Managing the fishery for Antarctic krill: A brief review of important environmental and management considerations

This paper provides a brief review of the management framework for the commercial fishery for Antarctic krill (*Euphausia superba* Dana), including mention of a number of issues currently under debate by interested stakeholders. It has been prepared using publicly available material and knowledge gained through personal experience and engagement with the body responsible for managing the krill fishery. The author has been actively involved with krill management for many years.

Information in this review is provided on a 'best endeavours' basis. No responsibility is given or implied for the way in which the contents of this report are used.

The vast, ice-covered Antarctic continent is a major component of the Earth's global climate system. The high contrast in reflective properties of white, ice-covered areas and surrounding dark sea surface in the region plays an important role in regulating regional and global climate.

The Southern Ocean is also renowned for its abundant wildlife and for the diversity of species that feed upon Antarctic krill. Many whales, seals, penguins and other seabirds feed on krill, as do different species of fish and squid.

Antarctic krill are also the focus of a small but growing fishery, which, if not well managed, has the potential to compete with those species that depend upon it.

Management responsibility for the Antarctic krill fishery

The commercial fishery for Antarctic krill is regulated by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR advocates an ecosystem-based management framework, and has agreed that any harvesting and associated activities in the Convention Area shall be conducted in accordance with the following principles of conservation (see Article II)[1]:

a. prevention of decrease in the size of any harvested population to levels below those which ensure its stable recruitment. For this purpose its size should not be allowed to fall below a level close to that which ensures the greatest net annual increment;

b. maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine living resources and the restoration of depleted populations to the levels defined in sub-paragraph (a) above; and

c. prevention of changes or minimisation of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades, taking into account the state of available knowledge of the direct and indirect impact of harvesting, the effect of the introduction of alien species, the effects of associated activities on the marine ecosystem and of the effects of environmental changes, with the aim of making possible the sustained conservation of Antarctic marine living resources.

CCAMLR now includes 24 Member states, plus the European Union; a further 11 states have Acceded to the Convention. Any Member intending to fish for krill must comply with Conservation Measure 21-03 by notifying their intention to harvest krill by 1 June of the preceding year and then also gaining the agreement of the Commission. Members harvesting krill must then ensure that their harvesting operations comply with the CCAMLR Conservation Measures that regulate krill fishing (CM 51-01, CM 51-02, CM 51-03, CM 51-04, CM 51-06, CM 51-07)[2]; in addition, all operations must comply with any other Conservation Measure that regulates other more general aspects of harvesting, including vessel marking, notification, gear regulation, bycatch mitigation, reporting, etc.

At present the international fishery for Antarctic krill only operates in FAO Area 48 (i.e. in the south-west Atlantic and north of the Antarctic Peninsula). In the past it has operated elsewhere and catch limits have been set for Division 58.4.1 (CM 51-02) and Division 58.4.2 (CM 51-03), but no harvesting has taken place in these Divisions for many years, apart from a very small catch in 2017.

The fishery is an Olympic style fishery and currently five Members (Chile, China, Korea, Norway and the Ukraine) fish for krill. Each Member is closely regulated by CCAMLR, with all Members subject to the same regulations. Fishing strategies of each operator may be influenced by the way other operators fish, especially where local catch limits restrict harvesting opportunities, or where past or current harvesting indicates the presence of exploitable krill aggregations.

Catch limits for Antarctic krill in the southwest Atlantic

The current catch limit for Antarctic krill is based on scientific data collected during 2000, following a multinational bioacoustics survey to estimate the standing stock of krill in the southwest Atlantic sector (Trathan et al. 2002)[3]. Analysis of the standing stock was completed in 2010, leading to an estimate of 60.3 million tonnes (CCAMLR 2010a)[4]. A precautionary catch limit of 5.61 million tonnes was agreed based on this estimate of standing stock (CCAMLR 2010b)[5] and is defined in CM 51-01.

