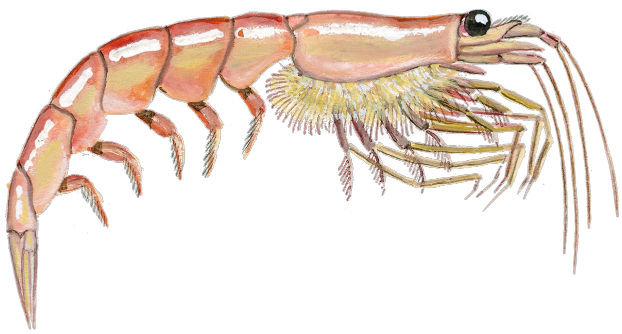
Monterey Bay Aquarium Seafood Watch®

Antarctic krill



Antarctica: Southern Ocean

Midwater trawls

Seafood Watch Consulting Researcher
Originally published: January 09, 2017 - Updated: March 1, 2021

Disclaimer
Seafood Watch strives to have all Seafood Reports reviewed for accuracy and completeness by external scientists with expertise in ecology, fisheries science and aquaculture.Scientific review, however, does not constitute an endorsement of the Seafood Watch program or its recommendations on the part of the reviewing scientists. Seafood Watch is solely responsible for the conclusions reached in this report.
Seafood Watch Standard used in this assessment: Fisheries Standard v3

Table of Contents

About Seafood Watch

Monterey Bay Aquarium's Seafood Watch program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from www.seafoodwatch.org. The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Watch Assessment. Each assessment synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices," "Good Alternatives" or "Avoid." This ethic is operationalized in the Seafood Watch standards, available on our website here. In producing the assessments, Seafood Watch seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch Research Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch's sustainability recommendations and the underlying assessments will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Watch assessments in any way they find useful.

Guiding Principles

Seafood Watch defines sustainable seafood as originating from sources, whether fished[1] or farmed that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

The following guiding principles illustrate the qualities that fisheries must possess to be considered sustainable by the Seafood Watch program (these are explained further in the Seafood Watch Standard for Fisheries):

- Follow the principles of ecosystem-based fisheries management.
- Ensure all affected stocks are healthy and abundant.
- Fish all affected stocks at sustainable levels.
- Minimize bycatch.
- Have no more than a negligible impact on any threatened, endangered or protected species.
- Managed to sustain the long-term productivity of all affected species.
- Avoid negative impacts on the structure, function or associated biota of aquatic habitats where fishing occurs.
- Maintain the trophic role of all aquatic life.
- Do not result in harmful ecological changes such as reduction of dependent predator populations, trophic cascades, or phase shifts.
- Ensure that any enhancement activities and fishing activities on enhanced stocks do not negatively affect the diversity, abundance, productivity, or genetic integrity of wild stocks.

These guiding principles are operationalized in the four criteria in this standard. Each criterion includes:

- Factors to evaluate and score
- Guidelines for integrating these factors to produce a numerical score and rating

Once a rating has been assigned to each criterion, we develop an overall recommendation. Criteria ratings and the overall recommendation are color coded to correspond to the categories on the Seafood Watch pocket guide and online guide:

Best Choice/Green: Are well managed and caught in ways that cause little harm to habitats or other wildlife.

Good Alternative/Yellow: Buy, but be aware there are concerns with how they're caught.

Avoid/Red Take a pass on these for now. These items are overfished or caught in ways that harm other marine life or the environment.

---

[1] "Fish" is used throughout this document to refer to finfish, shellfish and other invertebrates

Summary

Antarctic krill is targeted for the production of krill meal and oil, as well as for whole krill for human and animal consumption. Antarctic krill is patchily distributed throughout the Southern Ocean, where its aggregations are targeted with midwater trawls. This report covers Antarctic krill caught in the Bransfield Strait off the Antarctic Peninsula (CCAMLR Subarea 48.1), northwest of Coronation Island (Subarea 48.2), and to the north of South Georgia (Subarea 48.3) by Norway, China, and South Korea, and by other countries (managed under CCAMLR) that periodically fish the resource.

Antarctic krill in the Southern Ocean is currently above target biomass levels, but comprehensive biomass surveys are infrequent. Krill biomass is periodically determined from acoustic surveys, and is updated based on improvements to the techniques used to analyze acoustic survey data. Catch limits are set with the objective of preventing a decrease in the size of the population "to levels below those which ensure its stable recruitment," and to account for the requirements of krill predators (75% escapement). Catches have remained below subarea-specific catch limits intended to prevent localized depletion (CM 51- 07).

Antarctic krill is managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). Part of the Antarctic Treaty System, CCAMLR is an international commission with 25 members. The Scientific Committee of CCAMLR (SC- CAMLR) is responsible for collecting biomass survey data, aggregating research from CCAMLR member countries, and making a recommendation to CCAMLR, which then sets conservation measures for each subarea. The Commission has a strong track record of following scientific advice, although discrepancies between observer data and reported catches may indicate compliance issues around onboard scientific observers, and there is an ongoing effort to better understand the cause of these discrepancies. The Scientific Committee and Commission meetings have included a great deal of discussion about how to implement the CCAMLR Scheme of International Scientific Observation (SISO) in the fishery.

The impacts of the krill fishery on non-target species are unclear; reported bycatch rates differ between vessels, countries, and observer reporting practices. The information collected here is based on CCAMLR reports and expert opinion. Fur seals were periodically caught in large numbers (up to 292 within one season, according to a 2004 report) in the earlier stages of the fishery. Although reports of fur seal bycatch have declined, there were two mortalities reported in 2015, and the Commission recently amended gear regulations to require mammal exclusion devices on nets and other gear changes that should minimize mammal bycatch. Larval fish are often caught with krill, but the impact of the fishery on the adult populations of these species is unknown. Krill predators are also caught incidentally in the fishery; icefishes are the species that occur most commonly. Because tows with a higher proportion of krill by weight are more valuable, and because of CCAMLR regulations, the fishery tends to avoid bycatch.

The krill fishery has low potential impact on the physical habitat in the Southern Ocean, but the potential impacts of the fishery on the ecosystem are larger. Because krill occupies a crucial role as a forage species in the food web of the Southern Ocean, several management requirements are in place specifically to protect predators. Trigger limits are designed to prevent localized depletion; catch limits are determined by simulation and set conservatively to ensure the availability of krill for its predators. The Antarctic krill fishery is generally considered a good example of precautionary ecosystem-based fishery management (EBFM). But major uncertainties about Antarctic krill management remain. The spatial management strategy currently in place may not be sufficient for the protection of predators from local depletion. Furthermore, future developments in the fishery are likely to coincide with climatic changes that will influence krill recruitment and spatial distribution, as well as the abundance and distribution of krill predators. Climate change and the possibility of localized depletion make the future of the fishery and its ecological impact uncertain. Although fishing is not presently considered a threat to ecosystem health, there is significant uncertainty about how Antarctic krill and the predators that rely on it will fare in the future.

Final Seafood Recommendations

SPECIES | FISHERY	CRITERION 1 TARGET SPECIES	CRITERION 2 OTHER SPECIES	CRITERION 3 MANAGEMENT	CRITERION 4 HABITAT	OVERALL RECOMMENDATION
Antarctic krill | Southern Ocean | Atlantic, Antarctic | Midwater trawls	2.644	2.644	3.000	3.873	**Good Alternative (3.002)**

Scoring Guide

Scores range from zero to five where zero indicates very poor performance and five indicates the fishing operations have no significant impact.

Final Score = geometric mean of the four Scores (Criterion 1, Criterion 2, Criterion 3, Criterion 4).

Best Choice/Green = Final Score >3.2, and no Red Criteria, and no Critical scores

Good Alternative/Yellow = Final score >2.2-3.2, and neither Harvest Strategy (Factor 3.1) nor Bycatch Management Strategy (Factor 3.2) are Very High Concern2, and no more than one Red Criterion, and no Critical scores

Avoid/Red = Final Score ≤2.2, or either Harvest Strategy (Factor 3.1) or Bycatch Management Strategy (Factor 3.2) is Very High Concern or two or more Red Criteria, or one or more Critical scores.

---

[2] Because effective management is an essential component of sustainable fisheries, Seafood Watch issues an Avoid recommendation for any fishery scored as a Very High Concern for either factor under Management (Criterion 3).

Introduction

Scope of the analysis and ensuing recommendation

This report covers Antarctic krill *(Euphausia superba)* caught with midwater trawls in the Southern Ocean by countries fishing under management by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). These include Norway, China, and South Korea, as well as other countries that periodically fish this CCAMLR-managed resource. Two companies from Norway that fish for krill in the Southern Ocean are Marine Stewardship Council (MSC) certified. Because the data to distinguish bycatch and compliance between countries are not available, this report evaluates all fishing countries together, including those with MSC-certified catches.

Species Overview

Antarctic krill *(Euphausia superba)* is a small crustacean with a circumpolar distribution in the Southern Ocean. It lays eggs in the surface layer of the ocean, and embryos sink before they hatch, so developing larvae have to actively swim upward to reach the surface. Larvae arrive at the surface in autumn, develop during winter under the ice, and emerge as juveniles in the spring (Nicol 2006). Adult krill are found in high concentrations on shallow shelves and around islands, along the continental shelf and slope (Nicol 2006), and at the convergence of ocean currents such as the Weddell-Scotia Confluence. Krill reproduces in its second summer, and continues to reproduce annually in the summer. It has a maximum lifespan of more than 6 years (Nicol 2006), although Ikeda {Ikeda 1985} proposed that Antarctic krill may have a maximum lifespan of 7.5 to 11.3 years. It reaches a maximum size of 6 cm.

Genetic evidence for population structure in Antarctic krill has been inconclusive. Krill has a circumpolar distribution, with about 70% of the population residing within the 0–90° W range. The krill fishery has historically been concentrated in two areas in the Southern Ocean: a location in the Indian Ocean (Area 58), and two locations in the Southeast and Southwest Atlantic (Area 48; (Kawaguchi and Nicol 2007). Although genetic differences between these two aggregations have been detected in the past, pairwise comparisons of samples from each aggregation have shown them to be genetically indistinguishable (Zane et al. 1998), and the most recent genomic analysis indicated no discernible genetic structuring between sites (Deagle et al. 2015). Other studies have found no genetic differences between these aggregations, and it is possible that the circumpolar movement of krill throughout its lifetime swamps any observable genetic difference (Siegel 2005).

