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Updating the Antarctic krill biomass estimates for CCAMLR Subareas 48.1 to 48.4 using available data

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Abstract We present a novel index of Antarctic krill biomass in CCAMLR subareas 48.1 to 48.4, based on data from scientific nets and covering the years between 2000 and 2011. The annual biomass variation was significant (CV=73%) but no systematic change in krill biomass was evident during the period. The index also suggests that realised exploitation rates were below 0.5% (i.e. catch was <0.5% of biomass) and that the potential exploitation rates implied by the operational catch limit (the trigger level) were below 2% during this period. These exploitation rates are much lower than the precautionary yield estimate for the krill fishery (which is 9.3%). Biomass indices from local scale acoustic surveys also suggest that exploitation rates are low and that there is no evidence of a systematic change in the krill stock. This evidence suggests that the trigger level is a highly precautionary operational catch limit which is currently appropriate for achieving the conservation criteria for the krill stock. It also suggests that the catch levels seen in the first decade of the 21st century are unlikely to have adversely impacted the krill stock. Nonetheless the Commission also needs to manage the risk of adverse impacts on dependent and related populations which might occur if fishing is concentrated in sensitive areas. Advances are needed to improve management of krill fisheries to manage these risks and to ensure that management is robust to the potential impacts of climate change. We suggest that frequent assessment of the krill stock, at scales relevant to the Commission's conservation objectives, is a prerequisite for such advances. The most effective means to achieve this is likely to be through increased use of fishing vessels to collect data, while maintaining current time series.

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ABSTRACT

We present a novel index of Antarctic krill biomass in CCAMLR subareas 48.1 to 48.4, based on data from scientific nets and covering the years between 2000 and 2011. The annual biomass variation was significant (CV=73%) but no systematic change in krill biomass was evident during the period. The index also suggests that realised exploitation rates were below 0.5% (i.e. catch was <0.5% of biomass) and that the potential exploitation rates implied by the operational catch limit (the trigger level) were below 2% during this period. These exploitation rates are much lower than the precautionary yield estimate for the krill fishery (which is 9.3%). Biomass indices from local scale acoustic surveys also suggest that exploitation rates are low and that there is no evidence of a systematic change in the krill stock. This evidence suggests that the trigger level is a highly precautionary operational catch limit which is currently appropriate for achieving the conservation criteria for the krill stock. It also suggests that the catch levels seen in the first decade of the 21st century are unlikely to have adversely impacted the krill stock. Nonetheless the Commission also needs to manage the risk of adverse impacts on dependent and related populations which might occur if fishing is concentrated in sensitive areas. Advances are needed to improve management of krill fisheries to manage these risks and to ensure that management is robust to the potential impacts of climate change. We suggest that frequent assessment of the krill stock, at scales relevant to the Commission's conservation objectives, is a prerequisite for such advances. The most effective means to achieve this is likely to be through increased use of fishing vessels to collect data, while maintaining current time series.

INTRODUCTION

The purpose of this paper is to introduce the current catch limits for the Antarctic krill fishery in subareas 48.1 to 48.4; to explain the basis for these catch limits and clarify their relationship with krill biomass estimates; to present potential options for providing future estimates of krill biomass; and to assess the operational catch limit against available biomass data.

WHAT ARE THE CATCH LIMITS AND HOW WERE THEY CALCULATED?

The main Conservation Measure governing the Antarctic krill fishery in subareas 48.1 to 48.4 is CM 51-01. This identifies two catch limits, a higher precautionary catch limit (5.61 million tonnes) and a lower trigger level (0.62 million tonnes). The precautionary catch limit specifies the amount of catch that might be permitted when “the Commission has defined an allocation of this total catch limit between smaller management units”. The trigger level is the operational catch limit that applies until the Commission has defined this allocation. An additional conservation measure, CM 51-07, sets individual catch limits for subareas 48.1 to 48.4. These are 25%, 45%, 45% and 15% of the trigger level for subareas 48.1, 48.2, 48.3 and 48.4 respectively. These subarea catch limits sum to more than 0.62 million tonnes to allow flexibility for the fishery, but the overall catch is still capped at 0.62 million tonnes. CM 51-07 expires at the end of the 2015/16 fishing season.

