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CCAMLR's precautionary approach to management focusing on Ross Sea toothfish fishery

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Abstract: Several recent papers have criticized the scientific robustness of the fisheries management system used by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), including that for Ross Sea toothfish. Here we present a response from the wider CCAMLR community to address concerns and to correct some apparent misconceptions about how CCAMLR acts to promote conservation whilst allowing safe exploitation in all of its fisheries. A key aspect of CCAMLR's approach is its adaptive feedback nature; regular monitoring and analysis allows for adjustments to be made, as necessary, to provide a robust management system despite the statistical uncertainties inherent in any single assessment. Within the Ross Sea, application of CCAMLR's precautionary approach has allowed the toothfish fishery to develop in a steady fashion with an associated accumulation of data and greater scientific understanding. Regular stock assessments of the fishery have been carried out since 2005, and the 2013 stock assessment estimated current spawning stock biomass to be at 75% of the pre-exploitation level. There will always be additional uncertainties which need to be addressed, but where information is lacking the CCAMLR approach to management ensures exploitation rates are at a level commensurate with a precautionary approach.

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Key words: Antarctic toothfish, CCAMLR, ecosystem, managing uncertainty, reference points, stock assessment

Introduction

A number of recent papers have criticized the robustness of the fisheries management approach used by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), including for the Ross Sea toothfish (*Dissostichus mawsoni* Norman) fishery (Blight *et al.* 2010, Jacquet *et al.* 2010, Ainley *et al.* 2012, Ainley & Pauly 2013, Abrams 2014). The criticisms focus on issues related to CCAMLR stock assessment parameterization and decision rules, especially the uncertainty associated with current and future population dynamics and potential ecosystem effects of fishing. Sustainable fishery certification programmes, such as the Marine Stewardship Council (MSC) and Monterey Bay Aquarium's Sea Food Watch, as applied to CCAMLR toothfish fisheries were also criticized, calling into question the certification criteria.

The common thread running through these papers is that uncertainty about the dynamics of ecosystem processes and individual statistical estimates of key quantities make safe management of the effects of fishing on target species, or on the ecosystem as a whole, exceedingly difficult (unless catch limits are reduced by unquantified, though apparently substantial, amounts). Yet few, if any, of the sustainable fisheries throughout the world would be able to meet most of the criteria which these papers suggest should be applied.

The responsible management of the exploitation of all living marine resources must take account of the risks associated with the uncertainty inherent in the effect of exploitation on the target species and subsequently on the ecosystem. This paper presents a response from the CCAMLR community addressing some of the concerns expressed and correcting some apparent misconceptions about how CCAMLR acts to promote conservation of ecosystems and fish stocks at the same time as allowing safe exploitation of all of its fish resources, with a particular focus on Antarctic toothfish in the Ross Sea.

CCAMLR's fisheries management

The ecosystem approach

The ecosystem approach to fishing is encapsulated in Article II of the CAMLR Convention (www.ccamlr.org). The approach utilizes decision rules based on both population status targets and on limit reference points, taking into account uncertainty and ecosystem status in how they are calculated. A target escapement level was first developed for krill (de la Mare 1996). This approach was later extended to fish species, with target escapement levels developed for icefish and toothfish (Constable *et al.* 2000). The approach uses different reference points, depending on the location of the species in the food web, to account for the needs of dependent predators in the ecosystem. CCAMLR is recognized as amongst the world's leading fisheries management organizations in developing and implementing ecosystem approaches to fishing and the precautionary approach (Kohen *et al.* 2007, Lodge *et al.* 2007).

Application of the ecosystem fisheries management approach by CCAMLR involves use of move-on rules to protect trophic interactions and limit direct effects of fishing on fish bycatch, seabirds and Vulnerable Marine Ecosystems (VMEs). Technical mitigation measures (e.g. line weighting, net modifications, streamer lines, etc.) are used to minimize seabird bycatch, resulting in a substantial reduction in accidental seabird mortalities in the CAMLR Convention Area as a whole. Mandatory escapement panels in icefish and krill nets ensure negligible bycatch of mammalian predators.