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The Commission has decided that until an allocation of the precautionary catch limit between smaller management units can be agreed, the total combined catch in FAO Subareas 48.1, 48.2, 48.3 and 48.4 (Figure 1) shall be further limited in any fishing season to an interim catch limit of 620,000 tonnes (the so called 'trigger level'). CM 51-07 spatially subdivides the interim catch limit such that no more than 25% of the catch can be taken from FAO Subarea 48.1, 45% from 48.2, 45% from 48.3 and 15% from 48.4. This is equivalent to Subarea catches of, respectively, 155,000 tonnes, 279,000 tonnes, 279,000 tonnes and 93,000 tonnes. These interim Subarea limits sum to greater than 620,000 tonnes in order to allow operational flexibility for the fishery; however, the overall catch across the four Subareas is still limited by the trigger level.

Setting the catch limits for krill

CCAMLR does not regulate the krill fishery by product type, simply by catch level (CM 51-01) and catch location (CM 51-01 and CM 51-07). There is therefore no causal relationship between the process for setting krill catch limits (or the actual level of a specific Subarea catch limit), and the uses made or specific product types of krill.

CCAMLR sets catch limits using 'decision rules' to determine what proportion of the krill stock can be harvested whilst still achieving the objective of the Convention[6]. This is undertaken using population modelling methods to project the stock forward in time under different simulated catch conditions; simulations are run thousands of times varying key parameters to account for the effects of fishing, natural variability, and other uncertainties. Two population levels have been agreed by CCAMLR as the basis for the krill decision rules. These levels are the fractions of the population that can be taken by the fishery each year so that the spawning biomass:

- only drops below 20% of the pre-fishing median on 10% of simulations of a 20-year period of fishing;
- has a median, after the 20-year period of simulated fishing, of 75% of the median before fishing started.

The actual catch limit is set at the lower of these two proportions multiplied by the estimated stock size determined from acoustic surveys.

For more information on krill catch limits and the population parameters used see the CCAMLR Fishery Report for the krill fishery[7].

Current catch and notifications

The level of catch achieved by the fishery is reported annually in the publicly available CCAMLR Statistical Bulletin (CCAMLR 2016)[8]. The catch taken during the past three fishing seasons (1 December to 30 November) is shown in Table 1. This shows that in FAO Subarea 48.1, the fishery has reached the allocated interim catch limit in all recent years; the interim catch limit was also reached in the 2015/2016 fishing season, though catch data are not yet complete. Subarea 48.1 closed between mid-May and mid-June in these four years; that is, over five months before the end of the krill fishing season (30 November). Elsewhere, the allocated interim catch limit has not been achieved in recent decades.

	Subarea 48.1	Subarea 48.2	Subarea 48.3	Subarea 48.4	Area 48
2012/13	153,830.30	31,305.74	32,221.30	0.00	217,357.34
2013/14	146,191.19	72,454.56	75,168.74	0.00	293,814.49
2014/15	154,176.96	17,100.85	54,368.13	0.00	225,645.94

Table 1. *Catch of Antarctic krill (tonnes) from Area 48 during recent fishing seasons (source CCAMLR Statistical Bulletin V28)*

	2012/13	2013/14	2014/15		2012/13	2013/14	2014/15
CHL	7,258.81	9,277.74	7,278.62	CHL	0.03	0.03	0.03
CHN	31,944.19	54,303.48	35,426.90	CHN	0.15	0.18	0.16
KOR	43,861.26	55,406.17	23,342.31	KOR	0.20	0.19	0.10
NOR	129,646.78	165,898.60	147,075.11	NOR	0.60	0.56	0.65
UKR	4,646.30	8,928.50	12,523.00	UKR	0.02	0.03	0.06
All	217,357.34	293,814.49	225,645.94	All	1.00	1.00	1.00

Table 2. *Catch of Antarctic krill (tonnes) from Area 48 taken by CCAMLR Members during recent years; the proportion caught by each Member is also shown (source CCAMLR Statistical Bulletin V28)*

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Currently, five Members harvest Antarctic krill; the Member catching the highest proportion is Norway, taking between 55% and 65% of the catch. The catch (and proportion) taken by each Member during the past three fishing seasons (1 December to 30 November) are shown in Table 2.