The key part of CM 51-01 which influences the current operation of the fishery is the trigger level. This is a clear limit on the amount of krill that the fishery is allowed to catch in each fishing season. This limit is slightly higher than the sum of maximum historic catches in each subarea, and the CCAMLR Scientific Committee reports that “there is no evidence thus far to suggest that historical catch levels in Statistical Area 48 [have] significantly impacted either on krill stocks or on associated predators dependent on these stocks for food” (SC-CAMLR X para 3.65).

CCAMLR acknowledges that management of the krill fishery will ultimately require localised controls on catch to minimise the risk of concentrated fishing in sensitive areas. The precautionary catch limit specifies the catch that could be taken each season once these localised controls are in place. Calculation of the precautionary catch limit involved four main steps:

(1) Identification of a set of conservation criteria for the krill stock intended to help CCAMLR meet its objectives for the krill stock and for dependent and related species, as set out in Article II of the CAMLR Convention. These conservation criteria are that the long term average krill biomass should not fall below 75% of a reference biomass (B_0) and that the probability of the spawning stock falling to 20% of a reference level (SSB_0) should be no more than 10%. Constable et al. (2000) and Miller & Agnew (2000) provide full details of these criteria and their underlying logic.

(2) Estimation of the reference biomass (B_0) and spawning stock biomass (SSB_0). These estimates were originally based on data from the FIBEX survey conducted in 1981 (Trathan et al. 1993), but have been updated based on data from the CCAMLR 2000 synoptic survey (Hewitt et al. 2004). This latter survey provided data on krill biomass in subareas 48.1 to 48.4 in January 2000, which CCAMLR agreed was an appropriate reference biomass. It is often referred to as “unexploited biomass” (e.g. Miller & Agnew 2000), suggesting that it approximates the state of the krill stock in the absence of fishing.

(3) Estimation of a precautionary yield. This is the maximum yield (catch/ B_0) that model projections suggest can be taken while ensuring that the conservation criteria for the krill stock are met. Constable and de la Mare (2003) provide details of the modelling process.

(4) Final calculation of the precautionary catch limit, which is the product of precautionary yield and B_0.

Thus the precautionary catch limit is a long-term measure which is intended to help CCAMLR meet its objectives for the krill stock and for dependent and related species, provided the underlying assumptions are robust and that it is used in conjunction with localised controls on catch.

THE CCAMLR 2000 SYNOPTIC SURVEY

The CCAMLR 2000 synoptic survey was a major international research effort, involving four ships. It covered a nominal area of 2 million km^2. This compares with a total area for subareas 48.1 to 48.4 of about 3.5 million km^2. The survey used acoustics to assess the post-larval krill biomass in the upper 500m of the water column and therefore probably underestimated the total krill biomass in the four subareas.

There have been several estimates of krill biomass based on the data collected during this survey. The initial estimate of B_0 was 44.3 million tonnes, (Hewitt et al 2004). CCAMLR's expert group on acoustics (SG-ASAM) has since refined methods for estimating Antarctic krill biomass based on acoustic data and revised the survey estimate to 60.3 million tonnes (Jolly & Hampton CV =12.8%) (SC-CAMLR 2010, Fielding et al. 2011). The precautionary catch limit specified in CM 51-01 is based on this revised estimate.

The precautionary catch limit is intended to be robust to inter-annual fluctuations in krill biomass. At the time of the survey design, there was no intention to repeat the CCAMLR 2000 synoptic survey to provide regular assessments of krill biomass.

Since the trigger level, rather than precautionary catch limit, is the operational catch limit for the fishery, the biomass estimate from the CCAMLR 2000 synoptic survey does not currently influence the total amount that the fishery is allowed to catch.

IS A SINGLE ESTIMATE OF B_0 SUFFICIENT?

The krill stock in subareas 48.1 to 48.4 is distributed over a vast area. CCAMLR does not have the resources to commission regular surveys of this area. Thus the intention of managing the Antarctic krill fishery with a long term precautionary catch limit was pragmatic. However, new information on variability and change in the krill stock has become available since the CCAMLR 2000 synoptic survey. An analysis of data from scientific nets by Atkinson et al. (2004) showed a decline in the abundance of post-larval krill in the 1980s. An update on this study shows that the high krill abundances which occurred in 5 of 7 years from 1982 to 1988 did not occur in any subsequent year (Atkinson et al.

