the success of each of the management changes – what worked, what didn’t work, and what could be improved.

In considering the future management of the fishery it is important to consider the long-term goals of the fishery management in relation to Article II of the Convention. To address those long-term goals we will identify key operational objectives which need to be achieved over the next 5–7 years. To achieve many of those goals will require both a detailed research plan and a management plan which has been designed to enable that research to be undertaken. The development of a more structured research plan for Subarea 88.1 and 88.2 was recommended by the Scientific Committee in 2006 (SC-CAMLR XXV para. 4.210).

2. HISTORY OF THE TOOTHFISH FISHERY UP TO 2004/05

2.1 Operational management of the fishery

Catch limits have been set for *Dissostichus* spp. in Subarea 88.1 since 1996/97. Although the main target for the fishery is the Antarctic toothfish (*D. mawsoni*), the catch limit includes catches of the closely related Patagonian toothfish (*D. eleginoides*), which is mainly taken in the northern part of the zone (Hanchet 2006). In the first three years of the fishery separate limits were set for north and south of 65ºS. For the 1999/00 to 2002/03 seasons the area south of 65ºS was divided into four SSRUs and the catch limit divided equally amongst the SSRUs (Figure 1a). To ensure a reasonable spread of effort within SSRUs, vessels were required to carry out a requisite number of research hauls each separated by a minimum distance, and were restricted to a maximum catch of 100 t in any Fine Scale Rectangle (FSR; an area of 0.5º latitude by 1º longitude). For the 2003/04 and 2004/05 seasons, the FSR’s were replaced by a larger number of SSRUs. The whole of Subarea 88.1 was divided into twelve SSRUs based on bathymetric and ecological differences within the area, and the total catch limits subdivided amongst SSRUs based on fishable seabed area and historical CPUE (Figure 1b). For these two seasons SSRUs 88.1A, 88.1D, and 88.1F had zero catch limits.

Subarea 88.2 has been managed slightly differently. The area to the north of 65ºS in this Subarea has never been open for fishing. Catch limits for *Dissostichus* spp. in the area to the south of 65ºS have been set since 1999/00. For the 1999/00 to 2004/05 seasons the area south of 65ºS was divided longitudinally into seven SSRUs, but there were no individual SSRU catch limits (Figure 3b).

2.2 Catch and effort in the fishery

The exploratory longline fishery in Subareas 88.1 and 88.2 was initiated by a single New Zealand vessel fishing in 1996/97 and 1997/98 (Table 1). The fishery developed slowly with two and then three vessels fishing in the next two years. In 2000/01, the three New Zealand vessels were joined by 4 vessels from South Africa and Uruguay. The number of vessels dropped to two in 2001/02 but then there was a rapid expansion of effort, which saw the number of vessels increase to nine in 2002/03 and to 21 in 2003/04. The number of vessels dropped to 10 in 2004/05 then increased to 13 in 2005/06 and further to 15 during 2006/07 and 2007/08. The effort deployed by the vessels, in terms of numbers of sets, has shown a similar pattern increasing from 82 sets in 1997/98 to 2164 sets in 2003/04 before declining to 1529 sets in 2004/05. In contrast to the effort, the total catch of *Dissostichus* spp has shown a steadier increasing trend, exceeding 1000 t for the first time in 2001/02 and peaking at 3477 t in 2004/05, which was the first year when it was close to the catch limit.

The location of toothfish catch in the fishery from 1996/97 to 2004/05 is illustrated in Figure 2 and summarised in Table 2. The majority of the toothfish catch was taken in most years from SSRUs 88.1C, 88.1H, and 88.1I. However, in some years such as the 2004/05, when sea-ice conditions were favourable to fishing operations, a significant amount of the catch was also taken from the more southern and eastern SSRUs 88.1K and 88.1L. The strong effect of sea-ice conditions on toothfish catches was clearly demonstrated by Hanchet et al. (2005). The location of effort in the fishery shows a similar pattern to catches, with a particularly high effort in SSRUs 88.1C, 88.1H, 881.I, and 881.K (Figure 3).

2.3 Context for the initiation of the 3-year experiment

Several factors led to the development of the 3-year experiment including the need to reduce the uncertainty in the assessment by improving the usefulness of the information coming from the fishery, a need to address problems experienced by the Secretariat in monitoring the large number of catch limits for target and bycatch species, as well as difficulties experienced by fishers in relation to competition and gear conflict within SSRUs. These are considered in more detail below.

For up to and including the 2004/05 season, catch limits for the toothfish fishery in each of Subarea 88.1 and 88.2 were based on analogy with the stock assessment of *D. eleginoides* in Subarea 48.3 (SC-CAMLR-XXII). The analogy essentially involved multiplying the yield at South Georgia by the relative density (CPUE), the relative productivity of the two species (gamma), and the relative fishable seabed areas between South Georgia and each of the two subareas. The resultant yield estimates for Subareas 88.1 and 88.2 were then multiplied by a discount factor to allow for uncertainty in the approach.

Because of the many potential problems associated with this approach, New Zealand investigated alternative methods of monitoring and assessing the fishery. Using simulations they investigated the feasibility of using a tagging programme to monitor trends in the toothfish stock (Sullivan et al. 2003). The simulations suggested that based on a tagging rate of 1 toothfish per tonne of toothfish caught, and a total annual catch of about 3000 t, it would take at least ten years to provide precise estimates of biomass. The tagging programme, first initiated by New Zealand vessels in 2000/01, was made compulsory for all vessels participating in the fishery from 2004/05 onwards. During 2004 and 2005, New Zealand developed an integrated stock assessment model to analyse and fit the tag, CPUE and catch-at-age data (e.g., Dunn et al. 2004, Dunn et al. 2005). At its 2005 meeting, CCAMLR accepted the integrated stock assessments of *D. mawsoni* and used them to provide independent catch limits for the Ross Sea toothfish fishery (defined as Subarea 88.1 and SSRUs 88.2A and 882.B) and for SSRU 88.2E for the first time. In endorsing these stock assessments the Scientific Committee recognised the need to reduce the uncertainty surrounding the assessment SC-CAMLR XXIV, paragraph 4.162–4.163).

In addition to catch limits for *Dissostichus* spp, bycatch limits for *Macrourus* spp, for skates and rays, and for 'other species' in each SSRU were introduced to all the exploratory fisheries in the 2001/02 season. During the 2001/02 season all the catches of target and bycatch species were within the prescribed catch limits. During the 2002/03 season the bycatch species were within the prescribed catch limits but the toothfish catch limit was exceeded in one SSRU and in two FSRs. As mentioned above, for the 2003/04 and 2004/05 seasons catch limits on FSRs were removed and the number of SSRUs in Subarea 88.1 was increased from 5 to 12. Thus, over 50 catch limits required monitoring for target and bycatch species in SSRUs in Subareas 88.1 and 88.2. Four toothfish catch limits and three bycatch limits were exceeded in 2003/04 and a further three toothfish catch limits and three bycatch limits were exceeded in 2004/05. The Scientific Committee noted the difficulties in administering the large number of catch limits in small SSRUs (SC-CAMLR XXIV, paragraph 4.159).

There was additional concern that the problem with exceeding the bycatch limits may have been exacerbated by the requirement to carry out research hauls (Fenaughty 2005). The deployment of research hauls was quite prescriptive with minimum distance between lines, minimum soak times and minimum numbers of hooks. Because much of the fishery is focused on features, such spreading of effort often led to an increased proportion of bycatch species, particularly *Macrourus* spp, in the research haul catch. Other operational problems arose particularly in bad ice years where the increasingly large number of vessels was competing to catch toothfish from quite localised features in the SSRUs. This led to competition for space and resulted in gear conflicts where, in some instances, longlines were set on top of other longlines which were already fishing on the seabed.

3. THE THREE YEAR EXPERIMENT

3.1 Objectives of the experiment

At the 2005 CCAMLR meeting, the Scientific Committee recommended, and the Commission endorsed, a new three year experiment for managing the Subarea 88.1 and 88.2 toothfish fishery. The main objectives of the experiment were as follows:

1. To concentrate effort in areas of greatest recent fishing activity, thereby reducing access to other areas
2. To allow a limited amount of research fishing in these other areas
3. To increase the number of tag recoveries, which would lead to improved precision in estimates of biomass from the stock assessment model
4. To improve the ease of administering catch limits by the Secretariat
5. Reduce uncertainty in the length and age distribution of the catch

3.2 Experimental framework

In providing the framework for the three year experiment the Scientific Committee considered the issues surrounding the management of the fishery. These are outlined in Section 2.3 above. The key aspects of the experiment were as follows:

- The Ross Sea fishery was defined as Subarea 88.1 and SSRUs 88.2A and B, and the catch limits for this fishery were to be based on the assessment which equalled 2964 t.
- Fishing in Subarea 88.1 should be concentrated in a north-south series of SSRUs – B, C, G, H, I, J, K, and L.
- The remainder of the SSRUs in Subarea 88.1 – A, D, E, and F – as well as SSRUs A and B in Subarea 88.2 would be closed for the duration of the experiment.
- Catch limits for the open SSRUs in Subarea 88.1 should be based on the proportional catch rates and seabed areas in each SSRU.
- Catch limits for SSRUs B, C, and G be amalgamated into a "northern" management area, and SSRUs H, I, and K be amalgamated into a "slope" management area.
- Within the closed SSRUs a 10 t research catch limit would apply.
- The catch limit for SSRU 88.2E was assigned a catch limit of 273 t based on the stock assessment for that area.
- The combined catch limit for the remaining SSRUs in Subarea 88.2 (C, D, F, and G) was pro-rated from the previous catch limit of 375 t and equalled 214 t (being four-sevenths of 375 t).
- The requirement to carry out specific research sets upon entering an SSRU was removed and in its place all fish of each *Dissostichus* spp. (up to a maximum of 35 fish) are measured and randomly sampled for biological studies from all lines hauled in Subareas 88.1 and 88.2.