Explicit focus is placed on the ongoing collection of detailed data for science and monitoring using dedicated observer programmes (including international and national observers), mandatory satellite vessel monitoring systems and catch documentation schemes to reduce illegal, unregulated or unreported (IUU) fishing. In CCAMLR fisheries for icefish and toothfish there is a requirement for 100% coverage by an international (i.e. not from the same state as the flag state of the vessel) as well as a national scientific observer.

Spatial management is applied through closed areas and seasons to avoid fishing impacts on particular life stages of fish, and to minimize bycatch of fish and seabirds, impacts on fragile habitats and risks of other ecosystem impacts in locations where such risks are most probable (e.g. restriction of fishing close to colonies of land-based predators during their breeding season).

Monitoring, evaluation and recommendation of further management actions in response to ecosystem wide issues is undertaken by CCAMLR's Working Group on Ecosystem Monitoring and Management (WG-EMM) which meets annually to review progress and has initiated generic workshops on Fisheries and Ecosystem Models in the Antarctic (FEMA) within the past decade (SC-CAMLR 2007, 2009).

Management under uncertainty

The global fisheries management community realizes that scientists do not, and will never, understand 'everything about everything' related to marine ecosystem dynamics; but this does not imply that successful, precautionary, well-informed and science-based management systems cannot be, or have not been, developed. Over the years, fisheries scientists have developed a range of approaches for considering uncertainty including sensitivity analyses, simulation studies and precautionary decision rules. However, since the adoption of the Precautionary Principle in Rio de Janeiro in 1992, Management Strategy Evaluation (MSE), also known as the Management Procedure (MP) approach when applied tactically to specific fisheries, has been acknowledged as best practice to take due account of unavoidable uncertainties and develop robust management systems (Butterworth & Punt 1999, De Oliveira *et al.* 2008). The MP approach involves simulation testing to ensure that the management processes being applied will achieve fishery sustainability despite the uncertainties, and as a part of this provide an appropriate trade-off between catches from, and conservation risk to, the resource under consideration. This robustness must hold not only for present best perceptions of the resource's dynamics and those of the associated ecosystem, but also for alternative scenarios that cover the range of uncertainties that are plausible and compatible with existing information. Thus, the actual management processes or decision rules applied do not require exact knowledge of the underlying biological mechanisms, and they need not be complex either (e.g. catch limits may be calculated from only basic resource monitoring indices, as in Geromont & Butterworth 2014). The key to the success of these decision rules is their feedback-control nature that adjusts catches (or other management control measures) in response to those indices.

The CCAMLR toothfish harvest control rule

Ideally, the full MP approach would be applied to every toothfish fishery, but it is resource intensive in situations where resources are often limiting and the process is just beginning. Thus to date, CCAMLR has drawn on MSE experience gained elsewhere in defining a general framework for its precautionary generic harvest control