2014). There are no published studies which show the consequences of this decline in abundance for krill biomass. In addition to this decline, various studies indicate high inter-annual variability in krill biomass and abundance at a variety of scales. For example estimated biomasses or abundances below 25% of the long-term mean have occurred in most of the available time-series. These low values occurred in 2 of 16 years at South Georgia, 3 of 16 years in subarea 48.1, and 13 of 32 years in the sector 10^{o}E to 90^{o}W (Fielding et al. 2014; Kinzey et al. 2015, Atkinson et al. 2014). There is increasing evidence that recruitment variability in Antarctic krill is linked to environmental factors including sea ice extent and the Southern Annular Mode, such that krill biomass could be negatively affected by ongoing climate change (Atkinson et al. 2004, Saba et al. 2014). It is difficult to disentangle real variability in the size of the krill stock from survey noise (e.g. the effects of variability in the distribution of the krill stock, the timing of recruitment and migration events, and the location and sampling events). However, increasing evidence of environmental controls on krill recruitment suggest that the observed scale of variability is plausible.

With such variability, a single snapshot estimate of krill biomass is a highly uncertain representation of the unexploited biomass. If the snapshot estimate is higher than the mean unexploited biomass, then the precautionary catch limit will be higher, and therefore less precautionary, than intended. Conversely if the snapshot estimate is lower than the mean unexploited biomass, then the precautionary catch limit will be lower than intended. The precautionary yield estimate is based on model projections in which the conditions affecting the krill stock vary around constant averages. These projections do not include systematic changes such as might occur as a result of regional climate change. If the krill stock declines over time due to factors other than fishing, then the precautionary catch limit that results from these model projections might prove less precautionary than intended. Reliance on a single biomass estimate, or a long term precautionary catch limit, might impair CCAMLR's ability to achieve its objectives for the krill stock and for dependent and related species.

The trigger level was not based on information about krill stock size or its variability. Nonetheless, CCAMLR's use of the trigger level as the operational catch limit provides extra precaution that may allow for the uncertainty associated with variability and tends in the krill stock. The trigger level is equivalent to ~1% of the estimated krill biomass in 2000. This exploitation rate is lower than the precautionary yield estimate for krill (9.3%) and the catch limits set for CCAMLR finfish fisheries (e.g. around 4% of the biomass estimate for mackerel icefish (Darby et al 2013) and toothfish (Scott et al. 2013) on the South Georgia shelf). However, the management of these fisheries is based on regular updates of stock status.

There are clear benefits in incorporating regular updates on stock status into the management of the krill fishery. Such updates will facilitate assessment of whether catch limits remain precautionary, and more robust estimation of uncertainties associated with biomass estimates.

IS A NEW SYNOPTIC SURVEY FEASIBLE?

There would be advantages in a new synoptic survey. Firstly this would provide a new snapshot estimate of krill biomass. This would be an appropriate basis for assessing and, if necessary, refining the precautionary catch limit. Secondly the CCAMLR 2000 synoptic survey provided valuable additional information on the distribution and ecological role of krill. A new synoptic survey would provide a platform for further research into these factors, the understanding of which is important to ensure that management of the krill fishery remains consistent with Article II of the CCAMLR convention. There is a significant potential for climate change to impact both the biomass and distribution of krill, and high uncertainty associated with attempts to predict this impact. Regular (circa decadal) synoptic assessments of krill biomass and distribution would be useful for monitoring such impacts and allowing timely adaptation of management measures. However, a repeat survey using research ships (as in the 2000 survey) is unlikely in the current economic climate. SG-ASAM has approved the use of fishing vessels to collect acoustic data on krill for addressing scientific questions. In our opinion, future synoptic surveys are only likely if they are supported by the fishing industry and make extensive use of fishing vessels for data collection.

WHAT ARE THE OTHER OPTIONS FOR PROVIDING FUTURE ESTIMATES OF KRILL BIOMASS?