The resulting spatial management in place for the three years of the experiment is shown in Figure 1c. The overall catch limit for the Ross Sea fishery has changed slightly each year and so the SSRU catch limits have also changed slightly.

3.3 Review of the experiment

We now review the various aspects of the experimental framework and how successful it was in meeting the objectives – what worked, what didn't work, and how things could have been improved.

3.3.1 Concentration of effort

The location of toothfish catch and effort in the past three years is shown in Figures 4 and 5, and the catch of all species is summarised by year and SSRU in Table 3. It is clear that the effort and the toothfish catch have been more concentrated during the experiment than during the earlier years of the fishery. Effort has remained focused on the ridges in the northern SSRUs 88.1B and 88.1C, on the Mawson and Iselin Banks in SSRUs 88.1H and 88.1I, and on the south-eastern continental slope in SSRU 88.1K. In addition, there has been more catch and effort in SSRU 88.1J, particularly in the deep hole off Terra Nova Bay and off the north-east coast of Ross Island (Figure 5). This area is particularly interesting as it comprises mainly sub-adult (100-120 cm long) Antarctic toothfish, and appears to act as a corridor for fish moving between the shelf and the north (Hanchet et al. 2008). The amalgamation of the catch limits in the northern SSRUs and in the slope SSRUs doesn't appear to have led to localised targeting of hot spots, and there has been no decline in the median length of toothfish within SSRUs (Hanchet et al. 2007).

As expected, during the experiment there was virtually no effort in the closed SSRUs. However, surprisingly there was also virtually no effort or catch from SSRU 88.1G. This is presumably because it is part of the northern area catch limit. When the fish opens each year on 1 December, SSRU 88.1G is usually still covered in ice and so vessels fish the open water in SSRUs 88.1B and 88.1C. By the time SSRU 88.1G is clear of ice the northern catch limit has already been taken.

In Subarea 88.2, the spatial management has allowed the continued collection of data from SSRU 88.2E whilst also encouraging the collection of data from the other SSRUs 88.2C, 88.2D, 88.2F, and 88.2G (Table 3).

3.3.2 Research fishing in closed SSRUs

Only a limited amount of research fishing was carried out in the closed SSRUs. SSRUs 88.1A, and 88.2A were fished in 2005/06, SSRUs 88.1A, 88.1E, and 88.1F were fished in 2006/07, whilst none were fished in 2007/08 (Table 4).
In most cases the number of sets made and the toothfish catch taken during the research fishing has been quite small, although the tagging rates achieved have been well in excess of the 3 tags per tonne required by the CM. In general, the research fishing has provided only limited data on population parameters from these other parts of the Ross Sea region. The main problem cited by fishers is that the 10 t research exemption is too small to make it worthwhile exploring these other SSRUs. To encourage exploration of these areas and to obtain more useful data would require an increase in the amount of effort over a longer 2-3 year time frame. This would allow time for developing a time series of catch and length data and for the recapture of tagged individuals over a period of time. This kind of approach has been successful at the South Sandwich Islands (Subarea 48.4) and has been discussed at recent CCAMLR meetings (e.g., SC-CAMLR XXVI).

3.3.3 Increase tag recaptures

There has been a large increase in recaptures of tagged *D. mawsoni* in the Ross Sea fishery from 26 and 45 in 2003/04 and 2004/05 to 65, 191, and XXX[1] over the past three seasons. There has been a similar increase in tag recaptures in SSRU 88.2E from 17 and 16 in 2003/04 and 2004/05 to 28, 29, and 33 over the past three seasons. This increase is to be expected because of the additional number of tags being released each year. However, the concentration of effort has almost certainly contributed towards the increased recaptures in both areas.

The increased number of tags has also led to an increase in the precision of the biomass estimates (Table 5). Although the median estimates of B_0 and stock status have changed in each assessment over the past 2–3 years, the confidence intervals have become narrower for each parameter in each assessment. Although an assessment was not completed for SSRU 88.2E in 2007 and assessments for both areas are not scheduled for 2008, it is likely that the confidence intervals will be further reduced as more tags have been recaptured.

3.3.4 Improve ease of administering catch limits

As a result of the experiment, and in particular the amalgamation of catch limits across SSRUs, the number of catch limits to administer in Subareas 88.1 and 88.2 was reduced to 24 (six “management areas” by four “species groups”) which was about 50% of the earlier level. This is clearly a significant reduction in the number of catch limits to administer.

Although there was a reduction in the total number of catch limits there were still overruns of both toothfish and Macrourid catch limits. In 2005/06, two toothfish catch limits and two Macrourid catch limits were exceeded. In 2006/07, two toothfish catch limits were exceeded, and no bycatch limits were exceeded. In 2007/08 no catch limits were exceeded. In most cases the overall catch limit for toothfish or Macrourids has not been exceeded and most individual overruns have been small.

[1] The number for 2007/08 is not yet known, but initial data suggest a higher number than in 2006/07.

The general improvement in administering the catch limits has been due to several factors including improved algorithms used by the secretariat, better liaison between fishing vessels, fisheries managers and the secretariat, a new rule clarifying what vessels are required to do when a fishery is closed, and the generally larger individual SSRU catch limits. In addition, the reduction in overruns of the Macrourid catch limits has been helped by the removal of the requirement to complete 20 research sets upon entering an SSRU, the new move-on rules, better knowledge of Macrourid hotspots, and a reduction in fishing effort in the south-eastern SSRUs 88.1I, and 88.1K where the Macrourid bycatch rates tend to be higher (Ballara & O'Driscoll 2005, Hanchet et al. 2008).

3.3.5 Increase number of fish examined for biological data

There has been an increase in the number of fish measured and sexed from all sets as a result of the change to the research data collection plan, and the representativeness of the data collected has been improved.

3.4 Discussion of the 3-year experiment

In general, the experiment appears to have been very successful with all of the objectives of the experiment being achieved. The experiment led to significant improvements in the management of the fishery, and a consequential reduction in catch limits to administer and overruns. This is probably at least partly due to the stability and consistency that it has introduced to the fishery in terms of fishing operations and management. The amalgamation of catch limits has been successful and amalgamation of SSRUs 88.1J and 88.1K would further reduce the catch limits for monitoring and would be more consistent with the approach used elsewhere in these subareas. This consistency and stable management has reduced the need for management intervention and consequently streamlined the work of the SC.

The experiment has produced a concentration of effort, and an increased recapture of tags leading to a more precise assessment of the stock, whilst still allowing some research effort in closed SSRUs. However, this doesn't appear to have led to a significant localised depletion of toothfish as there are no changes in the location of hot spots and there has been no detectable change in the median length of toothfish within SSRUs (Hanchet et al. 2007). Although the stock assessments have become more precise, there is some concern that they may also have become negatively biased (Dunn 2006, Dunn & Hanchet 2008). During the 2006/07 season the majority of tags were recovered from three very localised regions in SSRUs 88.1C, 88.1H, and 88.1J (Dunn et al. 2007). An assessment based on these data provides a very precise estimate of the local abundance of toothfish, but may not provide an unbiased estimate of the abundance of the entire area. In contrast, the lack of fishing in some SSRUs due to the occurrence of ice in some years may provide a bias in the other direction. Research aimed at addressing these issues using a Spatial Population Model is currently underway (Dunn & Rasmussen 2008), which may resolve some of these issues.

The provision of a 10 t research exemption in closed SSRUs allowed a small amount of data to be gathered from these areas. However, with the exception of SSRU 88.2A, the amount of research undertaken and tags released were not enough to contribute to the stock assessment of these areas. The closed SSRUs have however provided areas for monitoring ecosystem effects of fishing and effects of bottom fishing.

The proportional allocation of catch limits between SSRUs was based on the seabed area and toothfish CPUE of the SSRUs. As the catch limits have been reached on the north and slope this has encouraged fishing in the shelf SSRUs 88.1J and 88.1L. These SSRUs have a much higher proportion of smaller (sub-adult) toothfish and are probably sub-optimal in terms of Yield Per Recruit. The current allocation could be updated based on the new estimates of

CPUE but they are unlikely to change by a large amount. The use of the spatial model should help provide more optimal allocation of catch limits between regions in the future.

Increased number of fish sampled per line has improved amount of data across the fleet, although there are still issues with data quality (Middleton & Dunn 2008).