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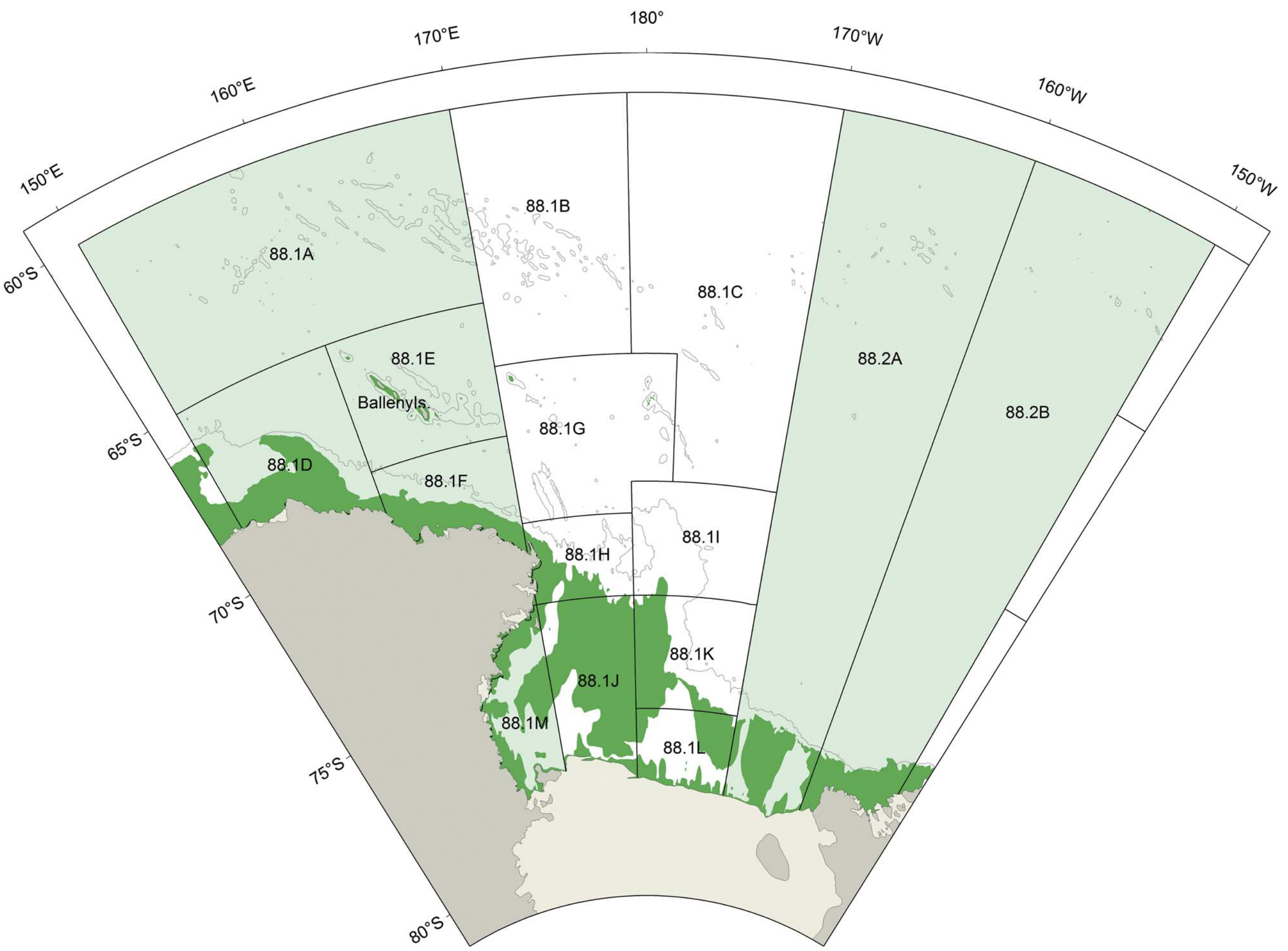

Fig. 1. The Ross Sea region and Small Scale Research Units (SSRUs) used for managing the fishery. Vessels are currently prohibited from fishing in the closed SSRUs (light green) and in depths less than 550 m (dark green). The depth contour at 2000 m (grey) indicates the depth beyond which fishing rarely occurs.

rule framework (Constable *et al.* 2000), which is then customized and modified following each assessment to account for the uncertainty inherent within each stock.

The CCAMLR toothfish fisheries decision rules are based on determining the catch level that will ensure that the median estimated spawning stock biomass (not total biomass) is greater than or equal to 50% of the average pre-exploitation spawning biomass after a further 35 years of fishing (i.e. 35 years from the year of assessment), with the additional condition that there is less than a 10% probability that the spawning biomass will decline below 20% of the pre-exploitation level at any time during this period (Constable *et al.* 2000).

The 50% (target) and 20% (limit) reference points used by the CCAMLR decision rules exceed the requirements for target and limit reference points set by almost all national and international fisheries management organizations, even for species longer lived than toothfish. Extensive analyses of fisheries generally indicate that most fisheries reach maximum sustainable yield at 30–35% of their pre-exploitation abundances (Hilborn 2010). The higher reference levels used by CCAMLR reflect its approach to allow exploitation only to the extent that toothfish recruitment, and the ecosystem as a whole, is not appreciably impacted, as set out in Article II of the CCAMLR Convention.

One key misunderstanding of the CCAMLR decision rules is the supposition that, under the catch limit calculated at present, the decline in population size will follow a clear trajectory from the starting year to a point 35 years later when the stock size will be 50% of pre-exploitation levels, and that there is no feedback to prevent this. However, in reality the catch limit is re-calculated each time an assessment is conducted (usually annually or biennially), and is based on all updated and/or revised data. This approach was developed to ensure that the 50% level will be approached slowly, during which time appropriate catch levels are continually re-adjusted as knowledge improves (Constable *et al.* 2000).