Krill is associated with sea ice at nearly every stage of its life cycle. Krill abundance distribution and life history are strongly affected by the timing and extent of sea ice. Therefore, some of the greatest uncertainties about stock status and the appropriateness of the current management strategy concern the combined effects of fishing and climate change on krill abundance and the distribution of krill for predators.

Movement of adult krill is influenced by oceanographic conditions and behavioral aggregation patterns. The highest concentrations of Antarctic krill occur in the Scotia Sea at the Antarctic Peninsula and the northern reaches of the Weddell Sea (Area 48). Adult krill form large patches and swarms, and the fishery targets these swarms using midwater trawls. Since the 1990s, most of the fishing activity has occurred in the Atlantic sector of the Southern Ocean; in the past 10 years, the fishery has become concentrated in the region of the Bransfield Strait off the Antarctic Peninsula (Subarea 48.1), to the northwest of Coronation Island (Subarea 48.2), and to the north of South Georgia (Subarea 48.3; (CCAMLR 2015a). Small catches have also been reported from CCAMLR Areas 58 and 88 (Figure 1). Historically, within Area 48, Japan and South Korea have concentrated fishing effort in Subarea 48.1 (Figure 2), and Norway has distributed effort across all the Subareas (48.1–48.3; Figure 2). But fishing effort is highly variable between years and distribution of effort may change significantly in the future (Hill 2013a).

The current estimate of total Antarctic krill biomass in the Southern Ocean is ≈215 million metric tons (MT; (Hill 2013a). In CCAMLR Subareas 48.1–48.3, where the majority of krill catches occur and where this report is focused, the biomass was estimated to be ≈62.6 million MT in 2019. The Antarctic fishery is the largest krill fishery in the world; in 2015, the fishery caught 225,466 MT (CCAMLR 2015a). In comparison, annual catches of *Euphausia pacifica* in Japan are 60,000 to 70,000 MT, and another small fishery for *E. pacifica* occurs in the strait of Georgia in British Columbia, where the annual catch limit is 500 MT.

Two companies from Norway (AkerBioMarine and Rimfrost) are MSC certified. In 2015, these companies caught ≈60% of the total reported krill catch in the Southern Ocean (117,000 MT by AkerBioMarine, 18,918 MT by Rimfrost). This report covers all catches in the Southern Ocean, including those from MSC-certified companies.

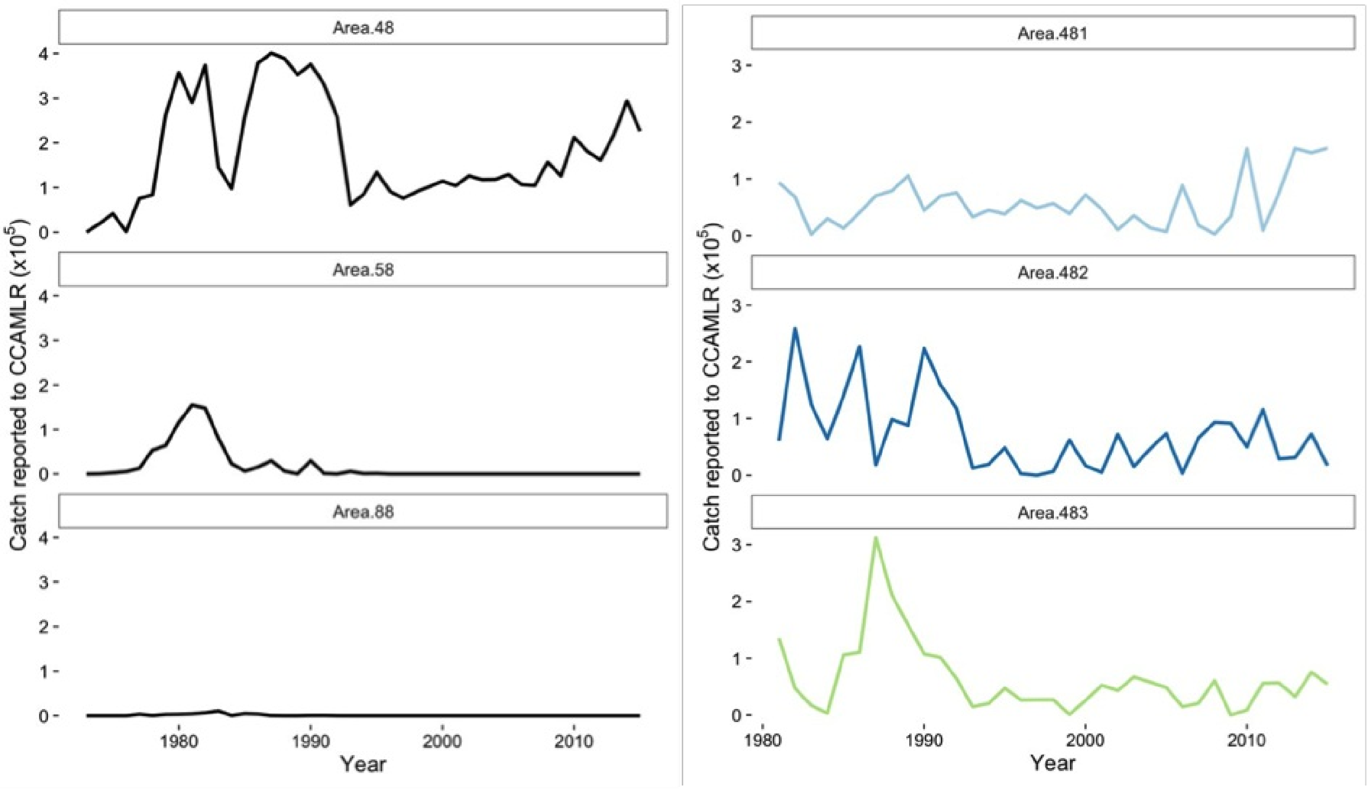


Figure 1: Catches by CCAMLR management area (left) and catches in Subareas 48.1–48.3 (right), where most catches occur (Data from CCAMLR (https://www.ccamlr.org/en/fisheries/krill- fisheries)).

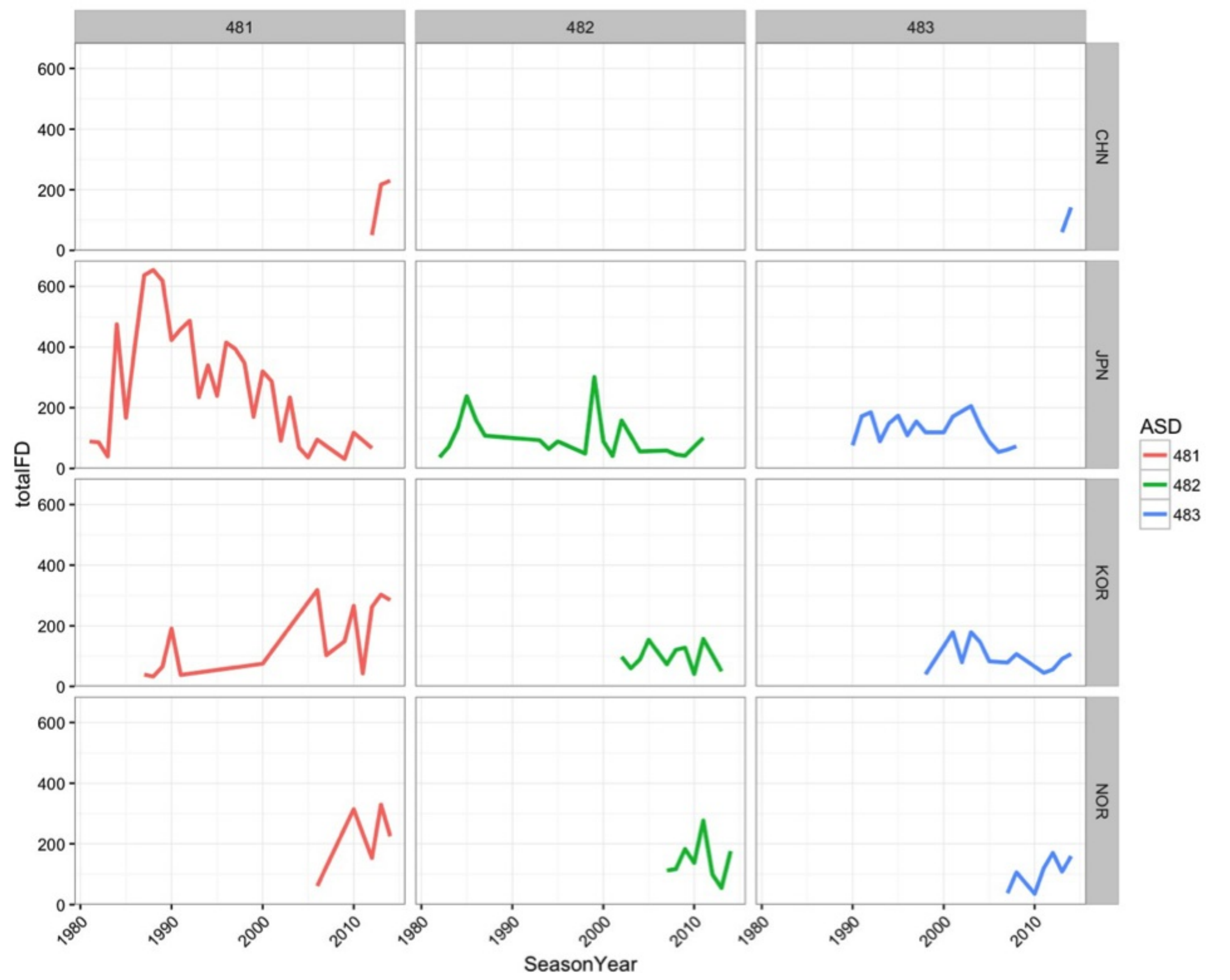


Figure 2: Effort (in fishing days) for China, Japan, South Korea, and Norway by Subarea (48.1– 48.3). There has been little effort in the other areas since 1990.