4. DEVELOPMENT OF MEDIUM-TERM OBJECTIVES

In developing medium term (5–7 year) objectives for the Subarea 88.1 and 88.2 toothfish fishery we need to consider the following:

1. What are the long-term management goals for the fishery based on Article II of the Convention?
2. Are we currently achieving those goals? If not, then what are the key areas of uncertainty which still need to be addressed?
3. What are the key research objectives to address those areas of uncertainty?
4. What operational framework could best facilitate that research?

4.1 CCAMLR goals

The CCAMLR goals for all Antarctic fisheries are detailed in Article II of the Convention.

The three key goals are summarised below:

1. The target fished population is above a level which ensures stable recruitment (generally defined as being at or above 50% B_0 for toothfish).
2. The ecological relationships between harvested, dependent, and related populations are maintained.
3. Prevention of changes or minimisation of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades, including the direct and indirect impacts of harvesting, alien species, associated activities, and environmental change, with the aim of making possible the sustained conservation of Antarctic marine living resources

4.2 Maintenance of the toothfish population in Subareas 88.1 and 88.2 above target levels

The most recent stock assessments suggest that the toothfish population in the Ross Sea fishery is currently at 78–85% B_0 (SC-CAMLR XXV) and in SSRU 88.2E is at 83–97%B_0 (SC-CAMLR XXIV), both of which are well above the 50% target level currently defined in the CCAMLR Decision Rules.

However, there is uncertainty over various aspects of the stock assessments, in particular potential bias caused by uneven distribution of tags and fishing effort (e.g., Dunn & Hanchet 2007a, 2007b). This is primarily caused by the variable ice coverage between years, but may be accentuated by the catch limits (for target and bycatch species) in place for different SSRUs including the zero catch limits for the closed SSRUs. Other key uncertainties in the assessment relate to stock structure, biological and model parameters, and data quality issues. Although toothfish in the Ross Sea fishery is currently modelled separately from toothfish in SSRU 88.2E, it is quite likely that they form a single stock. The relationship between toothfish in the shelf, slope, and northern regions of the Ross Sea fishery is also poorly understood (Fenaughty 2006). Studies are needed to better understand the life history of toothfish (including, for example, distribution of eggs, larvae, and juveniles; the length/age at maturity; natural mortality; and frequency of spawning). There is also uncertainty over other model parameters such as tag-related mortality and growth retardation, stock recruitment relationship (steepness), recruitment variability, and factors affecting such variability, etc,. Data quality issues have also been highlighted at recent meetings (SC-CAMLR XXV), and research is currently underway to objectively identify robust data sets (Middleton & Dunn 2008). There is also uncertainty over the effect of the current allocation of toothfish catch between regions.

We have identified several key medium-term research objectives:

4.2.1 Reduce bias in stock assessment due to non-mixing of tags

This could be achieved through a more structured fishing approach. However, this is still likely to be problematic due to variable ice cover, and would also require more management controls (catch limits) and could be operationally difficult for fishers. We believe that the best solution is to continue with spatial management measures similar to those currently in place and to address tag mixing issues using an appropriate spatial population model (e.g., Dunn & Rasmussen 2008). This in turn requires a good knowledge of the stock structure of Antarctic toothfish, which is intimately linked with progress on the research on the life history (see below).

4.2.2 Reduce uncertainty in life history and stock structure

The life cycle of Antarctic toothfish is still poorly understood, including; location of eggs, larvae, and juveniles, and also migrations of pre-spawning and post-spawning fish (Hanchet et al. 2007, in press), although recent research has begun to develop testable life history hypotheses. Dedicated research programmes would be required to find the location of the early life history stages. (e.g., egg buoyancy tests with freshly ovulated eggs, tows with plankton nets, shore based fishing for juveniles). This requires an operational framework that is sufficiently flexible to allow the ability to sample in winter in the northern area of the Ross Sea and/or sampling in areas not traditionally fished (or little fished).

In addition, there is some data that would suggest that the Terra Nova Bay area in the south-western Ross Sea might act as an important corridor for maturing fish migrating to the north to spawn for the first time (Hanchet et al. 2007). An approach to facilitate the operational management of this area would be to split the area to the west of 170ºE in the western Ross Sea including Terra Nova Bay and McMurdo Sound off from the rest of SSRU 88.1J. This would be an extension of the 170ºE line which currently separates the closed and open SSRUs to the north of Cape Adare (Figure 1c), and would create a new SSRU, say SSRU 88.1M. If implemented then an appropriate catch limit for this area would need to be determined.

4.2.3 Reduce uncertainty in biological and model parameters

Key stock assessment parameters are natural mortality (including any age-dependent natural mortality), length/age at maturity, annual spawning proportions, age-related initial tag mortality and growth retardation, stock-recruit relationships and recruitment variability. Many of these parameters cannot be assessed experimentally and estimates are likely to be improved as the fishery develops. However, estimates of initial tag mortality could be derived using appropriately experimental methods (e.g., by tracking acoustically tagged fish). Also the relative abundance of juvenile toothfish could potentially be monitored on the shelf area using small-scale longline pre-recruit surveys. The creation of the new SSRU 88.1M (discussed above) would provide greater flexibility for such an experiment. The operational framework would need to be developed so that it encouraged fishers to carry out such experimental work without being commercially disadvantaged.

4.2.4 Develop a Management Strategy Evaluation (MSE) for toothfish

A Management Strategy Evaluation (MSE) for toothfish based on the single stock model should be developed. This should address a number of components such as potential tag biases arising from incomplete mixing, tag rates, appropriate spatial scales for assessment, data issues, other model assumptions, what critical aspects of the models need to be included in assessments, frequency of assessments, and appropriate trigger levels for doing assessments. This will require an operational framework that is sufficiently flexible to allow scientists to test some of the important assumptions within the model.

4.3 Maintenance of ecological relationships between harvested, dependent, and related populations

To ensure that ecological relationships between *D. mawsoni*, its predators and prey, and other species taken as bycatch in the fishery are maintained we need to carry out these steps:

1. Identify key ecological relationships.
2. Develop methods and means of assessing, mitigating, and monitoring risks to those relationships.
3. Develop a robust ecological risk management framework for those relationships (e.g., Weddell seals, 'Type C' Orca, Macrourids, icefish, moray cods, deep-sea cods).

4.3.1 Ecological relationships

The full nature of the ecological relationships between *D. mawsoni* and its predators and prey are poorly understood. The diet of *D. mawsoni* in the Ross Sea region has been the subject of several studies (e.g., Fenaughty et al. 2003, Stevens 2004), but these have only looked at stomach contents in the summer. At this time of the year, they are primarily piscivorous, with the main prey items varying depending on their location and habitat. In continental slope waters, the macrourid *M. whitsoni* and the icefish *C. dewitti* predominate in the diet, while on oceanic seamounts *M. whitsoni*, violet cod (*Antimora rostrata*) and cephalopods are important (Fenaughty et al. 2003, Stevens 2004). In the coastal waters around McMurdo Sound, adults feed principally on Antarctic silverfish (*Pleuragramma antarcticum*). The predators of *D. mawsoni* in the Ross Sea are also reasonably well known (Ainley et al. 2008, Pinkerton et al. 2008). To the north of the Ross Sea they are fed on by sperm whales (Yukhov 1971), whilst in the Ross Sea shelf they are preyed on by Weddell seals (Ainley & Siniff 2008, Pinkerton et al. 2008) and "Type C" Orca (Ainley & Siniff 2008). However, the degree of dependence of the predators on *D. mawsoni* as a prey species is unknown. Key uncertainties include the temporal and spatial extent of the predation, the proportion of predators eating *D. mawsoni*, the daily consumption, and the degree of overlap in their vertical distribution.

4.3.2 Monitoring changes in predators and prey

Currently there are no CCAMLR endorsed methods of monitoring the ecological relationships between *D. mawsoni* and its predators or prey. Annual counts of Weddell seals in Erebus Bay (McMurdo Sound) have been made since 1974, and other ground and aerial counts have been made sporadically along the Victoria land coast since the 1960s (Siniff & Ainley 2008). Siniff & Ainley (2008) proposed that aerial surveys of Weddell Seals in the western Ross Sea be used to monitor trends in their abundance and recommended to WG-EMM that this be developed as a CEMP index. We note that although the Working Group agreed that an aerial census was probably the best method for monitoring Weddell seal abundance in the western Ross Sea, it did not endorse the aerial census as a CEMP index because it was not clear whether a change in the index could be attributed to a change in the toothfish population by the toothfish fishery (SC-CAMLR-XVII/3, paragraph 6.41). It further noted that additional data would be needed in developing a monitoring program, including data on the distribution and abundance of *D. mawsoni*, species of demersal fish and silverfish, and estimates of the importance of diet components to Weddell seal production.