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This regular monitoring with its associated potential re-adjustments serves to emphasize a key aspect of the CCAMLR approach, which is its adaptive feedback nature. Environmental conditions will change over time and affect resource dynamics, with a consequent impact on projections as evaluated earlier. This approach enables adjustments to take such factors into account where necessary, thus adding to the overall robustness of the management system.

While the precautionary approach is now well entrenched within CCAMLR's approach to managing its fisheries, and is based on some simulation testing, formal MP testing of the rule for individual fisheries is required. Furthermore, essential work is required to further develop MPs that are robust against a wider range of the unknown and uncertain behaviours of the Antarctic ecosystem (Constable *et al.* 2000). For example, further development of spatially explicit operating models, such as that for the Ross Sea (Mormede *et al.* 2014b, 2014d), will be required to evaluate management strategies for toothfish more fully at both the single species and the ecosystem level.

How CCAMLR's precautionary approach is applied in the Ross Sea toothfish fishery

Ross Sea integrated stock assessment

The most recent integrated stock assessment of Antarctic toothfish in the Ross Sea region was based on information from a mark-recapture programme, which has been underway since 2003, and catch-at-age data. An algorithm has been developed to ensure that tag data from vessels with low recapture rates are excluded from the assessment (Mormede & Dunn 2013a). This has resulted in an assessment based on the release of 24 000 tagged toothfish and 1200 recaptures (Mormede *et al.* 2014a). Current spawning stock biomass is estimated to be at 75% of the pre-exploitation level (95% Bayesian probability interval 71–78%), well above the 50% target reference point. We concur with Abrams (2014) that estimates of the variance associated with biomass and stock status from the current assessment remain too precise. This is a common statistical situation arising from assuming that the model structure used to provide this estimate is perfectly correct. Other methods are currently being explored to address this issue further (Francis 2011, Mormede *et al.* 2014a). The impact of these uncertainties on the assessment is best evaluated using sensitivity analyses or a MP approach. Sensitivity and retrospective analyses are routinely conducted in CCAMLR to investigate the sensitivity of estimates of the modelled biomass and sustainable yields to uncertainties in biological parameters, fishing selectivity assumptions and the mark-recapture data used in the model (e.g. Mormede *et al.* 2011, 2014a).

Spatial management

The Ross Sea toothfish stock is assumed to be confined to the region extending from 150°E to 150°W, which is divided into 15 Small Scale Research Units (SSRUs) for management purposes (Fig. 1). In 2005, six of these SSRUs were closed to fishing to concentrate effort in areas of greatest recent fishing activity to increase the recapture of tagged toothfish (SC-CAMLR 2008). A seventh SSRU (88.1 M) was closed to fishing in 2008 and, apart from a small amount of research catch, all these SSRUs have remained closed. In addition, fishing is prohibited in waters shallower than 550 m and in 47 'VME risk' areas (each *c.* 10 km^2) which have been closed to provide protection for potentially vulnerable benthic marine ecosystems.

Bycatch limits and mitigation measures

There are bycatch limits for the key fish bycatch species and move-on rules for fish and invertebrate bycatch, whereby vessels are required to move a prescribed distance away from areas of high bycatch. There are also extensive seabird mortality mitigation measures, which have resulted in only two seabird deaths caused by fishing in the Ross Sea region since the toothfish fishery commenced in 1997.

Key uncertainties recently addressed in the Ross Sea toothfish fishery

The Ross Sea toothfish fishery was reviewed in 2008 (Delegation of New Zealand 2008, SC-CAMLR 2008). The review led to a number of changes in the management of the fishery and identified a number of key uncertainties that required further research, some of which were noted by Abrams (2014). The research conducted over the past five years to address these uncertainties has yielded continuous improvements in the assessment model structure and input parameter values, and consequently in the soundness of the resulting management advice. For example, potential bias arising from incomplete mixing of tagged Antarctic toothfish with the rest of the population has been investigated (e.g. Mormede *et al.* 2014b), a survey for monitoring Antarctic toothfish recruitment has been developed (Mormede *et al.* 2014c) and estimates of the age and length of Antarctic toothfish at sexual maturity have been revised (Parker & Grimes 2010). Furthermore, there is a recognized need to actively continue the development of research and to address issues raised where there is scientific justification (Delegations of New Zealand, Norway, and the United Kingdom 2014).