Production Statistics

Exploration of the krill fishery began in the 1960s. Catches of krill peaked in 1981–1982 at 528,201 MT; the total catch of krill reported in 2015 in Subareas 48.1–48.3 was 225,466 MT, about 50% of which was taken from Subarea 48.1 (CCAMLR 2015a). Recent developments (after the year 2000) in the krill fishery are reviewed in Nicol et al. (Nicol et al. 2012). China, South Korea, and Norway currently have the highest fishing effort (in fishing days; Figure 3). The countries responsible for the largest krill catches and their 2014 landings are: Norway (165,899 MT), South Korea (55,414 MT), China (54,303 MT), Chile (9,601 MT), and Ukraine (8,928 MT; (CCAMLR 2016); Figure 4). The future of the fishery is uncertain; catches have remained quite low relative to the catch limit set by CCAMLR, but changes in harvesting technology, new products, and new vessels and countries entering the fishery are likely in the next decade {Nicol et al. 2012}.

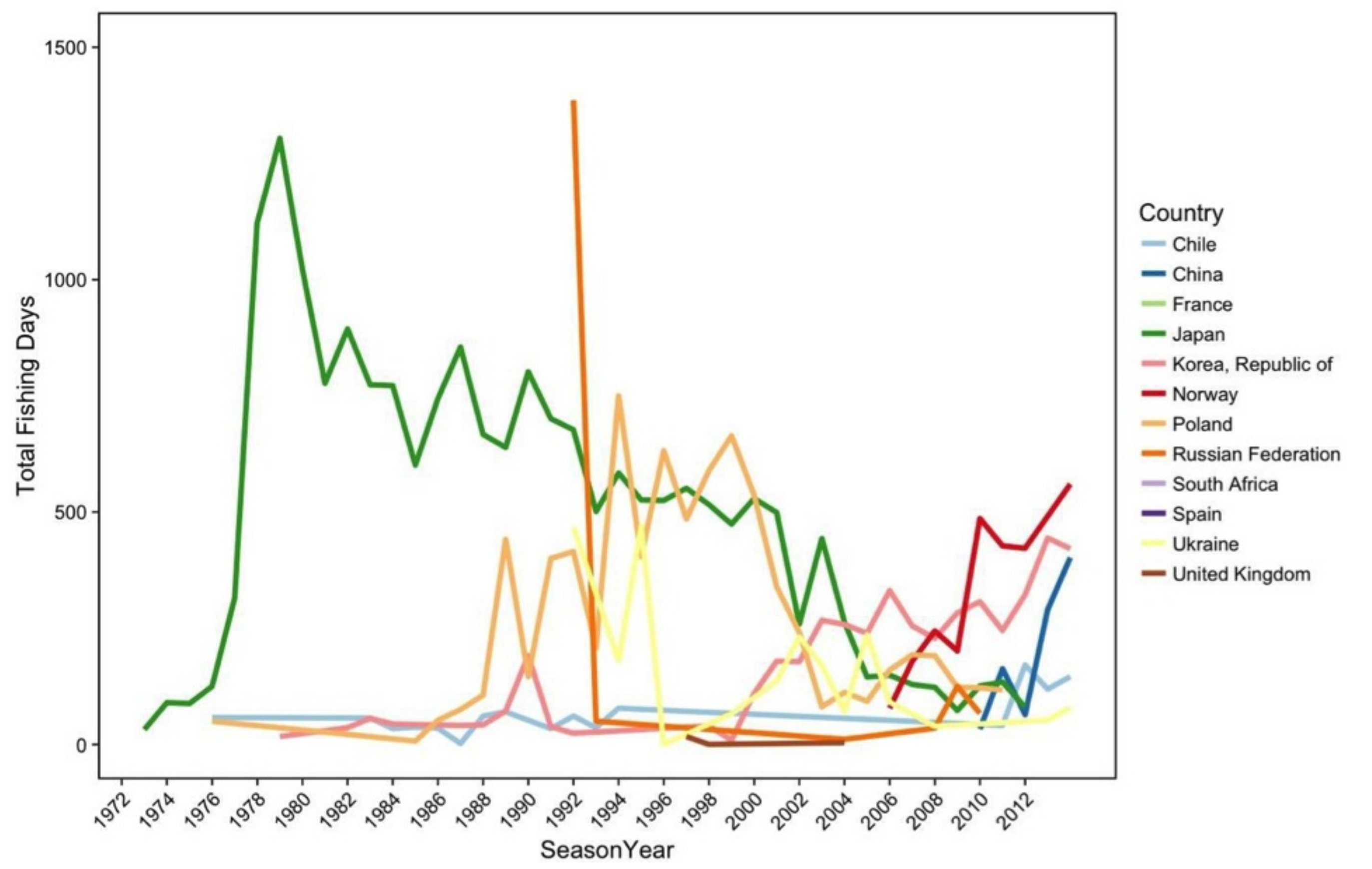


Figure 3: Effort (in fishing days) for all countries in the Antarctic krill fishery that fished more than 100 cumulative hours between 2010–2014 (data from CCAMLR, accessed March 2016)).

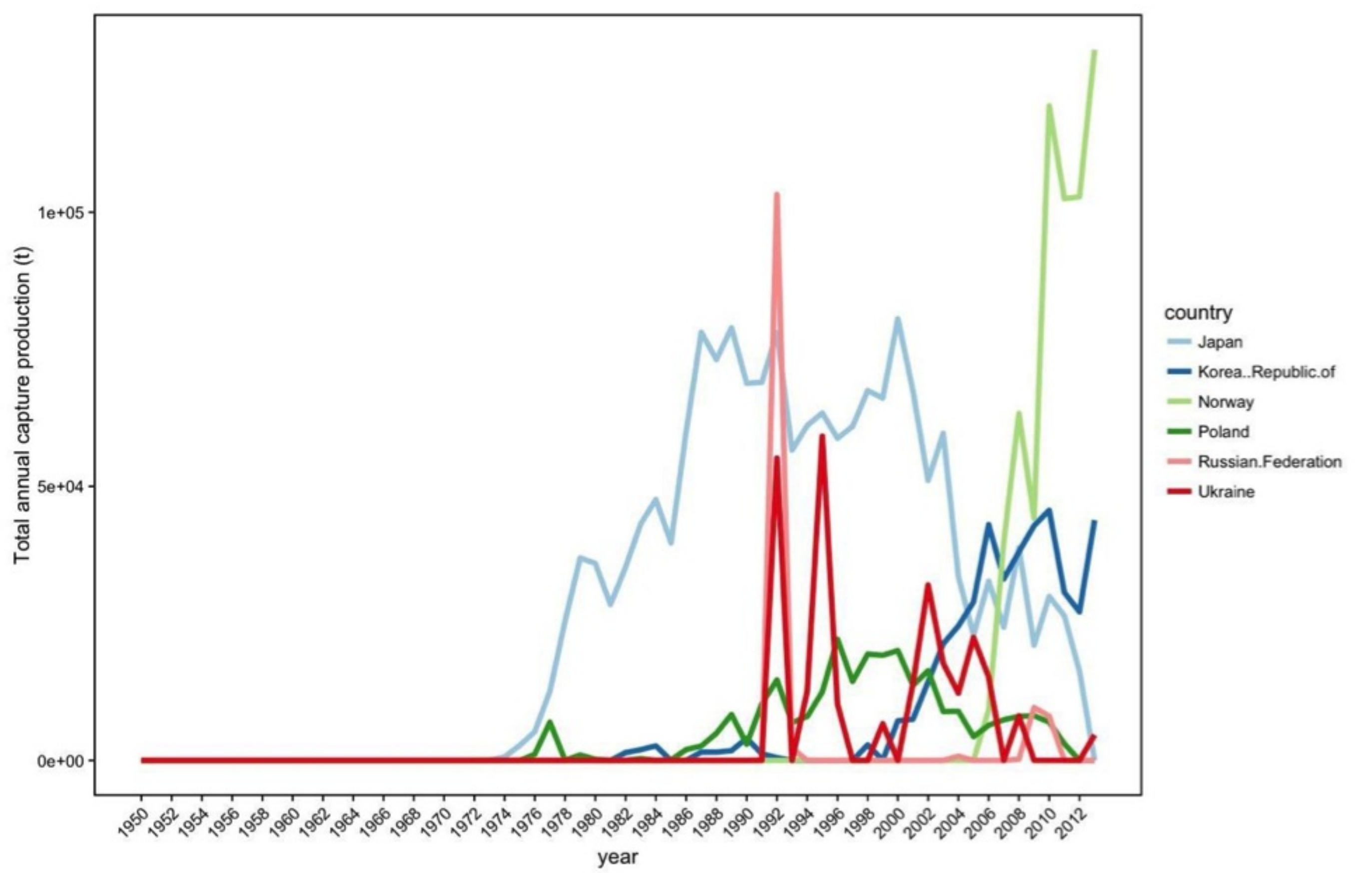


Figure 4: Total capture production of E. superba since 1950 (data from FAO, accessed March 2016).

Importance to the US/North American market.

Globally, krill products are sold either as boiled and frozen krill for human consumption, krill oil for human consumption, fresh frozen krill for animal feed, or krill meal. The main krill product (by volume) imported to the United States is whole bodies for animal feed, and the main exporters to the United States are South Korea, Japan, China, and Canada (Figure 5). Krill meal is used in the U.S. for pet food, and krill oil is sold as a dietary supplement. The majority of the catch is currently captured by Norway and South Korea, although Chinese vessels caught nearly as much as Korean vessels in 2014 (CCAMLR 2016).