Potential methods for monitoring Macrourids in the Ross Sea region were reviewed by O'Driscoll et al. (2005). They concluded that a trawl survey and/or monitoring catch-at-age (via curve analyses) were likely to be most successful for monitoring Macrourids. An extensive trawl survey of demersal fish on the Ross Sea slope was planned to be carried out as part of the New Zealand IPY survey in 2008 (Hanchet et al. 2008). Unfortunately, due to the extreme ice conditions experienced during the survey, the main area of Macrourid abundance to the east of the Iselin bank and on the Iselin bank itself could not be surveyed. Only six trawls were eventually completed in the slope area in SSRU 88.1H, which could only provide indicative estimates of *M. whitsoni* biomass for the area (Hanchet et al. 2008). A parallel survey was carried out using underwater video transects. *M. whitsoni* individuals were commonly seen during transects and this approach may be a feasible monitoring method in the future. Although *C. dewitti* were caught by trawl and seen on videos they were uncommon, and neither method may be suitable for monitoring their abundance.

Methods for monitoring the abundance of the other key prey species or for monitoring the abundance of 'Type C' orca would need to be developed.

4.3.3 Ecological risk management

Pinkerton et al. (2007) began the development of an ecological risk assessment for the Antarctic toothfish (*Dissostichus mawsoni*) longline fishery in the Ross Sea. While they identified risks associated with the ecological relationships between the predators of toothfish and its prey, they did not go on develop an assessment of the risks, consider strategies that avoid, mitigate, manage or tolerate risk; or develop methods for monitoring of the risks.

4.3.4 Medium-term research objectives

We have identified several key medium-term research objectives:

1. Understand the ecological relationships between toothfish, its predators and prey (e.g., by developing a spatially and temporally resolved Minimum Realistic Model of the Ross Sea (shelf and slope) ecosystem).
2. Address key uncertainties including the temporal and spatial extent of the predation, the proportion of predators eating *D. mawsoni*, the daily consumption, and the degree of overlap in their vertical distribution.
3. Develop a quantitative risk assessment for Macrourids (*M. whitsoni*) in the main slope fishery of the Ross Sea.
4. Development of methods and means of monitoring changes in predators and prey species in the Ross Sea.

4.4 Changes in the ecosystem are minimised and reversible

To ensure that other ecological changes to the ecosystem are minimised and are reversible, the following steps should be addressed:

1. Identify risks associated with; direct and indirect impacts of fishing, environmental change, alien species, and associated activities
2. Develop methods and means of assessing, mitigating, and monitoring those risks
3. Develop an ecological risk management framework

4.4.1 Direct impacts of fishing

We consider here bycatch of fish, seabirds, marine mammals, and benthos.

The fish bycatch taken in the Ross Sea toothfish fishery has been well documented (e.g., Hanchet et al. 2003, 2007). The main bycatch species are Macrourids (mainly *M. whitsoni*), which forms 5–10% of the total catch, and skates (mainly *A. georgiana*), which forms about 1% of the catch (most are released alive at the surface). Preliminary risk categorisations for these species were completed and presented to WG-FSA by O'Driscoll (2005). However, no comprehensive risk assessment of these species has been carried out.

There are several approaches to the mitigation of fish bycatch. Subarea and SSRU catch limits are in place for Macrourids, Rajids, and 'other species' which restrict the catch of these species taken in the fishery (CM 41/09, 41/10). There is also a 'move-on' rule in place to help prevent localised depletion of Macrourids and Rajids (CM 33-03). This rule requires a vessel to move to another location at least 5 n. miles distant if the bycatch of any one species is equal to or greater than 1 tonne in any one set. An additional measure in CM 33-03 makes vessels responsible for managing their individual Macrourus bycatch[2] by penalising vessels exceeding a proportion of 16% of the Macrourus catch to the catch of *Dissostichus* spp. Under this conservation measure, vessels are also requested to cut-off skates at the surface as it has been shown through recoveries of tagged skates and skate survivorship experiments that many skates survive the capture event. Potential mitigation measures for Macrourids and skates were examined by Ballara & O'Driscoll (2005). Using standardised CPUE analysis they determined that depth, SSRU, and method were the key factors affecting by-catch rates of Macrourids and Rajids in the Ross Sea. Investigation of the use of artificial baits is also being trialled as a mitigation method (Fenaughty 2008).

Potential methods for monitoring skates in the Ross Sea region were reviewed by O'Driscoll et al. (2005). They concluded that a tag-recapture experiment was likely to be most successful for monitoring skates. A very preliminary stock assessment based on skate tag-recapture data and ancillary data was completed by Dunn et al. (2007). They identified a large number of problems with the data currently being collected including: improve species identification, improve detection of tagged skates, increase number of skates measured and sexed, validate the estimates of age and growth, revise skate tagging protocols and undertake additional survivorship experiments. A skate sampling protocol was developed following their recommendations (Mormede et al. 2007), and led to the proposed CCAMLR 'Year of the Skate' in 2008/09. A trawl survey of demersal fish on the Ross Sea slope was carried out as part of the New Zealand IPY survey in 2008 (Hanchet et al. 2008). Catches of skate were very low during the survey. Monitoring of Macrourids is discussed above and is not repeated here. There is considerable uncertainty over the tools for monitoring the abundance of these bycatch species, biological and model parameters, and data quality issues.

Declines in the abundance of both *D. mawsoni* and *M. whitsoni* due to fishing may lead to changes in the diet of *D. mawsoni*. Because icefish do not appear to be particularly vulnerable to longline fishing, they may replace *M. whitsoni* to some extent in the diet. It may therefore be useful to carry out regular studies on the diet of *D. mawsoni*.

Only a single seabird has been caught on a longline during the history of the fishery (SC-CAMLR XXVI, Annex 5, Appendix I). This appears to be due to strict compliance with CMs 24-02 and 25-02 and other related mitigation measures in CMs 41/09 and 41/10 over the course of the fishery.

There has been no reported bycatch of marine mammals on longlines in the fishery.

[2] Paragraph 5 of CM 33-03 (2007)

Bycatch of invertebrates on the longlines appears to be relatively low and is dominated by echinoderms (see the New Zealand preliminary assessment with respect to CM22-06 in CCAMLR-XVII-26). Indirect impacts of the longlines on benthic invertebrates are considered below.

4.4.2 Indirect impacts of fishing on the ecosystem

A risk assessment of the effects of the IWL longline system on the benthos was recently carried out by New Zealand (see the New Zealand preliminary assessment with respect to CM22-06 in CCAMLR-XVII-26). The study indicated that only at most 0.008% of the fishable depths in the Ross Sea are likely to have come into contact with fishing gear to date and that an even smaller proportion is likely to have been adversely impacted by the fishing gear. Further, the likely impact of the gear on potential VMEs was considered negligible. The main uncertainties in the assessment are the effective width of the impact of the longline on the seabed and the benthic species likely to be most impacted.

Despite the assessed extremely low risk of significant adverse effects, a range of potential approaches to mitigate and reduce risk have been proposed. Key in the context of future research are additional data collection by observers, identification of the location of potential VMEs from fishery independent data, and testing the key assumptions in the risk assessment.

Potential ecosystem effects caused by the removal of toothfish and/or bycatch species by the fishery were reviewed by Pinkerton et al. (2007). They considered these second-order effects to include potential trophic cascades and keystone predator effects. Ecosystem responses to removal or depletion of species may be non-linear, with thresholds where changes may be rapid, substantial, and non-reversible. Characterisations of the nature of the food-web and changes in its relationships over time will need to continue. However, effects are very difficult to predict from trophic models and long-term monitoring of species likely to be affected may be required in order to both assess and manage risk.

Lost gear may also have an indirect impact on the ecosystem. The amount of gear lost by fishing vessels is reported by Scientific Observers, and these data should be monitored.

4.4.3 Climate change

Pinkerton et al. (2007) considered risks associated with the combination of climate change and the fishery for Antarctic toothfish. They noted that Antarctic toothfish could be affected by climate change in a number of ways including changes in recruitment, location, depth, natural mortality, and trophic linkages. Climate change could also have a more far reaching impact on other aspects of the ecosystem including regime shifts (Pinkerton et al. 2007).

Since the start of the 3-year experiment there has been a system of open and closed SSRUs in Subareas 88.1 and 88.2. The continued closure of these SSRUs may allow effects from fishing and other extraneous factors (including climate change, ocean acidification, freshening of the Ross Sea, and other environmental effects) to be distinguished in the long-term. There are currently no closed SSRUs in the Ross Sea shelf area, where many of these effects may first be felt. We note that the addition of new SSRUs in the western Ross Sea (e.g., SSRU 88.1M discussed above) might provide a management tool developing similar areas on the Ross Sea Shelf.

4.4.4 Alien species

Changes to the physical environment near the sea bed in the Ross Sea may, in time, change the geographic ranges of species and could allow temperate fishes to colonise these areas at the expense of polar species (Pinkerton et al. 2007). The frequency of these incursions, and the chances of the novel species gaining a permanent niche in the ecosystem, are likely to increase if the age structure of fish is truncated (for example due to fishing), if the resident fish is stressed (for example due to change of local environmental conditions), or conditions change more rapidly than normal (for example due to climate change). In these cases, fishing in concert with climate change, has the potential to facilitate significant changes in ecosystem function in the Ross Sea.

4.4.5 Associated activities

Other activity occurs in the Ross Sea region that may either directly or indirectly impact Antarctic toothfish and the ecosystem within which they occur. These activities may be managed through other parts of the Antarctic Treaty system. They are described here for completeness.