There are several regional krill monitoring programmes which provide annual estimates of krill biomass (Kinzey et al 2015; Fielding et al. 2014; Skaret et al. 2015) within parts of 48.1, 48.2, and 48.3 (Table 1). These surveys provide valuable local-scale information about inter-annual changes in the krill stock, which might be a useful basis for future feedback management. It is likely that any systematic change in the biomass of the whole krill stock in subareas 48.1 to 48.4 would include corresponding changes in biomass at the local scale. However, there is no clear information available about how the biomass estimated in these local surveys relates to the biomass of the whole krill stock. Some aspects of krill distribution are well described, including an association with shelf and shelf-break areas in the Scotia Sea (e.g. Trathan et al. 2003; Siegel et al. 2005; Atkinson et al. 2008) and there is sufficient information to provide insight into how the survey areas fit into the general distribution of krill or that observed during the synoptic survey. However, it is unclear how this distribution varies over time (on both intra and inter annual scales) and the extent to which krill move between areas, through either advection or active migration. It is therefore unclear how the krill populations in the three survey areas are connected to each other. Because of this uncertainty, it might be difficult to distinguish between changes to the biomass of the whole stock and shifts in distribution.

Table 1. Summary of annual local-scale krill surveys in subareas 48.1 to 48.3

Subarea	Organisation	Type	Start year	Survey area (km^2)	Subarea (km^2)
48.1	US-AMLR (US)	acoustic/net	1992	125,000	639,317
48.2	IMR (Norway)	acoustic/net	2011	27,000*	856,086
48.3	BAS (UK)	acoustic	1997	10,560	1,029,732

* This is the stratum area, see Appendix for further details.

Additional information is available from scientific net sampling. Scientific netting is conducted during the subarea acoustic surveys. Kinzey et al. (2015) provide biomass estimates based on net data in addition to estimates based on acoustic data. Scientific netting is also conducted during other surveys, most of which are single surveys of a particular location rather than regular (e.g. annual) events. Much of the available data on post-larval krill numerical density has been compiled in a single database (KRILLBASE) and standardised to adjust for differences in fishing depth, time-of-day etc. (Atkinson et al. 2008, 2009). Further information on krill length is available in separate tables within KRILLBASE. It is therefore possible to combine density and length information with length-mass relationships to derive an index of biomass. This index based on net data integrates information from multiple locations, and therefore provides a broad-scale index of biomass. There are caveats, particularly that krill density and length vary seasonally and between locations, so shifts in the timing and location of samples from year to year might bias the index. Also, the choice of length-mass relationship can influence the index. It might be appropriate to calculate mean mass for each sample using a seasonally relevant relationship. These issues warrant further exploration to establish how robust an index of krill biomass the net data provide.

There are additional metrics, such as catch per unit effort (CPUE) and the size of krill in predator diets. Although CPUE is widely used as an index of abundance for fished species Butterworth (1988), Mangel (1988) and Siegel et al. (1998) have previously concluded that it is not an appropriate abundance index for krill. However in 2010 WG-SAM proposed further work on investigating “the utility of CPUE data from the fishery ... particularly in areas of Area 48 which have limited research survey data” (SC-CAMLR XXIX, Annex 4, para 2.3). Several studies have used the average size of krill in predator diets as an index of krill availability to those predators (Murphy et al. 2007; Forcada et al. 2008, Forcada & Hoffman, 2014). This is based on the assumption that greater average sizes indicate low levels of recruitment and therefore lower availability (Reid et al. 1999). Fishing vessels are able to collect acoustic information during normal operations and fisheries observers already collect information on krill demographics, both of which offer potential insights into krill stock status. In the longer term, it might also be possible to monitor changes in the stock using unmanned underwater vehicles (e.g. Guihen et al. 2014) and acoustic moorings (e.g. Saunders et al. 2008).

Ongoing work within EMM includes the development of an integrated stock assessment, and of feedback management approaches. Integrated stock assessment is intended to make use of multiple data sources (including the fishery, surveys and krill predators) (SC-CAMLR XXIX, Annex 4, para 2.3) and to provide an alternative to synoptic surveys as a means of assessing krill stock status (SC-CAMLR XXIV, Annex 4, para 2.53). Current feedback management initiatives focus on managing the fishery at the local scale. It might be more tractable to assess the status of the krill stock and manage the fishery at these scales rather than at the scale of whole krill stock in subareas 48.1 to 48.4. However, these initiatives are intended to complement rather than replace the catch limit for the whole krill stock.

HAS KRILL BIOMASS CHANGED SINCE THE CCAMLR 2000 SURVEY?