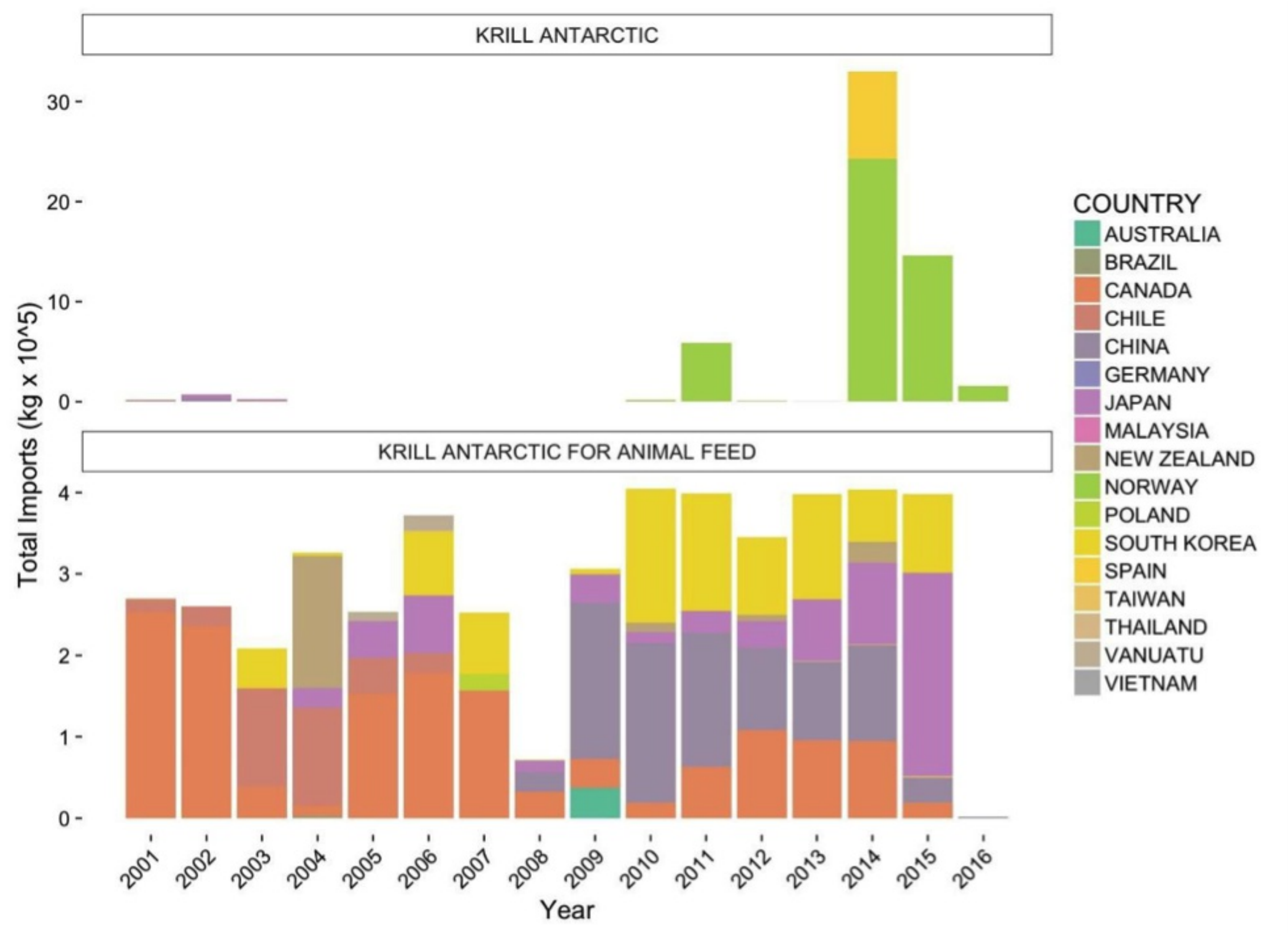


Figure 5: Total imports of krill to the U.S. since 2001. The top panel includes krill imported for human consumption and the bottom panel shows krill imported solely for animal feed. Imports for 2016 are year-to-date (as of March 2016; data from NOAA NMFS).

Common and market names.

Krill is the only FDA-accepted name for *E. superba*.

Primary product forms

Krill is sold as whole bodies for animal feed. It is also reduced to krill oil or meal — the oil is sold as a nutritional supplement for humans and meal is often sold as an additive to animal feed. The majority of Antarctic krill catch is processed onboard the trawlers that capture it.

Assessment

This section assesses the sustainability of the fishery(s) relative to the Seafood Watch Standard for Fisheries, available at www.seafoodwatch.org. The specific standard used is referenced on the title page of all Seafood Watch assessments.

Criterion 1: Impacts on the species under assessment

This criterion evaluates the impact of fishing mortality on the species, given its current abundance. When abundance is unknown, abundance is scored based on the species' inherent vulnerability, which is calculated using a Productivity-Susceptibility Analysis. The final Criterion 1 score is determined by taking the geometric mean of the abundance and fishing mortality scores. The Criterion 1 rating is determined as follows:

- ***Score >3.2=Green or Low Concern***
- ***Score >2.2 and ≤3.2=Yellow or Moderate Concern***
- ***Score ≤2.2 = Red or High Concern***

Rating is Critical if Factor 1.3 (Fishing Mortality) is Critical.

Guiding Principles

- *Ensure all affected stocks are healthy and abundant.*
- *Fish all affected stocks at sustainable level*

Criterion 1 Summary

ANTARCTIC KRILL			
REGION / METHOD	ABUNDANCE	FISHING MORTALITY	SCORE
Southern Ocean | Atlantic, Antarctic | Midwater trawls	2.330: Moderate Concern	3.000: Moderate Concern	Good Alternative (2.644)

Criterion 1 Assessments

SCORING GUIDELINES

Factor 1.1 - Abundance

Goal: Stock abundance and size structure of native species is maintained at a level that does not impair recruitment or productivity.

- *5 (Very Low Concern) — Strong evidence exists that the population is above an appropriate target abundance level (given the species' ecological role), or near virgin biomass.*
- *3.67 (Low Concern) — Population may be below target abundance level, but is at least 75% of the target level, OR data-limited assessments suggest population is healthy and species is not highly vulnerable.*
- *2.33 (Moderate Concern) — Population is not overfished but may be below 75% of the target abundance level, OR abundance is unknown and the species is not highly vulnerable.*
- *1 (High Concern) — Population is considered overfished/depleted, a species of concern, threatened or endangered, OR abundance is unknown and species is highly vulnerable.*

Factor 1.2 - Fishing Mortality

Goal: Fishing mortality is appropriate for current state of the stock.

- *5 (Low Concern) — Probable (>50%) that fishing mortality from all sources is at or below a sustainable level,* *given the species ecological role, OR fishery does not target species and fishing mortality is low enough to not adversely affect its population.*

- *3 (Moderate Concern) — Fishing mortality is fluctuating around sustainable levels, OR fishing mortality relative to a sustainable level is uncertain.*
- *1 (High Concern) — Probable that fishing mortality from all source is above a sustainable level.*

Antarctic krill

Factor 1.1 - Abundance

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

The most recent survey of krill biomass in Area 48 occurred in 2019, and the Scientific Committee agreed in 2019 that the best biomass estimate from the CCAMLR-2019 Survey was 62.6 million Mt (in Area 48; survey CV of 13%), which is slightly higher than the pre-exploitation biomass estimate (60.3 Mt) from the 2000 survey (CCAMLR 2019).

There is disagreement in the primary literature to the true nature of krill decline over the last several decades. While Cox et al. (2018) suggest that a decline in krill density has not occured, Hill et al. (2019) question the methodology used by Cox et al. (2018); which could increase the risk of failure to detect a decline in krill density (Hill et al. 2019). Specifically, it is suggested that the analysis by Cox et al. (2018) "...was biased by the exclusion of usable net types, the inclusion of negatively biased data and down-weighting of high densities in the early part of the analysis period, the absence of recent data from the north of the sector, and a lack of statistical hypothesis testing" (ibid); Hill et al. (2019) point to five significant results from the literature that support a decline in krill density. There has been recent evidence to suggest that the distribution of krill has contracted as a result of rapid warming in the high latitudes; recruitment has also declined sharply during this period of warming (Atkinson et al. 2019). Because krill distribution is contracting further south, and further retreat is blocked by the continental shelf, this contraction in range and density "...will translate to greater reductions in total abundance" (Atkinson et al. 2019). Meyer et al. (2020) argue that "there is no signal of directional change that is consistent across all of the indices (biomass, numerical density, size, and occurrence in predator diets), spatial scales, locations, or temporal scales" but that "there is a clear need to better characterize the uncertainties associated with the various indices and to develop scientific consensus on interpretation" (Meyer et al. 2020).

The catch limit for Antarctic krill is designed to prevent the depletion of krill below 75% of its unfished spawning biomass (to account for predator requirements) and is considered highly precautionary. CCAMLR bases its estimates of standing stock biomass on the CCAMLR-2019 survey, and these biomass estimates have been revised as analytic methods for acoustic data improve. Krill biomass and density can change significantly in a short amount of time (4- to 5- year periods (Fielding et al. 2012)); krill is patchily distributed within its range (Murphy et al. 1998); and it is subject to a high amount of biomass variation over time (Kawaguchi and Nicol 2015). This variability is expected to increase with changes in climate; a review by Flores et al. (Flores et al. 2012) found that krill recruitment is both highly variable and sensitive to climate change. The high spatial and temporal variability make it difficult to determine the spawning stock biomass in a given location and year.

Because spatial and temporal variation increase the degree of uncertainty in the biomass estimate, species like krill require more regular surveys to better understand fine-scale population trends, and there is conflicting information about the stock trends, this factor is scored as “moderate” concern.

Justification:

The stock assessment for Antarctic krill, the "Generalized Yield Model" or GLM (de la Mare 1996)(Constable and de la Mare 2011), is an age-structured population projection model. Biomass is estimated from hydroacoustic surveys, the most recent of which occurred in 2019. The current catch limits for Subareas 48.1–48.4 are set using data from a four-ship acoustic survey carried out in 2000 (Trathan et al. 2001). As improved methods for analyzing acoustic data have become available, these methods have been used to analyze the 2000 survey data. In 2007, the 2000 acoustic data was reanalyzed and updated to 38.29 million Mt. In 2010, the Scientific Committee agreed that the best estimate of krill biomass in Subareas 48.1–48.4 from the 2000 acoustic survey was 60.3 million Mt, with a survey CV of 12.8%.