Direct activities requiring ongoing consideration include quantification of catches from scientific research and tourist vessels (if any). Indirect impacts requiring ongoing consideration include potential secondary effects on areas of particular significance for toothfish (e.g. contaminated runoff from a base affecting key juvenile habitat), and additive cumulative impacts on habitat from maritime activity beyond fishing (e.g. anchoring of tourist vessels on potential VME sites).

No additional research is proposed on these issues at this time, however these are obviously areas for continuing engagement with other parts of the Antarctic Treaty system.

4.4.6 Medium-term research objectives

We have identified several key medium-term research objectives:

1. Continue to assess the potential impacts of the toothfish fishery on key fish bycatch species, benthos, and ecosystem structure.
2. Develop quantitative risk assessments for Macrourids (*M. whitsoni*) and Antarctic skates (*A. georgiana*) in the main slope fishery of the Ross Sea.
3. Develop methods and means of monitoring effects of toothfish fishery on the ecosystem.

5. DEVELOPMENT OF A MEDIUM-TERM OPERATIONAL FRAMEWORK

5.1 Key factors for operational framework

The key factors for implementing an operational framework are;

- flexibility to extend the fishing period and/or fishing area to undertake targeted projects (e.g. out-of-season sampling for stock structure work);
- a framework to allow for a proper “exploratory / experimental” fishery through a structured research plan, which doesn’t penalise fishers carrying out research;
- continuity in the system to allow answers to come out of existing work: changing data collection for specific short term projects may create bias problems and compromise long term effort such as population modelling;
- stabilised data collection by observers/industry: currently the observer manual, requirements, and protocols are changed every year;
- administratively easy to manage for Secretariat and Commission
- ability to distinguish ecosystem effects of fishing from other factors such as climate change
- ensure better collaboration between fishers and address issues of data quality
- better integration with other aspects of CCAMLR (e.g., MPAs, bioregionalisation etc)

The development of the operational framework needs to be carried out in conjunction with various working groups and *ad hoc* groups of the Scientific Committee including WG-FSA, WG-EMM, TASO, FEMA etc. Therefore an important aspect for the framework is to ensure it will allow the streamlining of the work of the Scientific Committee.

5.2 Recommendations

The last three years has seen a period of stability in the Ross Sea toothfish fishery. This stability has not only led to an improved stock assessment of Antarctic toothfish but has also assisted development of a preliminary stock assessment model for Antarctic skates and allowed us to begin the development of a risk assessment for Macrourids and other potential ecosystem effects of the toothfish fishery. The additional move to a biennial assessment of toothfish in 2006/07, has also allowed resources to be redirected into the development of a Spatial Population Model, which will be important for future MSE of the toothfish fishery. We strongly encourage the adoption of an operational framework for the medium term (next 4–5 years) which would allow good quality data to be gathered on a stable and consistent basis. We have identified a number of minor adjustments to the existing operational framework, which we believe will allow the research to develop without creating new biases into the stock assessment. We recommend the following minor changes to the operational framework to meet the science and management objectives of the fishery.

1. Retain existing network of open and closed SSRUs in Subareas 88.1 and 88.2, and, in addition, consider creating an additional SSRU in the region to the west of 170ºE in the western Ross Sea including Terra Nova Bay and McMurdo Sound.

2. Retain the current amalgamation of SSRU catch limits, and in addition consider amalgamation of catch limits for 88.1J (east of 170ºE) and 88.1L.

3. Readjust proportional catch limits based on revised seabed areas and new CPUE.

4. Modify research exemption for closed SSRUs (CM 24/01). Instead of 10 tonnes for each SSRU for each year, focus on research experiments lasting 2-3 years in a specific SSRU with 70 tonnes per year[3]. Retain tagging at a minimum of 3 tags per tonne for each year of experiment. Ensure an appropriate gap (e.g., 5–10 years) between such experiments in the same SSRU to minimise the impact.

5. Allow retention of catch limits for toothfish and bycatch species for 'out of season' experiments in open SSRUs.

6. Continue with biennial assessments of Antarctic toothfish in the two subareas.

7. Develop specific data collection plan and research plan for the Subarea 88.1 and 88.2 fishery. In addition to the existing data collection and research plan (CM 41/01), we recommend:
    a. The development of clear, refined and rationalized observer data requirements (e.g. length measurements, otoliths collection, gonad weights, percent hooks observed) and enhanced industry data collection.
    b. The need to critically review and examine individual data sets to reject non-valid data, improve data collection over time, and the use of accredited observers.

[3] Note 70 tonnes is the sum of the 10 t research exemptions from the seven closed SSRUs in Subareas 88.1 and 88.2

6. REFERENCES

Ainley, D.; Siniff, D. (2008). Addressing uncertainty over the importance of Antarctic toothfish as prey of seals and whales in the southern Ross Sea: a review. WG-EMM-08/22.

Ballara, S.L., O'Driscoll, R. L. (2005). A review of rattail (*Macrourus* spp) and skate bycatch, and analysis of standardised CPUE, for the exploratory fishery in the Ross Sea (CCAMLR Subareas 88.1 & 88.2) from 1997/98 to 2004/05. WG-FSA-05/24.

DeVries, A.L.; Ainley, D.G.; Ballard, G. (2008). Decline of the Antarctic toothfish and its predators in McMurdo Sound and the southern Ross Sea and recommendations for restoration. WG-EMM-08/21.

Dunn, A. (2006). Developments towards an investigation of potential bias from the analysis of tag–release and recapture data in Ross Sea Antarctic toothfish abundance estimates. WG-FSA-SAM-06/10.

Dunn, A.; Gilbert D.J.; Hanchet, S.M.; Bull. B. (2004). Development of an Antarctic toothfish (*Dissostichus mawsoni*) stock model for CCAMLR Subarea 88.1 for the years 1997–98 to 2003–04. WG-FSA-04/36. 39 p.

Dunn, A., Gilbert, D. J., Hanchet, S. M. (2005). A single-area stock assessment model of Antarctic toothfish (*Dissostichus mawsoni*) in the Ross Sea for the 2004–05 season. WG-FSA-05/33.

Dunn, A., Hanchet, S. M. (2007). Assessment models for Antarctic toothfish (*Dissostichus mawsoni*) in the Ross Sea including data from the 2006/07 season. WG-FSA-07/37.

Dunn, A.; Hanchet, S.M.; Ballara, S.; Francis, M.P. (2007). Preliminary investigations of an assessment model for skates in the Ross Sea. WG--SAM-07/4. 34 p.

Dunn, A.; Rasmussen, S. (2008). Development of a spatially explicit age-structured statistical catch-at-age population dynamics model for modelling movement of Antarctic toothfish in the Ross Sea.WG-SAM-08/14. 31 p.

Dunn, A.; Hanchet, S. M.; Ballara, S. (2007). An updated descriptive analysis of the toothfish (*Dissostichus* spp.) tagging programme in Subareas 88.1 and 88.2 for 2006–07. WG-SAM-07/5. 21 p.

Fenaughty, J.M.; Stevens, D.W.; Hanchet, S.M. (2003). Diet of the Antarctic toothfish (*Dissostichus mawsoni*) from the Ross Sea, Antarctica (Subarea 88.1). *CCAMLR Science 10:* 113–123.

Fenaughty J.M. (2006). Geographical differences in the condition, reproductive development, sex ratio, and length distribution in Antarctic toothfish *Dissostichus mawsoni* from the Ross Sea, Antarctica (CCAMLR statistical subarea 88.1). CCAMLR Science, 13: 27-45

Fenaughty, J.M. (2005). Ross Sea Fishery Research and Data Collection Plan. WG-FSA-05/49

Fenaughty, J.M. (2008). An Assessment of artificial bait (Norbait™) as a means of reducing the incidental catch of Macrourus and other bycatch species in high latitude toothfish fisheries. WG-FSA-08/xx

Hanchet, S.M. (2006). Species profile for Antarctic toothfish (*Dissostichus mawsoni*). WG-FSA-06/26. 22 p.

Hanchet, S.M.; Mitchell, J.; Bowden, D.; Clark, M; Hall, J.; O'Driscoll, R.; Pinkerton, M.; Robertson, D. (2008). Preliminary report of the New Zealand RV Tangaroa IPY-CAML survey of the Ross Sea region, Antarctica in February-March 2008. WG-EMM-08/18. 13 p.

Hanchet, S.M.; O'Driscoll, R.; Ballara, S.; Dunn, A. (2008). Grenadier bycatch in the toothfish longline fishery in the Ross Sea, Antarctica. American Fisheries Society Symposium 63: 451–462.

Hanchet, S.M., Rickard, G.J., Fenaughty, J.M., Dunn, A.; Williams, M.J. (2007). A hypothetical life cycle for Antarctic toothfish *Dissostichus mawsoni* in Antarctic waters of CCAMLR Statistical Area 88. *WG-FSA-07/35.*

Hanchet, S.M., Rickard, G.J., Fenaughty, J.M., Dunn, A.; Williams, M.J. (in press). A hypothetical life cycle for Antarctic toothfish *Dissostichus mawsoni* in Antarctic waters of CCAMLR Statistical Area 88. *CCAMLR Science 15.*

Hanchet, S.M., Stevenson, M.L., Dunn, A. (2007). A characterisation of the toothfish fishery in Subareas 88.1 & 88.2 from 1997/98 to 2006/07. *WG-FSA-07/28.*

Hanchet, S.M., Stevenson, M.L., Horn, P.L., Blackwell, R.G. (2003). Assessment of toothfish (*Dissostichus mawsoni* and *D. eleginoides*) stocks in the Ross Sea (CCAMLR Subareas 88.1 and 88.2). *New Zealand Fisheries Assessment Report 2003/43.* 27 p.