Reduce structural bias in stock assessment

Interannual differences in the distribution of fishing effort, caused by fish not mixing completely across large areas, can create bias in the abundance estimated using mark-recapture methods (Welsford & Ziegler 2013). Studies using mark-recapture data have shown that this incomplete mixing can lead to either an over- or underestimate of abundance. Recently, spatially explicit, age-structured operating models have been developed for the Antarctic toothfish population in the Ross Sea region to characterize the potential extent of this bias within the assessment of the stock and to test the sensitivity of the bias to scenarios for probable movement patterns (e.g. Mormede & Dunn 2013b, Mormede *et al.* 2014b). The operating models for these analyses were developed as generalized Bayesian population models fitted to fishery-based observation data. The spatial structure of the models was represented by dividing the Ross Sea region into 189 equal area cells (24 000 km^2). Three different spatial assumptions were made concerning the underlying distribution of the population: i) the stock was restricted to the 65 cells historically fished, ii) the stock occupied the entire Ross Sea region (all 189 cells), and iii) the stock was restricted to cells with suitable toothfish habitat (120 cells). Estimates of movement rates were consistent with the results of tagging studies and fit to the observations was adequate. Simulations based on these stock scenarios suggested that biomass estimates in the current single-area stock assessment are underestimated by 19–43% (Mormede & Dunn 2013b), thus the errors are in a precautionary direction and corresponding sustainable yields are probably higher than currently estimated by the model. Whilst not constituting a full MSE, these simulations have evaluated one of the key uncertainties in the stock assessment and hence a part of the overall management strategy.

Reduce uncertainty in life history and stock structure

Several authors have noted the paucity of information on the spawning dynamics and early life history of Antarctic toothfish as few spawning fish, and no eggs or larvae, have been found to date (e.g. Hanchet *et al.* 2008, Jacquet *et al.* 2010, Abrams 2014). This information would have little impact on estimates of spawning stock biomass and current stock status even if those data were available, and the present monitoring includes small toothfish (giving a direct indicator of recruitment success). The spatial structure of the fishery management is based on genetic and other information on stock structure. Nevertheless, this is a gap in knowledge and has been identified as a research priority by CCAMLR's Scientific Committee (SC-CAMLR 2013).

Because most of the fishery has concentrated on the Ross Sea slope where mainly older fish are found, a time series of annual sub-adult surveys was initiated in February 2012 in the relatively shallower waters of the Ross Sea shelf (Mormede *et al.* 2014c). The aims of the surveys are two-fold: i) to provide an abundance index for the 5–10 year old Antarctic toothfish in the Ross Sea population and hence an early warning system to detect changes in future recruitment to the fishery, and ii) to provide estimates of recruitment variability and recruitment autocorrelation for the assessment model.

The surveys use standardized gear and procedures, cover the same core strata and are conducted at the same time of year; the third survey in this time series was completed in February 2014 and the time series is summarized by Mormede *et al.* (2014c). The surveys have shown a consistent pattern across the three years with similar estimates of relative abundance and patterns of year class strength. The data from the first two surveys were evaluated within the CCAMLR 2013 Ross Sea stock assessment process which established that the surveys provide a useful signal of year class strength (Mormede *et al.* 2014a). Data from the four year time series will be used in informing decisions on catch limits in the 2015 stock assessment.