Other regional acoustic surveys of Antarctic krill biomass lead by national programs have taken place around South Georgia, South Orkneys, and the Antarctic Peninsula since the last comprehensive survey (e.g., (Siegel 2005)

(Warren and Demer 2010)(Siegel et al. 2013)). The UK and Norway have been taking acoustic krill surveys using fishing vessels since 2011 (SC- CAMLR 2015 Annex 6 Paragraphs 2.233-2.234). But the CCAMLR survey from 2000 is still the most recent synoptic dataset.

A recent report by the International Union for the Conservation of Nature (IUCN) on krill used the trend in krill biomass estimates over the last 15 years (three krill generation times) to evaluate the decline in krill biomass, and it found considerable inter- and intra-annual fluctuations in density (according to acoustic surveys and net surveys) at a single location. But between the two time series that were used (one from South Georgia (Fielding et al. 2014) and one from Elephant Island {Cossio et al. 2011}, they did not find a significant trend in the data (Kawaguchi and Nicol 2015).

Factor 1.2 - Fishing Mortality

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

During the 2017/18 fishing season, 10 vessels fished in Subareas 48.1-48.3 and Division 58.4.2, catching a total of 312,991 t; 11 vessels fished in the same areas and reported a total catch of 381,935 t as of September 12 2019, which is the highest catch since the early 1990s (CCAMLR 2019). Catches are consistently below the current TAC (620,000 t) for Atlantic sector, which is set at roughly 1% of B_0 (Hill et al. 2016). According to Hill et al. (2016) exploitation rates over the last two decades are "unlikely to have adversely impacted the krill stock as a whole or in each subarea." Even so, because of concern of local depletion CCAMLR divided the TAC by subarea for the Atlantic sector for the 2016 - 2020/21 seasons (CCAMLR 2016).

Catches are consistently below the TAC and well below the Precautionary Catch Level (PCL) of 5.61 Mt. The PCL is set at 9.3% of B_0, and the TAC is set at 11% of the PCL; these limits are set to ensure the stock does not decline to below 75% of B_0. However, there are uncertainties in regards to catch limits at the subarea level and current stock assessment models are unable to evaluate the sustainability of fishing mortality at this scale (Hill et al. 2020), especially as it relates to krill-dependent predators (Watters et al. 2020). Some researchers caution the presumption that "a catch limit for forage species is precautionary simply because the limit is a small proportion of the species' standing biomass at a regional scale" (Watters et al. 2020).

Based on the size of catch limits relative to the estimated size of the spawning stock for krill, fishing alone is not expected to have a large impact on abundance for Antarctic krill. This would normally result in a score of high concern according to Seafood Watch criteria, but the score has been mitigated because there is a precautionary management strategy in place. Therefore, krill is ranked as “moderate” concern for fishing mortality.

Justification:

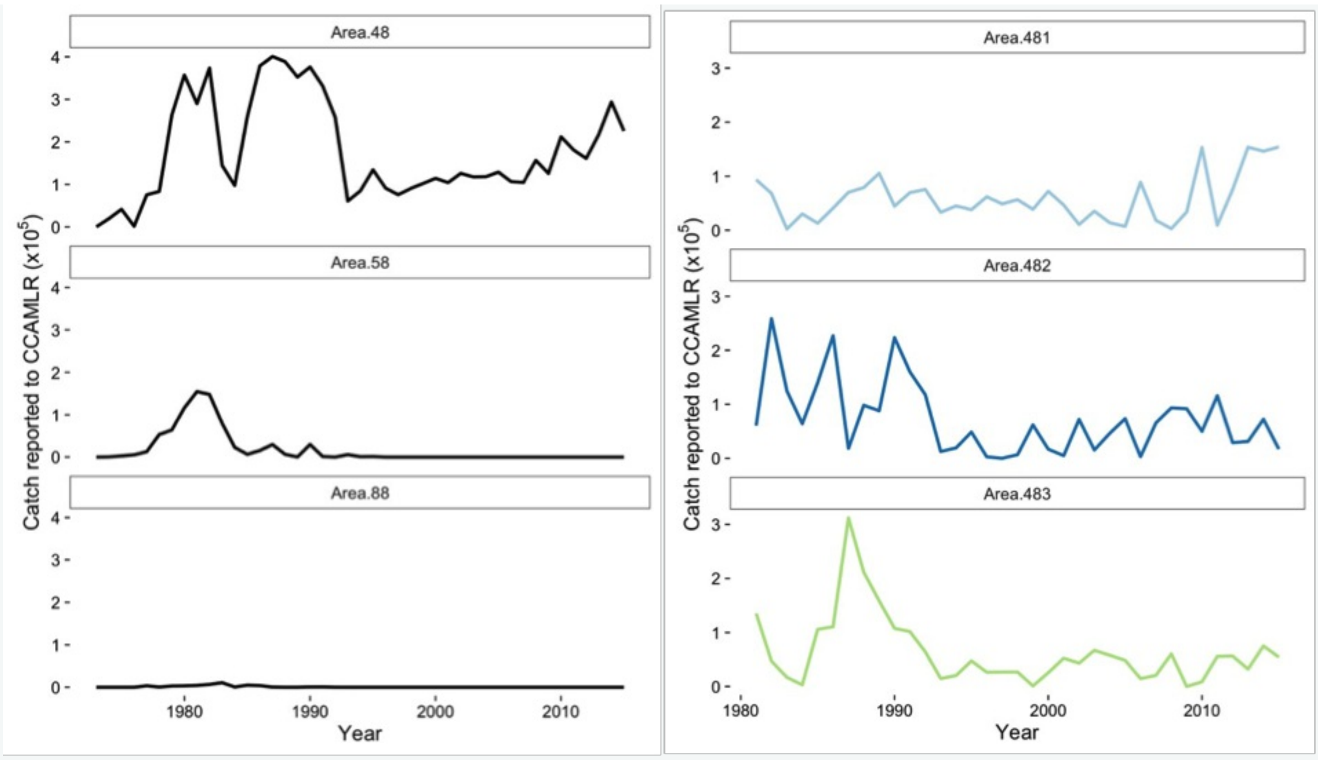


Figure 6: Catches by CCAMLR management area (left) and catches in Subareas 48.1–48.3 (right), where most catches occur (Data from CCAMLR (https://www.ccamlr.org/en/fisheries/krill- fisheries)).

According to catches reported to CCAMLR, total catches are currently lower than historical catches (Figure 4). The catch is currently below the trigger level (620,000 MT) in Subareas 48.1– 48.4, which is the level beyond which the fishery cannot proceed without an agreed-upon mechanism for spatially distributing further catches, to prevent local depletion. As of 2015, the catch limit was 155,000 MT in Subarea 48.1, 279,000 MT in each Subarea 48.2 and 48.3, and 93,000 MT in Subarea 48.4. Although the catch limits in each subarea add up to more than the trigger level, catch limits for all subareas remain at 620,000 t. In 2010, CCAMLR agreed to the current precautionary catch limit of 5.61 million MT per season in Subareas 48.1–48.4 combined. This was based on a revised analysis of the biomass survey data from 2000, which was B0 = 60.3 million MT (survey CV = 12.8%), and corresponded to a fishery exploitation rate of 0.093, using the Generalized Yield Model described below. In 2014, the total catch from Subareas 48.1–48.3 was 293,815 MT, which was just 5% of the catch limit.

There is some concern that there is significant additional mortality inflicted on krill by the fishing gear (escape mortality), in addition to fishing mortality (SC-CAMLR 2010). Some reports suggest that there is significant mortality to krill that do not end up in the cod end of the trawl, such that the true fishing mortality is higher than what is reported based on catches only (Nicol et al. 2012). There are currently no estimates of this escape mortality available, but Norway and Russia are evaluating escape mortality (Krafft et al. 2015). The CCAMLR Scientific Committee has also expressed concern that the methods used to calculate the "green weight" (the actual amount of krill caught, as opposed to the weight calculated from products) of landed krill vary significantly between vessels and countries, and this introduces uncertainty in the estimates of total take by the fishery (Nicol et al. 2012). CCAMLR has urged ships to report green weight separately from the total weight processed (2014), but there are still vessel-specific differences in green weight estimation methods and thus uncertainty in the total catches.

The current catch limit for krill is precautionary, and as of 2011, the precautionary catch limit for the entire Southern Ocean (8.6 million tons per year) was over 40 times the current annual catch (225,466 MT in Subareas 48.1–48.3 in 2015). Krill has been called one of the largest underexploited marine stocks (Nicol et al. 2012), and the conservative catch limits are intended as a buffer for the stock. Although it is unlikely that the fishery in its current state has a strong impact on the mortality of the stock, a precise estimate of fishing mortality would require more reliable and up-to-date survey data. Additionally, the magnitude of recruitment variability in the population may not sustain krill harvests above the trigger limit in Area 48 (Kinzey et al. 2013). Although the current harvest is highly precautionary, fishing mortality is not known precisely and estimates would improve with more current krill biomass data. Because of the high interannual variability in krill biomass, fishing mortality is expected to be currently low but highly variable.

Criterion 2: Impacts on Other Species

All main retained and bycatch species in the fishery are evaluated under Criterion 2. Seafood Watch defines bycatch as all fisheries-related mortality or injury to species other than the retained catch. Examples include discards, endangered or threatened species catch, and ghost fishing. Species are evaluated using the same guidelines as in Criterion 1. When information on other species caught in the fishery is unavailable, the fishery's potential impacts on other species is scored according to the Unknown Bycatch Matrices, which are based on a synthesis of peer-reviewed literature and expert opinion on the bycatch impacts of each gear type. The fishery is also scored for the amount of non-retained catch (discards) and bait use relative to the retained catch. To determine the final Criterion 2 score, the score for the lowest scoring retained/bycatch species is multiplied by the discard/bait score. The Criterion 2 rating is determined as follows:

- ***Score >3.2=Green or Low Concern***
- ***Score >2.2 and ≤3.2=Yellow or Moderate Concern***
- ***Score ≤2.2 = Red or High Concern***

Rating is Critical if Factor 2.3 (Fishing Mortality) is Crtitical

Guiding Principles

- *Ensure all affected stocks are healthy and abundant.*
- *Fish all affected stocks at sustainable level.*
- *Minimize bycatch.*

Criterion 2 Summary

Criterion 2 score(s) overview

This table(s) provides an overview of the Criterion 2 subscore, discards+bait modifier, and final Criterion 2 score for each fishery. A separate table is provided for each species/stock that we want an overall rating for.