Hanchet, S.M., Stevenson, M.L., Phillips, N.L., Dunn, A. (2005). A characterisation of the toothfish fishery in Subareas 88.1 & 88.2 from 1997–98 to 2004–2005. *WG-FSA-05/29.*

Middleton, D.A.J.; Dunn, D. (2008). Development of a methodology for data quality assessment.
WG-EMM-08/13. 31 p.

Momede, S., Dunn, A.; Fenaughty, J.M.; Francis, M., Hanchet, S.M., O'Driscoll, R., Smith, N. (2007). Preparing for the year of the skate: proposed information collection and tagging protocol for skates. *WG-FSA-07/39.*

O'Driscoll, R.L. (2005). Risk categorization for *Macrourus whitsoni* and *Amblyraja georgiana* in the Ross Sea. WG-FSA-05/21.

O'Driscoll, R.L., Hanchet, S. M., Wood, B. A. (2005). Approaches to monitoring and assessing the abundance of rattails (*Macrourus* spp.) and skates in the Ross Sea. WG-FSA-05/22

Pinkerton M.H.; Bradford-Grieve, J.M.; Hanchet, S.M. (2008) A preliminary balanced trophic model of the ecosystem of the Ross Sea, Antarctica, with emphasis on apex predators. WG-EMM-08/42.

Pinkerton, M.H.; Dunn, A.; Hanchet, S.M. (2007). Ecological risk management and the fishery for Antarctic toothfish (*Dissostichus mawsoni*) in the Ross Sea, Antarctica. WG-EMM-07/24. 21 p.

Pinkerton M.H.; Dunn, A.; Hanchet, S.M. (2008). Trophic overlap of Weddell seals (Leptonychotes weddelli) and Antarctic toothfish (*Dissostichus mawsoni*) in the Ross Sea, Antarctica. WG-EMM-08/43.

Siniff, D.; Ainley, D. (2008). Aerial surveys of Weddell seals during 2007/08, with notes on the history of aerial censuses in the Ross Sea and recommendations for continued count effort. WG-EMM-08/23.

Stevens, D.W. (2004). Stomach contents of the Antarctic toothfish (*Dissostichus mawsoni*) from the western Ross Sea, Antarctica. *WG-FSA-04/31.*

Sullivan, K.J., McL. Smith, N.W., McKenzie, J., Hanchet, S.M. (2003). A feasibility study for stock assessment of *D. mawsoni* in the Ross Sea (Subareas 88.1 and 88.2) using a tag and recapture experiment. *WG-FSA-SAM-03/10.* 22 p.

Yukhov, V.L. (1971). The range of *Dissostichus mawsoni* Norman and some features of its biology. *Journal of Ichthyology 11:* 8–18.

Table 1: Details of the toothfish (*Dissostichus* spp.) fishery in the Ross Sea, SSRU 88.2E, and SSRUs 88.2D, F, and G. The Ross Sea fishery includes SSRUs 88.2A and 88.2B. In 2007, SSRU 88.2E had a catch limit of 341 t, whilst SSRUs 88.2C, D, F, and G had a combined limit of 206 t.

			Ross Sea		882E		882 (CDFG)	88.1	88.2
Year	No. of vessels	Number of sets	Catch (t)	Number of sets	Catch (t)	Number of sets	Catch (t)	catch limit (t)	catch limit (t)
1997	1	2	<1	–	–	–	–	1 980	0
1998	1	82	41	–	–	–	–	1 980	0
1999	2	252	269	–	–	–	–	1 510	0
2000	3	489	752	–	–	–	–	2 281	250
2001	7	722	604	–	–	–	–	2 090	250
2002	2	436	1 358	–	–	–	–	2 064	250
2003	9	801	1 774	78	106	–	–	2 508	375
2004	21	2 164	2 177	168	362	–	–	3 760	375
2005	10	1 529	3 209	89	270	–	–	3 250	375
2006	13	1 040	2 963	193	318	74	107	2 964	487
2007	15	1 396	3 084	263	325	16	22	3 032	547
2008	15	1 012	2 259	84	333	44	83	2 660	547

Table 2: Catch (t) by SSRU and year for the main species/family groups. '–' denotes not fished.

												Subarea 88.1			Subarea 88.2	Total
Year	Species	A	B	C	E	F	G	H	I	J	K	L	A	B	E	(t)
2002	TOA	—	35	361	—	—	16	439	345	—	121	—	41	—	—	1 358
	TOP	—	10	2	—	—	<0.5	<0.5	<0.5	—	<0.5	—	<0.5	—	—	12.19
	GRV	—	1	7	—	—	6	27	96	—	17	—	4	—	—	158
	SRX	—	<0.5	0	—	—	<0.5	18	5	—	1	—	<0.5	—	—	25
	OTH	—	1	1	—	—	1	1	6	—	<0.5	—	<0.5	—	—	10
	Total	—	**47**	**371**	—	—	**24**	**485**	**453**	—	**139**	—	**46**	—	—	**1 564**
2003	TOA	<0.5	88	1 031	2	<0.5	41	470	142	—	—	—	—	—	106	1 881
	TOP	13	10	2	0	0	<0.5	<0.5	0	—	—	—	—	—	0	26
	GRV	1	4	6	1	<0.5	7	18	29	—	—	—	—	—	18	84
	SRX	0	0	0	<0.5	<0.5	<0.5	4	6	—	—	—	—	—	0	11
	OTH	<0.5	2	1	<0.5	<0.5	3	1	4	—	—	—	—	—	8	19
	Total	**14**	**105**	**1 041**	**3**	<0.5	**51**	**493**	**181**	**18**	**34**	—	—	—	**132**	**2 021**
2004	TOA	—	61	226	38	—	84	1 091	651	1	<0.5	12	11	1	362	2 540
	TOP	—	9	1	2	—	1	<0.5	<0.5	0	0	0	0	0	<0.5	12
	GRV	—	<0.5	1	31	—	16	69	202	0	<0.5	0	0	0	37	355
	SRX	—	0	<0.5	2	—	<0.5	6	14	0	<0.5	<0.5	<0.5	<0.5	0	23
	OTH	—	1	1	3	—	3	7	9	<0.5	<0.5	<0.5	<0.5	<0.5	8	32
	Total	—	**71**	**229**	**76**	—	**104**	**1 173**	**876**	**1**	**1**	**13**	**12**	**1**	**407**	**2 962**
2005	TOA	—	70	428	55	—	53	786	613	158	736	170	137	—	270	3 477
	TOP	—	0	<0.5	5	—	1	<0.5	<0.5	0	1	<0.5	0	—	<0.5	7
	GRV	—	1	3	2	—	16	27	158	46	205	4	<0.5	—	20	482
	SRX	—	0	0	<0.5	—	1	3	18	39	7	<0.5	<0.5	—	0	69
	OTH	—	1	2	<0.5	—	3	2	7	1	7	<0.5	<0.5	—	3	28
	Total	—	**72**	**434**	**61**	—	**74**	**819**	**797**	**244**	**956**	**175**	**138**	—	**293**	**4 063**
Total	TOA	<0.5	254	2 047	94	<0.5	194	2786	1 751	159	858	183	190	1	738	9 255
	TOP	13	29	5	6	0	2	<0.5	<0.5	0	<0.5	<0.5	<0.5	0	<0.5	57
	GRV	1	7	18	34	<0.5	44	141	485	46	222	4	4	0	74	1 080
	SRX	0	<0.5	0	3	<0.5	2	32	43	39	8	<0.5	<0.5	<0.5	0	128
	OTH	<0.5	4	4	3	<0.5	11	10	27	2	7	<0.5	<0.5	<0.5	19	89
	Total	**14**	**294**	**2 075**	**140**	**0.0**	**253**	**2 970**	**2 306**	**263**	**1130**	**188**	**195**	**1**	**832**	**7 280**

Table 3: Catch (t) by SSRU and year for the main species/family groups. '–' denotes not fished.