Reduce uncertainty in biological and other model parameters

Mark-recapture programmes provide valuable information on movement and growth, and a direct means of estimating exploited stock biomass, but these estimates are sensitive to tagging mortality (mortality arising from the capture and tagging process) and tag detection (Welsford & Ziegler 2013). Empirical estimates of tagging mortality of toothfish are difficult to obtain, and the estimate used in the present assessment came from tank experiments of the closely related Patagonian toothfish (*D. eleginoides* Smitt) on board several fishing vessels (Agnew *et al.* 2006). Agnew *et al.* (2006) estimated an initial tagging mortality of 10% based on all toothfish, and of 5% when considering only toothfish in good condition. An initial tag-related mortality of 10% has been assumed for toothfish in the model even though observers are required to only tag toothfish in good condition. No ongoing tag-induced mortality was applied to tagged fish, as there is no current evidence for this. Experiments to measure tagging mortality and tag detection have been identified by CCAMLR as having a high priority for further research (SC-CAMLR 2013, Welsford & Ziegler 2013).

Biological parameters, such as growth, age at attaining sexual maturity and natural mortality, have been updated where new or improved information became available. For example, estimates of the age and length of Antarctic toothfish at sexual maturity were revised by Parker & Grimes (2010), and the updated estimates were used in recent assessments. Age and growth estimates of Antarctic toothfish have been validated by Horn *et al.* (2003) and Brooks *et al.* (2011). We agree with Abrams (2014) that the use of life history invariants is a very weak basis for estimating natural mortality values, and hence that method was neither used nor is it proposed to be used for Ross Sea Antarctic toothfish. Instead, natural mortality was estimated using Ross Sea age data collected at the start of the fishery, several approaches to estimating natural mortality were considered, and a precautionary value was chosen towards the lower end of the plausible range (Dunn *et al.* 2006, Mormede *et al.* 2014a).

Two other important model components for population projections are the nature of the stock-recruitment relationship and recruitment variability. The spawning stock-recruitment relationship was assumed to be a Beverton-Holt relationship with steepness (h) equal to 0.75 and variability in future recruitment was assumed to be log normally distributed, with an associated log standard deviation of $\sigma_R = 0.6$ (Dunn *et al.* 2006, Mormede *et al.* 2014a). CCAMLR management rules require that the stock be managed to stabilize at 50% of pre-exploitation biomass, a level at which the value of steepness has little impact on the stock-recruitment relationship. For example, a steepness of 0.75 would provide 92% of pre-exploitation recruitment at 50% biomass and a steepness as low as 0.45 would provide over 75% of pre-exploitation recruitment. Recruitment variability will be estimated in time through the sub-adult survey, and incorporated into ongoing assessments as a part of the feedback nature of the CCAMLR approach. Therefore, the future outputs from the current model for management of this stock are unlikely to be particularly sensitive to the choices for these parameters.

Address potential ecosystem interactions with top predators and prey

It is beyond the scope of this paper to provide a complete description of the research conducted to address potential ecosystem interactions of toothfish with its main predators and prey. Extensive ecological data have been assembled and used in a mass-balanced trophic ecosystem model for the Ross Sea shelf and slope ecosystem (Pinkerton *et al.* 2010). This work has been reviewed and improved over several years through engagement with CCAMLR's WG-EMM and a specific FEMA workshop on the Ross Sea ecosystem and toothfish fishery in 2009 (SC-CAMLR 2009). Model outputs suggest that at the scale of the ecosystem and throughout the annual cycle, toothfish are unlikely to be a major prey item for Ross Sea air-breathing predators (e.g. Weddell seals, type C killer whales, sperm whales). Model results were supported by stable isotope analysis which showed that all three species are at the same trophic level (Pinkerton & Bradford-Grieve 2014). Furthermore, mixed trophic impact (MTI) analysis suggests that Antarctic toothfish do not have a high trophic importance across the wider Ross Sea ecosystem (Pinkerton & Bradford-Grieve 2014). However, both studies note that effects at smaller spatial and temporal scales and effects concerning only parts of populations were not addressed by these analyses (Pinkerton *et al.* 2010, Pinkerton & Bradford-Grieve 2014).

Other recent research indicates that toothfish may be important prey to top predators in particular locations and at particular times of year (Ainley & Siniff 2009, Torres *et al.* 2013). The most probable locations occur in parts of the south-western Ross Sea, where Weddell seals and killer whales have been observed feeding on toothfish. Although this area has been closed to commercial fishing since 2008 (SC-CAMLR 2008), there could be potential ecosystem interactions if there is a contraction in toothfish range.