Local-scale acoustic surveys and KRILLBASE provide indices of krill biomass which indicate variability and change in the krill stock since 2000 (Table 2). The caveats associated with these indices were introduced in the previous section. The local-scale surveys indicate variability and change within the survey areas summarised in Table 1. The KRILLBASE index indicates variability and change within the sector 20°-80°W (see Appendix for further details), but might have greater error due to sampling variability.

Table 2. Biomass indices for subareas 48.1 to 48.3 (tonnes km^{-2} scaled to 2000 values, except 48.2 scaled to 2011). KRILLBASE data as described in the Appendix, Subarea 48.1 data from Kinzey et al. (2015), subarea 48.2 data from Skaret et al. (2015) with further details in the Appendix, subarea 48.3 data from Fielding et al. (2014).

Year	KRILLBASE	subarea 48.1	subarea 48.2	subarea 48.3
2000	1.00	1.00		1.00
2001	1.58	0.17		13.41
2002	1.62	0.09		50.01
2003	1.32	0.70		30.87
2004	0.80	0.16		9.53
2005	0.56	0.25		32.64
2006	0.54	0.41		43.47
2007	1.02	1.37		22.31
2008	3.82	0.71		
2009	0.81	0.68		10.52
2010	0.86	0.56		5.49
2011	0.71	0.56	1.00	21.53
2012			0.45	32.89
2013			0.57	22.54
2014			1.42	
mean	1.22	0.56	0.86	22.79
CV	0.73	0.68	0.52	0.65

The data in Table 2 are a resource with which to address the concern that there might have been a systematic change in krill biomass since the CCAMLR 2000 synoptic survey. We caution that it is difficult to separate systematic change from natural variability in noisy time series. Multi-decadal series (30 to 40 years of data, Henson et al. 2010) or parallel series that control for the putative cause of change are usually necessary to make such distinctions. Nonetheless, it is appropriate to consider the evidence, with the caveat that formal statistical tests have very low power. We therefore examined the indices of biomass for signs of a systematic change or trend since 2000. Each index features considerable inter-annual variability, and the inter-annual CVs are similar for each index (65% to 73%). Table 3 presents statistics for each index, including correlations with year and inter-annual averages for the first and second sexennium (6 year period) of the time series. There is no evidence of a significant trend in any of the indices. In the KRILLBASE and subarea 48.1 indices, the mean biomass increased marginally (and non-significantly) between the first and second sexennia. In the subarea 48.3 index, the mean biomass decreased marginally (and non-significantly) between the first and second sexennia. This provides some reassurance that there has not been a systematic change in krill biomass since the CCAMLR 2000 synoptic survey.

Table 3. Summary statistics for biomass indices in Table 2.

	KRILLBASE	subarea 48.1	subarea 48.2	subarea 48.3
r (correlation with year)	-0.03	0.22		0.01
P (trend)	0.93	0.49		0.98
<u>2000 to 2005</u>				
Mean	1.14	0.40		22.91
CV	0.38	0.93		0.79
<u>2006 to 2011</u>				
Mean	1.29	0.72		20.66
CV	0.96	0.49		0.83
P (difference between means)	0.79	0.15		0.83

IS THE TRIGGER LEVEL PRECAUTIONARY?

As stated above, it is the trigger level, rather than the precautionary catch limit, which defines the total amount that the fishery is currently allowed to catch. The trigger level is equivalent to 11% of the current precautionary catch limit derived from the reference level, B_0.

The main concern about B_0 is that it might overestimate the natural state of the krill stock (the so-called unexploited biomass). A lower precautionary limit (LPL) based on a minimum biomass estimate would provide increased protection for the krill stock. This is conceptually similar to the approach used by CCAMLR to manage icefish stocks, where catch limits are based on the lower 95% confidence interval of biomass estimates. It follows that if the trigger level remains below this LPL, then the trigger level remains precautionary. The KRILLBASE index (Table 2) provides a series of biomass estimates from 2000 to 2011 and is therefore a means of calculating LPL:

$$LPL = 0.093 * 60.3 * I_{min}/I_{2000}$$

where 0.093 is the precautionary yield used to calculate the current precautionary catch limit, 60.3 is the acoustic estimate of biomass in the year 2000, and I_{min} is the minimum value of the KRILLBASE biomass index between 2000 and 2011. This approximates what the precautionary catch limit might have been if the synoptic survey had been conducted in 2006 when this minimum was recorded. The LPL is 3.04 million tonnes. The trigger level is 20% of this. Thus the trigger level remains precautionary by the logic described above.