Issues of recent concern within CCAMLR about the Antarctic krill fishery

During 2016, the CCAMLR Scientific Committee[9] considered the reporting interval for the continuous fishing system. It noted that the catch reported in a two-hour period is not the amount that is actually caught during that period, but the amount of krill passing from the holding tanks to the factory. The Scientific Committee agreed that the current two-hour reporting procedures should be continued in order to provide continuity and comparative analyses. However, it also agreed that a new method should be developed which should be trialled alongside the existing two-hour reporting procedure to align the actual catch with that reported in a two-hour period and the results presented to the CCAMLR Working Group on Ecosystem Monitoring and Management (WG-EMM) for evaluation (SC-XXXV Report paragraph 3.10).

During 2016, the Scientific Committee also noted increased levels of catch and numbers of hauls in Subarea 48.1 since 2013. It also noted the non-random exploitation of fishing grounds, with the fishing fleet repeatedly visiting fishing hotspots within the centre of the Bransfield Strait and the northern section of the Gerlache Strait. It recognised that there is currently a lack of empirical data describing krill abundance and distribution in fishing hotspots. The Scientific Committee noted that collection of acoustic data by fishing vessels to estimate temporal changes in biomass and the integration of a move-on rule may provide data to help reduce the effects of local concentration of fishing effort (SC-XXXV Report paragraph 3.47).

During 2016, the Scientific Committee also considered whether the CCAMLR season for the krill fishery should start at a time of year based on ecological events e.g. predator breeding cycles, rather than on a date that is convenient for management. It noted that the start date of the fishery and the period when fishing takes place each year must be balanced with the overall requirements for land-based predators during both the summer breeding period and other times of year, including the requirements for predators which overwinter in the areas in which the fishery operates. The Scientific Committee recommended further consideration of possible benefits of aligning operation of the fishery with spatial and temporal aspects of local ecosystem operation. The Scientific Committee recognised that the Olympic nature of the krill fishery meant interpretation of seasonal fishing activity required careful evaluation of seasonal patterns and interactions, and consideration of fishing season start date (SC-XXXV Report paragraph 3.12 to 3.16).

During 2016, the Scientific Committee noted that the localised effects of krill fishing were increasing and that CM 51-07 should continue for a minimum period of three years. It agreed that a future revision of CM 51-07 should consider how catch limits could be spatially and temporally apportioned within Subareas to avoid negative impacts on predator populations at smaller spatial scales, particularly in Subarea 48.1 (SC-XXXV Report paragraph 3.62 and 3.106).

The Scientific Committee further advised that risks associated with the concentration of catches, particularly in coastal areas and during the predator breeding season, might be offset by apportioning the catch at smaller spatial or temporal scales than the Subarea scale. Other mechanisms for reducing risks include the use of coastal buffer zones (SC-XXXV Report paragraph 3.110).

Since the beginning of CCAMLR, discussions within the Scientific Committee have sought to ensure that harvesting operations do not have adverse ecologically significant impacts upon non-target catch species, including upon seabirds, marine mammals and fish; these discussions are still ongoing. Similarly, there has been a long-standing debate about the level of scientific observer coverage required in the krill fishery; in 2016 CCAMLR reached consensus that after 2019/2020, 100% observer coverage would be required. This is mandated under CM 51-06[10].