Research to better understand the potential ecosystem importance of toothfish as predators and prey is ongoing (e.g. Eisert *et al.* 2013, Torres *et al.* 2013, Mormede *et al.* 2014c, 2014d). This work includes sampling top predators for stable isotope and fatty acid signatures, developing a better understanding of the overlap in their vertical distribution in the water column, and the development of a spatially explicit simulation model of toothfish and its main prey (Mormede *et al.* 2014d).

Conclusions

Scientists from CCAMLR have noted that recent criticisms of CCAMLR's management approach may reflect a general lack of understanding of CCAMLR's science, its data collection schemes, observer monitoring, assessment and overall management strategy. Ecosystem-based fishery management has long been advocated by CCAMLR, and has been enshrined in its Convention which entered into force in 1982. In addition, CCAMLR's management processes explicitly recognize that knowledge about the target species, related species and ecosystem is not, and never can be, perfect. These rules acknowledge that increased understanding is required, and CCAMLR's management processes put requirements in place to improve that understanding whilst explicitly limiting the scale of the fishery throughout its development to be precautionary at existing levels of understanding.

The main criticisms overall have been with regard to whether CCAMLR is achieving, and will continue to achieve, the objectives in Article II. The CCAMLR management process, which is applied in the Ross Sea, comprises operational objectives, data collection and validation, decision rules (harvest control rules), compliance and enforcement along with regular updating in a feedback management system. A key issue is whether the overall management strategy employed by CCAMLR over many years is achieving its objectives despite uncertainties in knowledge, data, assessment and forecast procedures. Simulations of the CCAMLR management process, and reviews of the science used as the basis for management of both the target stock and the ecosystem interactions, have been conducted within and external to CCAMLR, and are ongoing. There is a recognized need to actively continue the development of research and to address issues raised where there is scientific justification.

Within the Ross Sea, CCAMLR's precautionary approach has allowed the toothfish fishery to develop in a steady and orderly fashion, with an associated accumulation of data and continuously increasing scientific understanding, whilst maintaining the catch levels commensurate with the data and knowledge available at the time. Regular stock assessments of the Ross Sea toothfish have been carried out since 2005 and the most recent stock assessment in 2013 estimated current spawning biomass to be at 75% of the pre-exploitation level. This assessment used the best available information whilst also being precautionary. For example, where there was uncertainty in model parameters, such as natural mortality and tagging mortality, values were chosen which would lead to more conservative estimates of biomass and sustainable yields. Similarly tag data from vessels with low recapture rates were excluded from the assessment. Furthermore, simulations of structural bias in the stock assessment model arising from spatially unrepresentative patterns of fishing effort and/or from non-mixing of tagged fish suggest that biomass estimates are biased low by 19–43%.

There will always be additional uncertainties which need to be addressed and ideally the MP approach would be applied to every fishery, but the process is resource intensive in situations where resources are often limiting. Within the Ross Sea toothfish fishery formal MP testing has not been an immediate priority because the population size is estimated to be relatively close to its pre-exploitation level and the current management approach draws strongly on MSE experience elsewhere, has had some simulation testing and uses structured feedback controls. In the future a MP for this fishery might be developed; a spatially explicit operating model has recently been developed which could be used for this purpose. The outcome from such a MP development would (essentially 'by construction') be in synchrony with the general CCAMLR approach to management of a fishery: when key information is inadequate, exploitation rates are reduced to ensure that the precautionary approach is followed.

The essence of best practice for precautionary management of developing fisheries in an ecosystem context is being aware of the uncertainties and ecosystem context and taking account of uncertainties in management decisions during the development of the fishery. In this way, a buffer is established so that, over time, impacts remain within sustainable limits. The CCAMLR approach has been to adopt this practice from the outset.

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Author contribution statement

The authors were all involved in the original concept and design of the paper and have been involved in its subsequent drafting and revision.

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The authors recognize that whilst abstracts of CCAMLR Working Group papers are available on the CCAMLR website, the full papers are only available from the author or their Scientific Committee representative. Therefore, to increase the accessibility of these papers, all of the cited Working Group papers have been uploaded to the NIWA website (http://www.niwa.co.nz/fisheries/research-projects/the-ross-sea-trophic-model/toothfish-distribution-and-conservation).

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