It is also possible to project the B_0 estimate forward to 2011 using the KRILLBASE index and therefore to calculate the annual exploitation rate (catch/ biomass) (Fig. 1). This was below 0.5% for each year from 2000 to 2011, and the maximum potential exploitation rate (trigger level/biomass) was below 2% in each year.

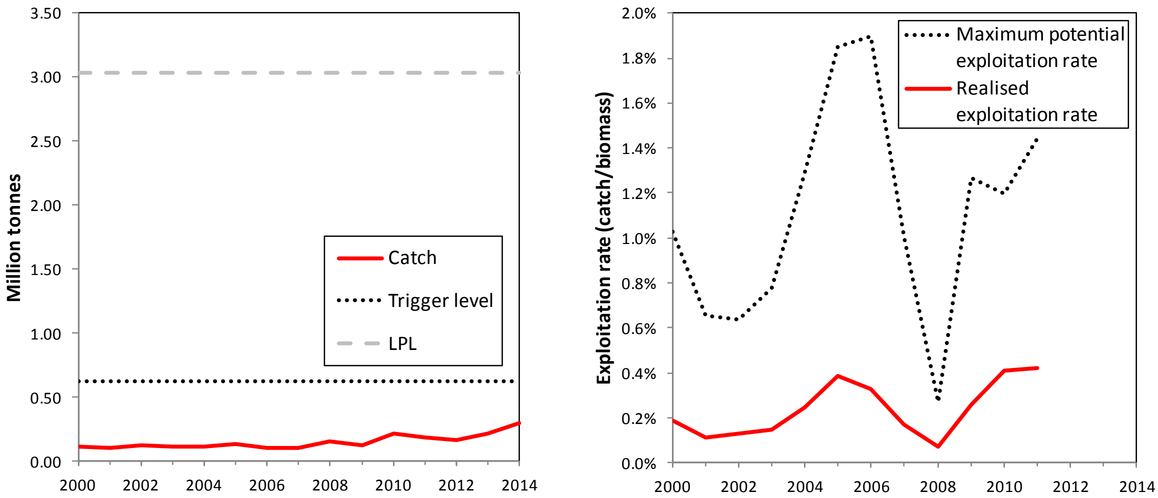

Figure 1. (Left) Krill catch by year, relative to the operational catch limit (Trigger level). The figure also shows lower precautionary limit (LPL) based on the biomass in 2006 (the lowest observed biomass in the period 2000 to 2011) (Right) Krill exploitation rate (catch/biomass) and the maximum potential exploitation rate implied by the trigger level (catch/trigger level).

Fielding et al. (2014) compared the total catch by year in subarea 48.3 with the biomass estimated from surveys in that subarea. As there are surveys in each subarea, it is possible to extend this approach (Table 4). None of the surveys attempt to estimate the biomass in a whole subarea. However it is reasonable to assert that the biomass in each subarea is at least that estimated in the survey. In the case of subarea 48.1 (where the survey area is 20% of the subarea), the catch has been consistently below 10% of the survey estimate of biomass. In the case of subarea 48.2 (where the survey (stratum) area is 1 to 3% of the subarea), the catch has been consistently below 3% of the survey estimate of biomass. In the case of subarea 48.3 (where the survey area is 1% of the subarea), the catch was below 25% of the survey estimate of biomass in all years except 2000 (the year of the CCAMLR synoptic survey). The subarea 48.3 survey in 2000 was conducted by a different ship from that used in other years. The possibility that the anomalously low value in 2000 was partly due to a ship effect cannot be excluded at present.

For subarea 48.1, the survey estimate of biomass in 20% of the subarea has been above the subarea catch limit for each year of available data. For subarea 48.2, the survey estimate of biomass in 1 to 3% of the subarea has been <27% the subarea catch limit in all years. For subarea 48.3, there were 10 years between 2000 and 2013 when the survey estimate of biomass in 1% of the subarea was above the subarea catch limit, and three years in which it was below the subarea catch limit.

This comparison suggests that subarea catches are generally small compared with survey-estimated biomass for a part of each subarea. The subarea catch limits are a higher proportion of the survey-estimated biomass. Nonetheless, local biomass is usually considerably greater than the subarea catch limit.