ANTARCTIC KRILL			
REGION / METHOD	SUB SCORE	DISCARD RATE/LANDINGS	SCORE
Southern Ocean | Atlantic, Antarctic | Midwater trawls	2.644	1.000: < 100%	Yellow (2.644)

Criterion 2 main assessed species/stocks table(s)

This table(s) provides a list of all species/stocks included in this assessment for each 'fishery' (as defined by a region/method combination). The text following this table(s) provides an explanation of the reasons the listed species were selected for inclusion in the assessment.

SOUTHERN OCEAN | ATLANTIC, ANTARCTIC | MIDWATER TRAWLS			
SUB SCORE: 2.644	DISCARD RATE: 1.000	SCORE: 2.644	
SPECIES	ABUNDANCE	FISHING MORTALITY	SCORE
Antarctic jonasfish	2.330: Moderate Concern	3.000: Moderate Concern	Yellow (2.644)
Antarctic krill	2.330: Moderate Concern	3.000: Moderate Concern	Yellow (2.644)
Antarctic toothfish	2.330: Moderate Concern	3.000: Moderate Concern	Yellow (2.644)

SOUTHERN OCEAN | ATLANTIC, ANTARCTIC | MIDWATER TRAWLS			
SUB SCORE: 2.644	DISCARD RATE: 1.000		**SCORE: 2.644**
SPECIES	**ABUNDANCE**	**FISHING MORTALITY**	**SCORE**
Blackfin icefish	2.330: Moderate Concern	3.000: Moderate Concern	Yellow (2.644)
Finfish	2.330: Moderate Concern	3.000: Moderate Concern	Yellow (2.644)
Painted notie	2.330: Moderate Concern	3.000: Moderate Concern	Yellow (2.644)
Spiny icefish	2.330: Moderate Concern	3.000: Moderate Concern	Yellow (2.644)
Mackerel icefish	3.670: Low Concern	3.000: Moderate Concern	Green (3.318)
Antarctic fur seal	2.330: Moderate Concern	5.000: Low Concern	Green (3.413)
Patagonian toothfish	3.670: Low Concern	5.000: Low Concern	Green (4.284)
Lanternfishes	5.000: Very Low Concern	5.000: Low Concern	Green (5.000)

The Antarctic krill fishery is generally acknowledged as a low-bycatch fishery. The aggregating behavior of krill leads to large, single-species swarms, and the fishery tends to target the center of the swarms because they contain the most high-value catches. One exception is continuous trawling vessels, which target the edges of swarms to avoid filling continuous trawls faster than krill can be processed onboard. Non-target catches in the Antarctic krill fishery are difficult to quantify despite using standard recording forms in the SISO program, because observer recording practices still vary among vessels and countries, and gear designs vary among vessels.

When juveniles and adults, krill display strong schooling behavior, forming large dense aggregations (from several hundred meters to several kilometers horizontally and tens of meters vertically (Watkins 2000)). Because krill are processed in bulk onboard, and krill catches with low bycatch are higher in value, there is a financial incentive for operators to target centers of schools. The fishery usually targets the centers of these schools to maximize the density and quality of krill catch and minimize bycatch of predators and other pelagic species (Kawaguchi and Nicol 2007); pers. comm., K. Reid 2016).

Coarse information on bycatch is available from CCAMLR; the most recent bycatch report (Doc.# WG-EMM-14/31 Rev. 1) contains data from 9,303 hauls collected on 60 cruises from 2010 to 2014. The report found that the frequency of occurrence of fish in krill trawls varied from 0.1 to 1.98, but this number is likely to be revised; scientists believe that the highest frequencies were recorded on vessels where observers did not record trawls with zero occurrences (thus inflating the proportion of trawls containing fish (pers. comm., K. Reid 2016). CCAMLR found 14 main taxa for which the frequency of occurrence was > 1% in a single subarea; 7 of those were icefish (Channichthids), with a modal size of < 10 cm. The report extrapolated the mass of fish bycatch from the survey data and estimated that a 200,000-MT krill catch might be expected to contain ≈40 t of *C. gunnari* and ≈38 t of *L. larseni*, “with large confidence intervals around those estimates” (Doc. # WG-EMM-14/31 Rev. 1 summary, CCAMLR 2015a). Proportions of total catch for each species are not yet available from this report; only presence/absence data are available. There are several Antarctic fish species caught in the krill fishery that are not targeted or surveyed, so krill tows are some of the only sources of data about their abundance.

Although there is systematic coverage of the fishery by the scientific observer program, individual observer practices vary between countries and vessels. The CCAMLR Scientific Committee decided to review the most recent bycatch report (Doc. # WG-EMM-14/31 Rev. 1) before releasing catch composition data to the public. Observers record warp strikes for seabirds and collect acoustic data on krill biomass and distribution. From each sampled tow, observers separate 25-kg subsamples and collect data on krill size distribution and species identification for adult and juvenile fishes (pers. comm.,

K. Reid 2016). Larval fish are not always identified to the genus or species; the level to which IDs are resolved can vary by observer and by the country to which that vessel belongs (pers. comm., K. Reid 2016). Different vessels consistently fishing in the same location can have different reports of bycatch amount and composition, so raw bycatch rates or composition are not easily comparable between countries. CCAMLR is planning to release an updated report of catch composition later this year (2016).

Non-target species do not make up more than 5% of the total catch by weight on krill-targeting vessels. On average across all tows, non-target species often make up < 1% of the total catch by mass (pers. comm., K. Reid 2016). Therefore, guidelines based on percentage mass of catch data may be misleading. The main bycatch species for Antarctic krill were determined from a combination of a literature survey (Everson et al. 1992)(Watters 1996), a review of the bycatch species mentioned in the most recent fishery status report (CCAMLR 2015a), and expert input. Species were designated as main species in the krill fishery if they were caught on krill-targeting vessels and either a) were of unknown stock status or had unknown impacts by the krill fishery on population size, or b) were recorded as frequent bycatch in more than one source (e.g., literature and recent status reports). Ice krill (*Euphausia crystallorophias*) was added during the interim update because there it has been suggested that this species is likely to be caught in the Antarctic krill fishery, but there is difficulty in identifying ice krill from Antarctic krill without microscopes on board (Brierly and Proud 2018). Ice krill is smaller than Antarctic krill (below 35mm) and 9% of the total krill caught between December 2017 and July 2018 on an MSC-certified vessel were smaller than 35mm (Roel and Rios 2020). Because the Antarctic krill fishery overlaps with the known range of ice krill, and it is highly likely that ice krill is incidentally caught (Brierly and Proud 2018), we have included ice krill as a main species.

Seabird mortalities are rare in the krill fishery. There was one incidental seabird capture in 2014 of one cape petrel (dead) and one gentoo penguin (released alive). Warp strikes[2] are also rare; only one (non-fatal) warp strike was observed in 2014 (CCAMLR 2015a). Several boats with scientific observers are noted as having streamers or other devices for avoiding seabird bycatch, but not all vessels are equipped with them. Bird bycatch mitigation devices are not required because seabird bycatch is considered negligible. Warp strikes are rare, potentially because of the slow trawling speed.

The lowest scoring main species for Antarctic krill are Antarctic toothfish *(Dissostichus mawsoni)*, blackfin icefish *(Chaenocephalus aceratus)*, Antarctic jonasfish *(Notolepis coatsi)*, spiny icefish *(Chaenodraco wilsoni)*, painted notie *(Nototheniops larseni)*, and larval fish. Aside from larval fish, these fish are krill predators that are occasionally recorded in tows. Their poor scoring is based mainly on the lack of information about the status of these species. In fact, for some of these species, observer data from krill-targeting vessels provide the only available population information. Because observer data are highly variable and observers don't always report all the fish that are caught, these species are scored as conservatively as possible, using Productivity-Susceptibility analysis (Seafood Watch Criteria 2016).

[2] **Warp strikes** occur when the wings of birds collide with trawl warps or cables. From BirdLife International: "If the warp hits the outstretched wing of a bird, the wing wraps around the cable and the drag created by the forward motion of the vessel and/or rough seas pulls the bird underwater, where it drowns. This is a cryptic form of mortality with the only obvious evidence coming from dead birds that are returned to the surface during hauling, after becoming snagged on splices."

Criterion 2 Assessment

SCORING GUIDELINES

Factor 2.1 - Abundance
(same as Factor 1.1 above)

Factor 2.2 - Fishing Mortality
(same as Factor 1.2 above)

Factor 2.3 - Modifying Factor: Discards and Bait Use

Goal: Fishery optimizes the utilization of marine and freshwater resources by minimizing post-harvest loss. For fisheries that use bait, bait is used efficiently.

Scoring Guidelines: The discard rate is the sum of all dead discards (i.e. non-retained catch) plus bait use divided by the total retained catch.

Ratio of bait + discards/landings	Factor 2.3 score
<100%	1
>=100	0.75

Antarctic fur seal

Factor 2.1 - Abundance

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

The largest population of fur seals is on the island of South Georgia, which supports about 95% of all Antarctic fur seals, according to the most recent IUCN report ({UCN 2008}. In 1999/2000, when the last survey occurred, the total population was estimated between 4.5 and 6.2 million seals, and is believed to have increased by 6%–14% since the 1990/1991 season (IUCN 2008). In 2004, all populations of fur seals are believed to be either increasing or stable (SCAR EGS 2004), but dynamics seem to be driven by different factors (bottom-up vs. top-down) in different locations (Schwarz et al. 2013), so it is possible that larger trends mask local dynamics.

Assessments of fur seal population size in Area 48, where the krill fishery occurs, are not currently available. Because of the lack of fur seal abundance information for krill fishing areas but given the general recovery of fur seal populations, fur seal abundance is considered "moderate" concern.