Krill-predator population change

A recent publication (Trathan and Hill 2016)[11] as well as one from a few years ago (Trathan et al. 2012)[12] contribute to the ongoing discussions related to consumption of krill by natural predators and how krill-predator populations might be changing. These papers review the 'krill surplus hypothesis', and how populations of krill predators might be responding to changing krill stocks in the context of recovering marine mammal populations following their historical over-exploitation in the 19th and 20th centuries. Confounding issues of climate change make simple interpretations difficult. These papers highlighted that removals by commercial krill fisheries are probably of lesser importance at current levels of harvesting, than are the potential effects of climate change on krill and other ecosystem components, or than the recovery of krill-eating whales and seals which in a number of cases are now approaching pre-exploitation levels.

Krill behaviour in relation to potential disturbance by fishing operations

Krill have probably evolved to minimise mortality impacts from a guild of different predators, each with different predation strategies and behaviour, whether they be squid, fish, seabirds or marine mammals. It is highly unlikely that they have evolved specific behaviours to

avoid fishing vessels; however, disturbance by fishing vessels and by nets may plausibly lead to changes in swarm structure, though data remain sparse[13]. Further research on these issues would have clear management benefits.

Is the fishery for Antarctic krill sustainable?

Much of the management information and data currently used to manage the krill fishery in the area where it operates is now over 17 years old; importantly this includes the stock assessment information used to provide the catch limits for Subareas 48.1, 48.2, 48.3 and 48.4 (Trathan and Agnew 2010)[14]. This creates a degree of uncertainty about the status of the regional marine ecosystem and the impact of the fishery; this is especially concerning, particularly given that the Antarctic Peninsular was one of the fastest warming parts of the planet during the latter part of the twentieth century (Turner et al. 2009)[15].

Therefore, during 2016, a multi-author paper prepared by UK and Norwegian scientists was submitted to WG-EMM in order to evaluate the current status of the krill fishery in Subareas 48.1 to 48.4, and to review current knowledge about the status of the regional krill stock[16]. The paper provides a precautionary assessment of exploitation rate by the fishery. The analysis determined that the fishery remains sustainable, particularly with CM-51-07 in place, as CM-51-07 ensures the exploitation rate across each Subarea remains within acceptable limits, even though it might be exceeded locally in some parts.

WG-EMM recognised that results from the paper indicate that if the fishery continues to achieve the catch limits established by CM 51-07 and the trigger limit continues to be fixed, the precautionary exploitation rate of 9.3% agreed by CCAMLR might be exceeded in one out of every five years within Subarea 48.1. The precautionary exploitation rate of 9.3% might be exceeded less frequently in Subareas 48.2 and 48.3, and never in Subarea 48.4 given the limited harvest in that Subarea.

Links to changing patterns of sea ice and Antarctic krill have been suggested in the past, with evidence for a decline in the abundance of krill during the 1980s (Atkinson et al. 2004)[17]. Since the 1980s, however, there has been little evidence of any further decline in krill abundance, whether determined by the use of acoustics (Fielding et al. 2014)[18], or through the use of net caught krill samples (Atkinson et al. 2014)[19]. Evidence suggests that though krill biomass shows high levels of inter-annual variability, krill stocks remain comparable to the levels surveyed during 2000. This provides a further level of reassurance that the fishery remains sustainable.

Frequent assessment of the krill stock would improve CCAMLR's ability to manage the fishery. Possibly the most effective means of acquiring such information would be through the use of krill fishing vessels to collect acoustic data. However, given that regular stock surveys are unlikely, CCAMLR has acknowledged the importance of developing management measures that do not rely upon data that is unlikely to be available.

Though the impact of an unregulated krill fishery would potentially be one of the greatest threats to the stability of the Antarctic marine ecosystem, current CCAMLR Conservation Measures ensure that the fishery is well managed and sustainable.

Products derived from krill

Krill is used for human and animal feedstuffs; one of the key products is feed for aquaculture. Across every subset of aquaculture, China is by far the largest producer of aquaculture products. According to the FAO's Fisheries and Aquaculture Department, China's history of aquaculture dates back more than 2,000 years, but it wasn't until after the 1949 founding of the People's Republic of China that production became large scale. It is one of the fastest-growing areas of agriculture for China, with farmed seafood accounting for more than half of the country's overall seafood production. Japan, India and Norway (all CCAMLR Members) also each have important aquaculture industries.