Table 4. Estimates of krill biomass in survey areas (covering 20%, <8% and 1% of subareas 48.1, 48.2 and 48.3 respectively) compared with subarea catches and catch limits.

	Survey estimate (tonnes)			Catch (tonnes)			Catch/survey			Catch limit/survey		
Year	48.1	48.2	48.3	48.1	48.2	48.3	48.1	48.2	48.3	48.1	48.2	48.3
2000	2,950,000		28,934	71,977	16,891	25,557	0.02		0.88	0.05		9.64
2001	516,000		387,974	46,778	4,981	52,423	0.09		0.14	0.30		0.72
2002	272,000		1,447,037	10,646	72,060	43,282	0.04		0.03	0.57		0.19
2003	2,070,000		893,270	35,377	15,427	66,924	0.02		0.07	0.07		0.31
2004	464,000		275,827	13,882	46,456	57,829	0.03		0.21	0.33		1.01
2005	739,000		944,275	7,095	73,494	48,437	0.01		0.05	0.21		0.30
2006	1,210,000		1,257,802	88,834	3,102	14,613	0.07		0.01	0.13		0.22
2007	4,040,000		645,427	18,419	65,591	20,576	0.00		0.03	0.04		0.43
2008	2,100,000			2,884	93,384	60,253	0.00			0.07		
2009	2,010,000		304,445	33,970	91,855	1	0.02		0.00	0.08		0.92
2010	1,660,000		158,928	153,262	49,999	8,712	0.09		0.05	0.09		1.76
2011	1,650,000	5,744,250	623,040	9,215	115,995	55,801	0.01	0.02	0.09	0.09	0.05	0.45
2012		2,559,330	951,562	75,630	29,040	56,415		0.01	0.06		0.11	0.29
2013		1,065,681*	652,186	153,830	31,306	32,221		0.03	0.05		0.26	0.43
2014		8,137,530		146,191	72,455	75,169		0.01			0.03	

* Biomass based on a smaller survey area (8,860 km^2) than other years (27,000 km^2) .

CURRENT MANAGEMENT OF THE KRILL STOCK

The exploration above suggests that the trigger level is an appropriate catch limit to help the Commission to achieve its conservation criteria for the krill stock in subareas 48.1 to 48.3. There is no evidence of a systematic change in the krill stock since 2000 and therefore no evidence that the effectiveness of the trigger level has been eroded.

In addition to its objectives for the krill stock, the Commission has agreed, in Article II, to maintain “the ecological relationships between harvested, dependent and related populations”. The conservation criteria for the krill stock make some provision for dependent and related populations. Specifically, the objective of maintaining average biomass above 75% of B_0 aims to reserve part of the stock’s production for predators and is consistent with the later recommendation of Smith et al. (2011). The Commission also need to manage the risk of concentrated fishing in sensitive areas. The preamble to CM 51-07 notes that the Commission recognises “that the distribution of the trigger level needs to provide for flexibility in the location of fishing in order to ... alleviate the potential for adverse impacts of the fishery in coastal areas on land-based predators” but it also states that “advances are urgently needed as the trigger level itself is not related to the status of the krill stock”. Neither the trigger level nor the set of subarea catch limits defined in CM 51-07 is an evidence-based means of managing the risk of concentrated fishing in sensitive areas. Watters et al. (2013) provided a model-based assessment of the risks associated with current management (i.e. CM 51-01 and CM 51-07), resolved to the spatial scale of the smaller management units mentioned in CM 51-01.

CONCLUSIONS

Local-scale surveys of krill biomass in subareas 48.1, 48.2 and 48.3 indicate considerable inter-annual variability throughout the first decade of the 21st century. However, there is no evidence of a systematic change over this period. A compilation of net based data provides a more general (larger scale) index of krill biomass which also indicates substantial variability but no systematic change. This index allows calculation of the potential exploitation rate implied by the trigger level (<2%) and the actual exploitation rate (<0.5%). These values are very low compared with the precautionary yield (9.3%). Catches within subareas are typically small fractions (0 to 25%) of the biomass observed in local-scale surveys which, in turn, cover a fraction (1 to 20%) of each subarea. This evidence suggests that the trigger level is precautionary and currently fit-for-purpose as an operational catch limit and that the catch levels seen in the first decade of the 21st century are unlikely to have adversely impacted on the krill stock as a whole or in each subarea.