		Subarea 88.1												Subarea 88.2						Total
Year	Species	A	B	C	D	E	F	G	H	I	J	K	L	A	B	D	E	F	G	(kg)
2006	TOA	1	10	333	—	—	—	—	990	396	546	588	87	17	—	42	318	65	1	3 392
	TOP	1	0	0	—	—	—	—	0	0	0	0.1	0	0	—	0	0	0	0	1.29
	GRV	<0.5	1	1	—	—	—	—	68	80	32	71	6	8	—	5	42	35	2	351
	SRX	0	0	0	—	—	—	—	3	1	1	<0.5	<0.5	0	—	0	0	<0.5	<0.5	5
	OTH	<0.5	<0.5	<0.5	—	—	—	—	8	4	4	1	1	<0.5	—	<0.5	11	1	<0.5	30
	Total	**2**	**11**	**335**	**—**	**—**	**—**	**—**	**1 068**	**481**	**583**	**659**	**93**	**25**	**—**	**47**	**370**	**101**	**3**	**3 779**
2007	TOA	<0.5	11	<0.5	—	<0.5	0	—	<0.5	<0.5	<0.5	—	—	—	—	0	0	0	—	12
	TOP	<0.5	198	375	—	<0.5	2	—	1 514	557	438	—	—	—	—	22	325	<0.5	—	3 431
	GRV	<0.5	2	1	—	2	1	—	69	75	4	—	—	—	—	3	51	<0.5	—	207
	SRX	0	0	0	—	<0.5	<0.5	—	23	9	6	—	—	—	—	0	<0.5	<0.5	—	39
	OTH	<0.5	1	1	—	<0.5	<0.5	—	15	23	2	—	—	—	—	0	12	<0.5	–	56
	Total	**<0.5**	**212**	**377**	**—**	**2**	**3**	**—**	**1 621**	**664**	**451**	**—**	**—**	**—**	**—**	**25**	**389**	**<0.5**	**—**	**3 743**
2008	TOA	—	87	164	—	—	—	—	1 364	126	410	60	39	—	—	38	333	45	—	2 666
	TOP	—	7	1	—	—	—	—	1	0	<0.5	<0.5	0	—	—	<0.5	0	0	—	9
	GRV	—	3	3	—	—	—	—	80	13	<0.5	5	1	—	—	4	4	4	—	116
	SRX	—	0	<0.5	—	—	—	—	4	<0.5	0	0	<0.5	—	—	0	0	0	—	4
	OTH	—	0	0	—	—	—	—		10	3	16	1	—	—	0	13	0	—	43
	Total	—	**97**	**168**	—	—	—	—	**1 449**	**149**	**413**	**81**	**41**	—	—	**43**	**349**	**49**		**2 838**
Total	TOA	1	107	498	—	—	—	—	2 355	523	956	648	125	17	—	80	650	109	1	6 070
	TOP	1	205	376	—	—	—	—	1 514	557	438	<0.5	0	0	—	22	325	<0.5	0	3 441
	GRV	<0.5	5	5	—	—	—	—	216	168	36	76	7	8	—	13	96	39	2	674
	SRX	0	0	<0.5	—	—	—	—	29	10	8	<0.5	<0.5	0	—	0	<0.5	<0.5	0	48
	OTH	<0.5	1	1	—	—	—	—	23	36	10	17	2	<0.5	—	<0.5	36	1	0	128
	Total	**2**	**319**	**880**	**—**	**—**	**—**	**—**	**4 138**	**1 294**	**1 447**	**741**	**134**	**25**	**—**	**115**	**1 108**	**150**	**3**	**10 361**

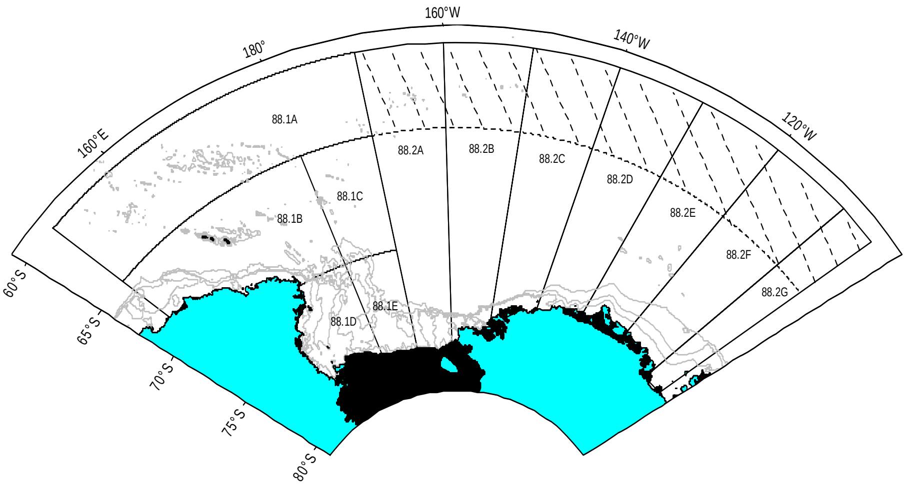
Table 4. Summary of research fishing carried out in closed SSRUs. Tag rate in tags per tonne.

Vessel	SSRU	Year	# sets	Toothfish catch (t)		# Fish tagged		Tag Rate
				TOA	TOP	TOA	TOP	TOT
San Aotea II	88.1A	2005/06	8	0.5	1.0	8	2	5.4
Argos Georgia	88.2A	2005/06	8		17.0	75		4.4
San Aotea II	88.1A	2006/07	2	<0.1	0.3	0	7	21.9
Avro Chieftain	88.1E	2006/07	5	0.4	<0.1	3	0	7.5
Janas	88.1F	2006/07	3	2.1		13		6.2

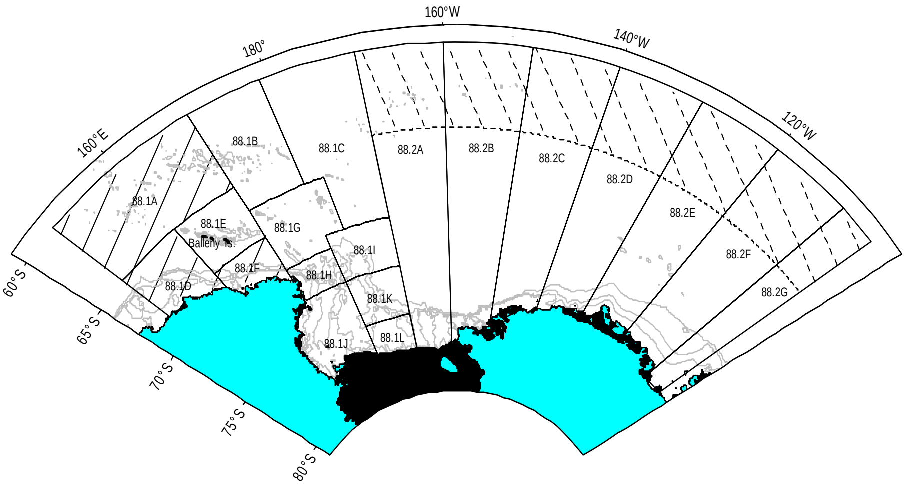
Table 5: Median MCMC estimates (and 95% credible intervals) of B0 and Bcurrent (%B0) for the 2005, 2006, and 2007 stock assessments of the Ross Sea fishery and SSRU 88.2E. (Source SC-CAMLR XXIV, SC-CAMLR XXV, SC-CAMLR XXVI) .

Area	Parameter	2005	2006	2007
Ross Sea	B_0	69 420 (47 690–111 930)	80 510 (59 920–119 920)	71 200 (59 570–87 900)
Ross Sea	$B_{current}$ (%B_0)	88.3 (82.9–92.7)	86.7 (82.1–90.4)	81.9 (78.4–85.4)
88.2E	B_0	7 720 (3 760–22 240)	10 300 (5 340–25 210)	–
88.2E	$B_{current}$ (%B_0)	91.8 (83.1–97.1)	91.4 (83.4–96.5)	–

(a) 1999/00 to 2002/03



(b) 2003/04 to 2004/05



(c) 2005/06 to 2007/08

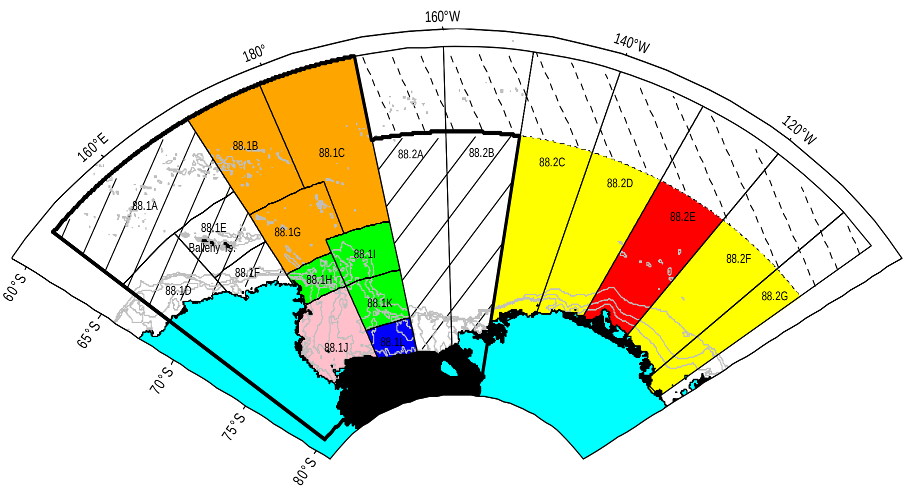


Figure 1: SSRU boundaries used for managing the exploratory toothfish fishery in Subareas 88.1 and 88.2 for (a) 1999/00 to 2002/03, (b) 2003/04 to 2004/05, and (c) 2005/06 to 2007/08. Dashed hatching represents area closed to fishing, solid hatching represents SSRUs with zero catch limits, and colour shading represents SSRUs amalgamated for management. The area defined and assessed as the Ross Sea fishery since 2005/06 is bounded in bold.