Market demand and future fishery expansion

In order for the krill fishery to expand beyond the interim catch limit (trigger level), CCAMLR must agree a spatial subdivision of the precautionary catch limit (5.61 million tonnes). This requirement is contained in CM 51-01, which mandates that until the Commission has defined an allocation of the total catch limit between smaller management units, based on advice from the Scientific Committee, the total combined catch in Statistical Subareas 48.1, 48.2, 48.3 and 48.4 shall be limited to 620,000 tonnes in any fishing season. Thus the catch limit is restricted by the fundamental recognition that the fishery has the potential to impact upon ecosystem structure if the catch is not managed well.

The method by which CCAMLR has agreed to develop the fishery, is through a process that CCAMLR refers to as 'Feedback Management'[20]. There is general agreement that Feedback Management includes monitoring, assessment and decision-making, and that a Feedback Management approach should use decision rules to adjust activities in response to the state of indicators to achieve the objective of Article II of the CAMLR Convention. Candidate systems include those which would restrict fishing in response to indications of a negative impact, and those which also relax fishing restrictions in response to indications of positive conditions.

To-date, no proposed implementation of a Feedback Management strategy has been agreed, even after five years of dedicated effort led

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by USA, UK and Norwegian scientists. Indeed, joint UK/Norwegian proposals for Subarea 48.2 have highlighted that there remains insufficient data to implement any proposal successfully for that Subarea. This is likely to remain the case for a number of years. The UK/Norwegian proposals have recommended the need for data collection by the international fishing fleet and collaboration with science groups across CCAMLR Members. These recommendations are now gaining traction within CCAMLR, but remain at an early phase of development.

Until a Feedback Management implementation is agreed, it is highly unlikely that the fishery will develop beyond 620,000 tonnes in FAO Area 48.

Final word

Further information and answers to a number of frequently asked questions (and misconceptions) about the krill fishery have been provided on the CCAMLR website[21].

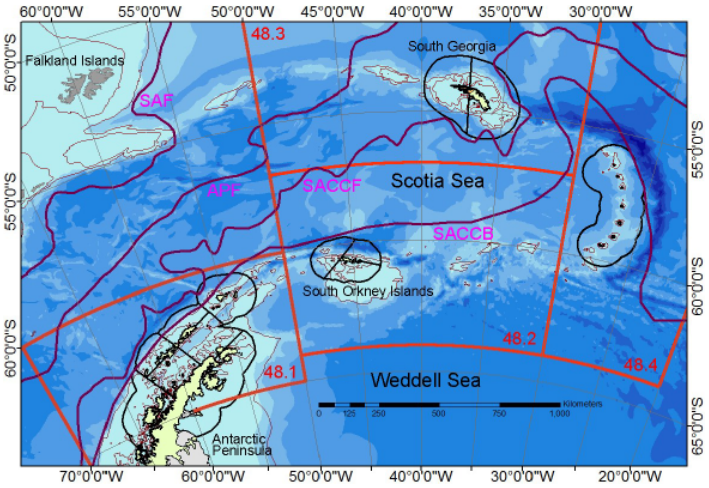

Figure 1. *The Antarctic Peninsula, Scotia Sea and the Weddell Sea. The boundaries of FAO Statistical Subareas 48.1, 48.2, 48.3 and 48.4 are shown in red, as are the boundaries of the CCAMLR Small Scale Management Units (SSMU) for the krill fishery in black. The major fronts of the Antarctic Circumpolar Current (ACC) are shown in pink: Southern ACC Boundary (SACCB); Southern ACC Front (SACCF); Antarctic Polar Front (APF); and Sub-Antarctic Front (SAF).*

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