The Commission recognises that neither the precautionary catch limit nor the trigger level is sufficient to prevent concentrated fishing in sensitive areas and acknowledges that “advances are urgently needed” (CM 51-07). The Commission also understands “that progress with feedback management could provide a mechanism to improve management of krill fisheries” (CM 51-07). Feedback management is defined as an approach which “will use decision rules to adjust selected activities (distribution and level of krill catch and/or research) in response to the state of monitored indicators” (SC-CAMLR 2011). We suggest that the key state that requires monitoring is the biomass of the krill stock at both the local and regional scales. Such information would be helpful even if catches remain below the trigger level, to provide timely information on any changes that might result from climate change, and to periodically evaluate existing conservation measures.

Ultimately, understanding the effects of the fishery on krill stocks and on dependent and related populations requires improved information on exploitation rates. This, in turn, requires information on both catches and the krill stock (biomass and, ideally, production) at scales that are relevant to the Commission’s conservation objectives. The challenge for CCAMLR is to develop an effective monitoring system for the krill stock which makes efficient use of the available resources. We have demonstrated a relatively simple approach to calculating exploitation rates based on existing survey time-series. The ongoing work with commercial vessels provides an opportunity to supplement current monitoring with surveys conducted using commercial vessels in the areas where the fishery operates.

At a recent workshop on Understanding Cross-Sector Objectives for Krill Fishing and Conservation participants “generally agreed that the current low levels of krill fishing are unlikely to threaten ecosystem health but that increases beyond the current catch limit will increase the risk. However, participants [were not] able to the define ecosystem states that are desirable or healthy. This reflects the gaps in the currently available information”. The current study has established that, despite the absence of repeated synoptic surveys of the krill biomass in subarea 48.1 to 48.4, there is sufficient information available to address some of this uncertainty. The local-scale acoustic surveys allow comparison between the magnitude of the current catches and the scientifically determined survey estimate of biomass. The results suggest that current catch levels are not resulting in long term changes to the stock at the subarea scale. However, further work is needed to determine smaller-scale effects and the impact on predators. Although the current local-scale surveys do not cover the complete spatial distribution of the krill stock, this study demonstrates that they are important for the provision of management advice.

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APPENDIX

1. Methods for calculation of the time series of krill biomass based on net data

For this analysis, recently updated versions of the KRILLBASE databases were used. KRILLBASE incorporates both existing time series (e.g. US AMLR) as well as a compilation of all available survey data from various countries. KRILLBASE comprises two separate databases, one on numerical density of postlarval *Euphausia superba* from untargeted oblique or vertical hauls (Atkinson et al. 2008) and the other providing sex, maturity and length frequencies from all available hauls (including targeted and horizontal hauls; see Atkinson et al. 2009). For this analysis both the abundance and length frequency databases were restricted to hauls from 20°-80°W spanning October-April inclusive in each split year from 2000-2011 (labelled with the last calendar year in the split year). For the abundance database, further screening was applied according to sampling depths and the data were standardised to a common sampling method; procedures all detailed in the supplementary appendix of Atkinson et al. (2008). For the length frequency data, trawls or scientific nets with mesh sizes >6 mm were excluded from the analysis. This provided a subset comprising 2697 stations for abundance and 1023 stations for length frequency used in this analysis. The biomass index was calculated as the product of the mean density (individuals m^2) and the mean wet mass of an individual krill (g) in each split year, where mean mass is calculated from mean length (mm) using the relationship: mass $= 2.05*10^{-6}*$ length$^{3.325}$ (Siegel, 1992).

2. Local-scale survey data from 48.2

The local scale survey in 48.2 (nominal area 65,000 km^2) has used a range of frequencies. Also, between year differences in ice cover change the accessible survey area from year to year. A stratum (nominal area 27,000 km^2) within the survey area is used for between-year biomass comparisons. However, even the accessible area within the stratum was also impacted by ice in 2013. The time-series shown in Tables 2 and 4 is based on the stratum biomass estimates using 120kHz data. However the 2013 values are based on the whole area accessible that year (nominal area 8,860 km^2). See Skaret et al. (2015) for further details.