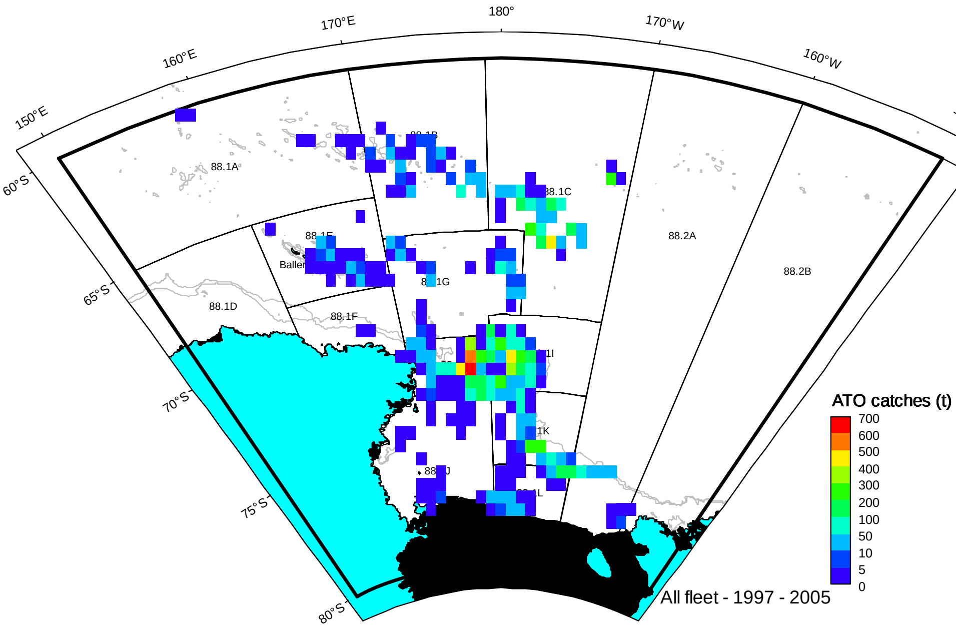


Figure 2: Summed catches (t) of *D. mawsoni* from all vessels for the years 1996/97 to 2004/05 in each 1° latitude by 1° longitude cell. Depth contours at 1000 m and 2000 m.

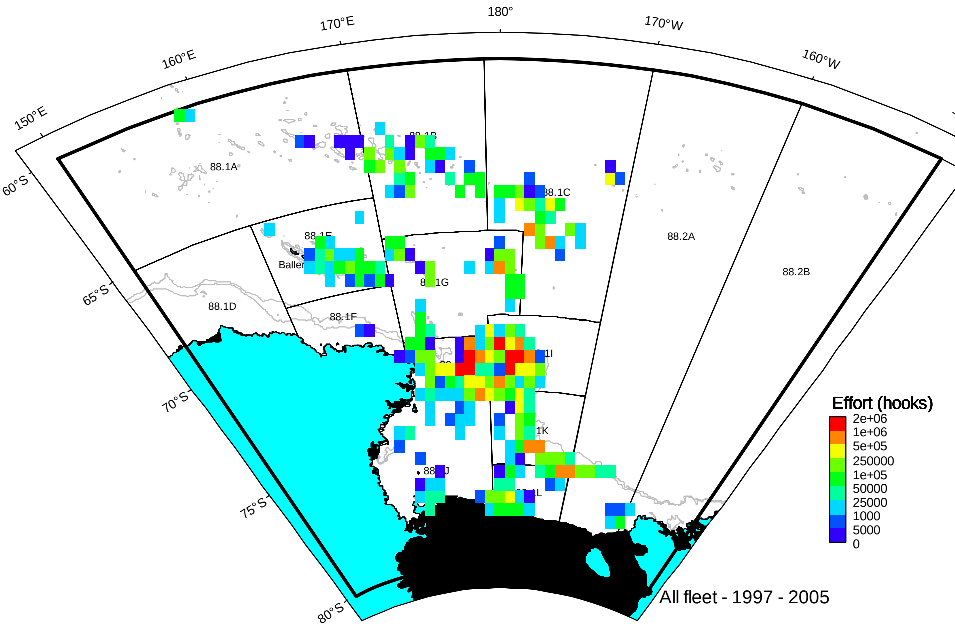


Figure 3: Summed effort (hooks) from all vessels for the years 1996/97 to 2004/05 in each 1° latitude by 1° longitude cell. Depth contours at 1000 m and 2000 m.

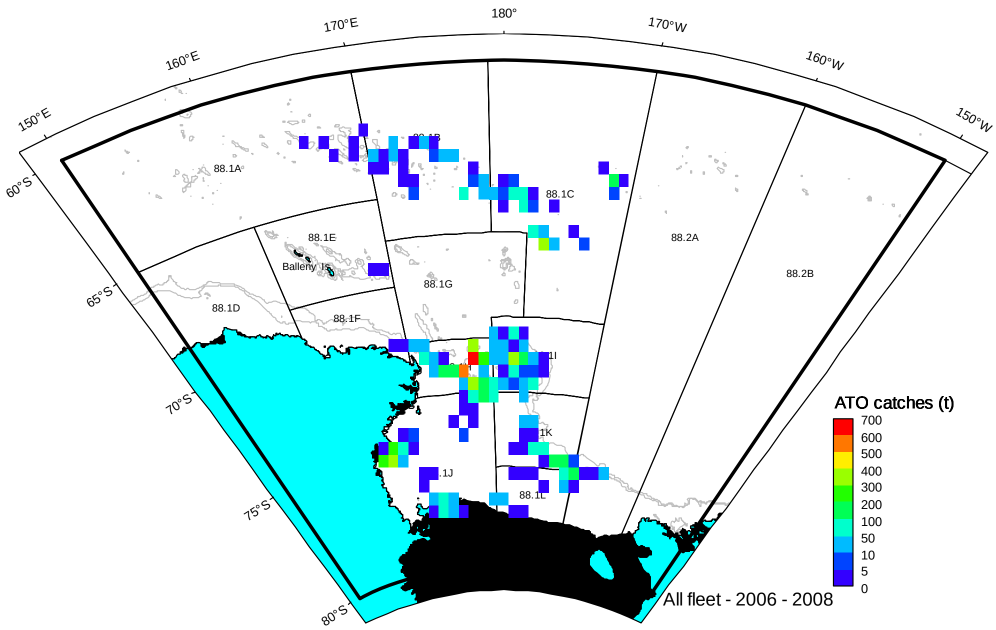


Figure 4: Summed catches (t) of *D. mawsoni* from all vessels for the years 2005/06 to 2007/08 in each 1° latitude by 1° longitude cell. Depth contours at 1000 m and 2000 m.

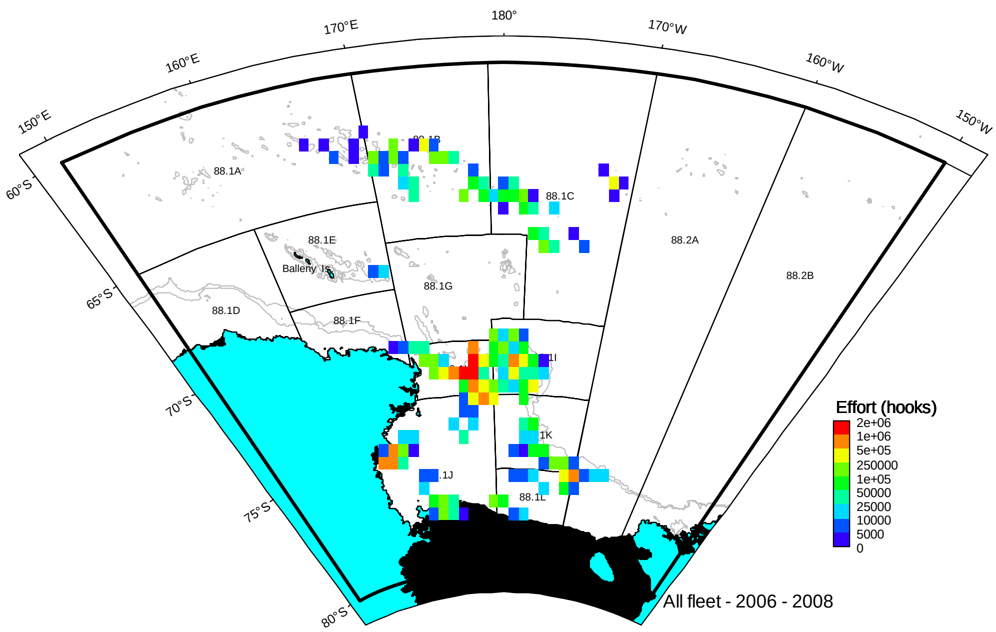


Figure 5: Summed effort (hooks) from all vessels for the years 2005/06 to 2007/08 in each 1° latitude by 1° longitude cell. Depth contours at 1000 m and 2000 m.