Justification:

Antarctic fur seals in some locations are experiencing gradual declines, but dynamics and the drivers (bottom-up vs. top-down) vary between subpopulations (Schwarz et al. 2013).

Factor 2.2 - Fishing Mortality

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Low Concern

Mortalities of fur seals in the krill fishery have declined over time, but were sometimes substantial before the mandatory deployment of seal exclusion devices. In 2003, 73 Antarctic fur seals were caught by one vessel in the krill fishery (26 were killed and 47 were released alive; (CCAMLR 2015a). In 2004, SISO observers in Area 48 recorded 292 fur seals caught in Subarea 48.3. This number declined to 97 in 2005, and rules that seal exclusion devices had to be attached to each vessel were implemented. Between 2008 and 2014, there were no fur seal mortalities reported, three were reported in 2015 and 2016, none in 2017, and 19 in 2018 (CCAMLR 2019). It is unlikely that these fishing-related mortalities compose a large proportion of the total mortality experienced by fur seals, so fur seal is considered "low" concern for fishing mortality.

Justification:

No Antarctic fur seal catches were reported prior to 2003. In 2003, one vessel captured 73, and 292 fur seals were caught in Subarea 48.3 in 2004. The Scientific Committee then recommended that the Commission require observers on vessels to improve bycatch mitigation efforts (SC-CAMLR-XXIII, Annex 5, paragraph 7.236; (CCAMLR 2015a) and released documentation on seal exclusion devices (SEDs) among CCAMLR members. In 2005, 97 fur seal mortalities were recorded in Area 48, but observer coverage was low (only four of nine trawl vessels submitted bycatch reports). In 2006 and 2007, one fur seal was captured each year. In 2008, six more seal mortalities were reported in Subarea 48.3, and in 2008 the Committee amended the general mitigation provisions to require SEDs on all vessels operating in Area 48 (CM 51-01), as well as regulated mesh sizes and cod end sizes to mitigate seal bycatch and mortality. Since these measures were enacted, fur seal bycatch has been very low; no mortalities were reported between 2008 and 2014, although 19 were reported in 2018.

Antarctic jonasfish

Factor 2.1 - Abundance

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

There is currently no population assessment for Antarctic jonasfish. Its FishBase vulnerability score is 41 out of 100 (moderate vulnerability). Because there are no abundance or biomass surveys for *N. coatsi*, it was evaluated using Seafood Watch's Productivity-Susceptibility Analysis of vulnerability (PSA; Seafood Watch 2016; Appendix 2). Its PSA score of 2.76 (P = 1.5, S= 2.32) equals medium vulnerability and is therefore rated "moderate" concern.

Justification:

Productivity-Susceptibility Analysis

Scoring Guidelines

1.) Productivity score (P) = average of the productivity attribute scores (p1, p2, p3, p4 (finfish only), p5 (finfish only), p6, p7, and p8 (invertebrates only))

2.) Susceptibility score (S) = product of the susceptibility attribute scores (s1, s2, s3, s4), rescaled as follows: SS = [(ss1 ∗ ss2 ∗ ss3 ∗ ss4) – 1/ 40] + 1.

3.) Vulnerability score (V) = the Euclidean distance of P and S using the following formula: V = √(P2 + S2)

Vulnerability Score Range

- *< 2.64 = Low vulnerability*
- *≥ 2.64 and ≤ 3.18 = Medium vulnerability*
- *3.18 = High vulnerability*

For details on the PSA method and scoring, please see the Seafood Watch Criteria

The PSA score for Antarctic jonasfish is V = 2.76. For this reason, it is considered medium vulnerability and thus moderate Concern.

Productivity Attribute	**Relevant Information**	**Score (1 = low risk, 2 = medium risk, 3 = high risk)**
Average age at maturity	Unknown	N/A
Average maximum age	Unknown	N/A
Fecundity	Unknown	N/A
Average maximum size (fish only)	38 cm (male) (Post 1990)	1
Average size at maturity (fish only)	Unknown	N/A
Reproductive strategy	Unknown	N/A
Trophic level	3 (FishBase)3	2
Density dependence (invertebrates only)	N/A	N/A

Susceptibility Attribute	Relevant Information	Score (1 = low risk, 2 = medium risk, 3 = high risk)
Areal overlap (Considers all fisheries)	No information available (use default score)	3
Vertical overlap (Considers all fisheries)	No information available (use default score)	3
Selectivity of fishery (Specific to fishery under assessment)	No information available (use default score)	2
Post-capture mortality (Specific to fishery under assessment)	No information available (use default score)	3

Factor 2.2 - Fishing Mortality

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

There are no catch composition data currently available that indicate the proportion of *N. coatsi* in the krill-directed catch. If no data on *N. coatsi* were available at all, it would be scored as high concern because it is a pelagic fish in a midwater trawl fishery. There is anecdotal evidence that Antarctic jonasfish is caught in 5%–10% of krill tows (pers. comm., K. Reid 2016). Because the impact of the krill fishery on this species is unknown, it is scored as "moderate" concern.

Antarctic toothfish

Factor 2.1 - Abundance

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

There is currently little information about the abundance in *D. mawsoni* in the areas where the krill fishery occurs, and the Stock Assessment Working Group has recommended that much more data be collected in order to assess the abundance of *D. mawsoni* (CCAMLR 2015b). There is a small research fishery for *D. mawsoni* in Area 48.2, which overlaps with the location of the krill fishery. A longline survey by Ukraine in 2014/2015 revealed that *D. mawsoni* is present in Subarea 48.2, which confirms that its habitat overlaps with the krill fishery (CCAMLR 2015b).

Catches of *D. mawsoni* in Area 48.2 were 31 MT in 2015; 157 were tagged and released. Productivity-Susceptibility Analysis (PSA) for *D. mawsoni* was used to determine a Vulnerability score of Medium (V = 3.159; see Detailed Rationale for full explanation). Because there is no stock assessment for *D. mawsoni* in Subareas 48.1–48.3, *D. mawsoni* abundance is considered "moderate" concern based on its vulnerability score.

Justification:

Productivity-Susceptibility Analysis

Scoring Guidelines

1.) Productivity score (P) = average of the productivity attribute scores (p1, p2, p3, p4 (finfish only), p5 (finfish only), p6, p7, and p8 (invertebrates only))

2.) Susceptibility score (S) = product of the susceptibility attribute scores (s1, s2, s3, s4), rescaled as follows: SS = [(ss1 ∗ ss2 ∗ ss3 ∗ ss4) – 1/ 40] + 1.

3.) Vulnerability score (V) = the Euclidean distance of P and S using the following formula: V = √(P2 + S2)

Vulnerability Score Range

- *< 2.64 = Low vulnerability*
- *≥ 2.64 and ≤ 3.18 = Medium vulnerability*
- *3.18 = High vulnerability*

?For details on the PSA method and scoring, please see the Seafood Watch Criteria

The PSA score for Antarctic toothfish is V = 3.159. For this reason, it is considered to have medium vulnerability and thus is scored moderate concern.

Productivity Attribute	Relevant Information	Score (1 = low risk, 2 = medium risk, 3 = high risk)
Average age at maturity	16 (Parker and Grimes 2010)	3
Average maximum age	39 (Brooks et al. 2011)	3
Fecundity	0.03 to 0.61 million eggs per year (Piyanova et al. 2008)	1
Average maximum size (fish only)	200 cm TL male/unsexed (Eastman and DeVries 2000)	2
Average size at maturity (fish only)	90–100 cm (Eastman and DeVries 2000)	2

Reproductive strategy	Broadcast spawner (Hanchet et al. 2008)	1
Trophic level	> 3.25 (Hanchet et al. 2015)	3
Density dependence (invertebrates only)	N/A	N/A

Susceptibility Attribute	**Relevant Information**	**Score (1 = low risk, 2 = medium risk, 3 = high risk)**
Areal overlap (Considers all fisheries)	No information available (use default score)	3

Vertical overlap (Considers all fisheries)	No information available (use default score)	3
Selectivity of fishery (Specific to fishery under assessment)	No information available (use default score)	2
Post-capture mortality (Specific to fishery under assessment)	No information available (use default score)	3

Factor 2.2 - Fishing Mortality

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

D. mawsoni is fished in other areas of the Southern Ocean (e.g., Subarea 48.4, where there is a fishery and an assessment); however, there is only a limited scientific fishery in Subareas 48.1– 48.3. Because there is no information available about fishing mortality for *D. mawsoni*, it is ranked "moderate concern".

Justification:

Although it is targeted in a fishery in the Ross Sea, *D. mawsoni* is not fished heavily in the areas where the krill fishery occurs. There are *D. mawsoni* populations in krill fishing Subareas 48.1, 48.2, and 48.4, and small fisheries in Subareas 48.2 and 48.4 (CCAMLR 2016). Total catches in both Subareas 48.2 and 48.4 have never surpassed 60 MT, although IUU fishing has been a problem for *D. mawsoni* in other areas and may be a concern here.

Blackfin icefish

Factor 2.1 - Abundance

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

There are several stocks of *C. aceratus* throughout the Southern Ocean. Although there is no official stock assessment for blackfin icefish in Subareas 48.1–48.3, recent reconstruction of the abundance of *C. aceratus* over time suggests that abundance has declined from 18,000 MT to 6,000 MT since the start of the fishery in 1977 (Nicol 1990). According to Kock {Kock 1992}, the estimated stock size of *C. aceratus* in South Georgia in 1990 was 15,000 MT. Because of the unknown current status of the stock and the declining trend in biomass, *C. aceratus* is ranked using the Unknown Bycatch Matrix (Seafood Watch 2015) and considered "moderate" concern.

Factor 2.2 - Fishing Mortality

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

The amount of *C. aceratus* mortality that is caused by the krill fishery is unknown. Everson {Everson 1992} documented *C. aceratus* in krill catches in 1981–87, and they currently appear in <10% of krill catches (pers. comm., K. Reid 2016). Because of the absence of information about current *C. aceratus* fishing mortality in the krill fishery and its overall fishing mortality across fisheries, fishing mortality is considered unknown and a "moderate" concern.

Finfish

Factor 2.1 - Abundance

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

The abundance of larval fish in the Southern Ocean is unknown but is assumed to be proportional to the abundance of adult fish of the same species. There are assessments available for *C. gunnari*, but abundance estimates are not available for lanternfish (Family Myctophidae) and rockcod *(Notothenia rossii)*, two other groups whose larvae are commonly caught in krill trawls. Although *C. gunnari* is known to be at or above its target biomass level, recruitment and recruitment variation for all larval fish species is largely unknown. There are also significant changes in larval abundance with seasonal changes and shifts in ice cover (Loeb et al. 1993). Because larval fish are common in krill tows and biomass/abundance estimates are not available, larval fish are considered "moderate" concern.

Factor 2.2 - Fishing Mortality

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

Larval fish are often documented in catches in the krill fishery and have been flagged by CCAMLR's Scientific Committee as an area of concern. Mackerel icefish larvae *(Champsocephalus gunnari)* and marbled rockcod larvae *(Notothenia rossii)*, as well as lanternfish (family Myctophidae) larvae, are common in krill trawls (Bibik and Zhuk 2008), although larvae are not always identified to the species level. Fish larvae make up less than 5% of the catch on Norwegian vessels (MRAG 2009), which were certified by MSC in 2015, but the composition of the larval catch and the variation among vessels, subareas, and years is still highly uncertain. Because of the unknown total impact of the krill fishery on this group, larval fish as a group are considered "moderate" concern.

Justification:

Estimates of how much larval fish make up each tow are uncertain, according to CCAMLR. Observer data are often not well resolved enough to determine the species composition of larval fish caught in krill trawls; larval fish are more often identified to the family level. The bycatch of larval fishes has been a concern of the Scientific Committee for some time, and observer sampling for krill and fish larvae is crucial to determining the extent to which bycatch occurs.

Lanternfishes

Factor 2.1 - Abundance

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Very Low Concern

Lanternfish (family Myctophidae) are a dominant mesopelagic fish in the world's oceans. They are common in the Southern Ocean, where they are considered to be an important alternative prey when krill are in locally low abundance (Saunders et al. 2015). Global biomass estimates for myctophids are around 600 million MT (Gjosaeter and Kawaguchi 1980). Because myctophids are highly abundant, they are considered "very low" concern.

Factor 2.2 - Fishing Mortality

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Low Concern

There is no directed fishery for myctophids and, although they may make up > 10% of some krill catches, the krill fishery is unlikely to contribute substantially to their total mortality. Therefore, myctophids are ranked "low" concern for fishing mortality.

Mackerel icefish

Factor 2.1 - Abundance

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Low Concern

Recent biomass estimates (from acoustic and trawl surveys) from CCAMLR indicate that *C. gunnari* in Subarea 48.3 is at or above its long-term average biomass (as of 2015, biomass was estimated to be 59,081 MT and slightly above the average since 2000, with a one-sided lower 95% confidence interval of 36,530 MT (CCAMLR 2015a)(SC-CAMLR 2015)). A survey by the UK in January 2015 of the South Georgia (Subarea 48.3) and Shag Rocks areas estimated a total of 59,081 MT, which was slightly above the average since 2000. *C. gunnari* in Subarea 58.5.2 is characterized by large fluctuations in biomass (CCAMLR WG-FSA-11/34). But because two data sources indicate that biomass is currently above its long-term mean biomass, *C. gunnari* is scored “low” concern.

Justification:

The stock assessment for *C. gunnari* uses length frequency and biomass density to estimate biomass, and the harvest control rule is set using this length-based approach. The details of the stock assessment for *C. gunnari* are contained in WG-FSA-15/25. Estimates of *C. gunnari* biomass are taken from stratified random bottom trawl surveys, which have been carried out by UK vessels since 1986.

The abundance of *C. gunnari* has been linked to the abundance of krill, which is their main prey. Krill predators such as gentoo penguins and fur seals can also switch to eating *C. gunnari* in years when krill availability is lower. Therefore, there is some concern that an expanded krill fishery would cause higher fishing mortality for *C. gunnari*.

Factor 2.2 - Fishing Mortality

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

The direct impact of the krill fishery on *C. gunnari* population sizes is unknown. But mackerel icefish is a main predator of krill and one of the most common species caught in krill trawls (< 30 MT/year across the whole krill fishery (pers. comm., K.Reid)). Moreover, the total catch of *C. gunnari* reported in 2015 was 277 MT, so 30 MT could be a significant proportion of the total fishing mortality for the stock. There are not yet explicit limit reference points for *C. gunnari*, but the length-based model used to calculate catch limits has been demonstrated to give robust precautionary estimates of catch limits (SC-CAMLR 2015). Because of the high uncertainty about the impact of the fishery, *C. gunnari* is conservatively ranked as “moderate” concern.

Painted notie

Factor 2.1 - Abundance

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

The inherent vulnerability for *N. larseni* is 34 of 100, which is considered to be low to moderate inherent vulnerability. But the stock status for *L. larseni* is unknown, so it is considered "moderate" concern.

Factor 2.2 - Fishing Mortality

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

Painted notie is among the fish species most frequently caught by the Antarctic krill fishery (pers. comm., K. Reid). There is anecdotal evidence that *N. larseni* feed around the edges of krill swarms, so that ships targeting the centers of the swarms would generally avoid catching large numbers of painted notie. Because of the absence of information about *N. larseni* fishing mortality in the krill fishery and its overall fishing mortality across fisheries, fishing mortality is considered unknown and a "moderate" concern.

Patagonian toothfish

Factor 2.1 - Abundance

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Low Concern

Patagonian toothfish has a high inherent vulnerability, and stock status varies by location. Although CCAMLR manages this species in Area 48 where it is most likely to be caught in the krill fishery, biomass trends are not available and population size is currently being assessed through a mark-recapture study. The most recent stock assessment for *D. eleginoides* in Subarea 48.3 was in 2015. In Subarea 48.3, B2015 /B0 was estimated to be 0.84. CCAMLR's reference points are based on pristine or unfished spawning stock biomass (SSB0), and catch limit rules are designed to maintain stocks at 0.5 SSB0. Stochastic projections by CCAMLR indicate that a constant yield of 2,400 MT will maintain SSB above 50% of B0 over the next 35 years with 50% probability {SC-CAMLR 2014}. Because there is a stock assessment, which indicates that biomass is above this reference point, abundance is considered "low" concern.

Factor 2.2 - Fishing Mortality

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Low Concern

For all the stocks of Patagonian toothfish evaluated by Seafood Watch in 2014, the fishing mortality rate did not exceed estimated natural mortality {SFW 2014}. More recent estimates of fishing mortality are not available. Therefore, Patagonian toothfish is considered "low" concern for fishing mortality.

Justification:

The value of U is calculated as the maximum posterior density (MPD) estimate of annual catch divided by the spawning stock biomass. Where U is less than natural mortality (M), stocks are deemed to be able to support that level of exploitation (pers. comm., A. Dunn, cited in SFW Antarctic Toothfish Report).

Spiny icefish

Factor 2.1 - Abundance

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

C. wilsoni has been targeted in the Antarctic in the past, but it is not a regularly assessed stock. Icefishes as a group are slow to mature (5–8 years old at maturity) and grow rapidly (6–10 cm a year (LaMesa et al. 2009)); however, their present abundance is unknown. *C. wilsoni* has not been a target of the fishery since CCAMLR was established, so historical abundance data are unavailable. Because of the lack of stock status or trend information, *C. wilsoni* are considered "moderate" concern.

Factor 2.2 - Fishing Mortality

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern

C. wilsoni appears in ≈5%–10% of krill tows in groups of one or two fish per tow (pers. comm., K. Reid 2016). The proportion of *C. wilsoni* in the total catch of the krill fishery is mostly unknown, but the krill fishery likely catches them while they are foraging for krill or other pelagic prey. Because of the absence of information about *C. wilsoni* fishing mortality in the krill fishery and its overall fishing mortality across fisheries, fishing mortality is considered unknown and a "moderate" concern.

Factor 2.3 - Discard Rate/Landings

Southern Ocean | Atlantic, Antarctic | Midwater trawls

< 100%

In the Antarctic krill fishery, estimates for the proportion of bycatch in the total catch range from 4%–12% reported by fishing vessels, but may be up to 56% according to observations reported by the SISO program. This discrepancy is addressed in Criterion 3.2. But none of these estimates is greater than 100%, so retained catches are always greater by weight than discards/bait.

Criterion 3: Management Effectiveness

Five factors are evaluated in Criterion 3: Management Strategy and Implementation, Bycatch Strategy, Scientific Research/Monitoring, Enforcement of Regulations, and Inclusion of Stakeholders. Each is scored as either 'highly effective', 'moderately effective', 'ineffective,' or 'critical'. The final Criterion 3 score is determined as follows:

- *5 (Very Low Concern) — Meets the standards of 'highly effective' for all five factors considered.*
- *4 (Low Concern) — Meets the standards of 'highly effective' for 'management strategy and implementation' and at least 'moderately effective' for all other factors.*
- *3 (Moderate Concern) — Meets the standards for at least 'moderately effective' for all five factors.*
- *2 (High Concern) — At a minimum, meets standards for 'moderately effective' for Management Strategy and Implementation and Bycatch Strategy, but at least one other factor is rated 'ineffective.'*
- *1 (Very High Concern) — Management Strategy and Implementation and/or Bycatch Management are 'ineffective.'*
- *0 (Critical) — Management Strategy and Implementation is 'critical'.*

The Criterion 3 rating is determined as follows:

- ***Score >3.2=Green or Low Concern***
- ***Score >2.2 and ≤3.2=Yellow or Moderate Concern***
- ***Score ≤2.2 = Red or High Concern***

Rating is Critical if Management Strategy and Implementation is Critical.

Guiding principle

- The fishery is managed to sustain the long-term productivity of all impacted species.

Five factors are evaluated in Criterion 3: Management Strategy and Implementation, Bycatch Strategy, Scientific Research/Monitoring, Enforcement of Regulations, and Inclusion of Stakeholders. Each is scored as either 'highly effective', 'moderately effective', 'ineffective,' or 'critical'. The final Criterion 3 score is determined as follows:

Criterion 3 Summary

FISHERY	MANAGEMENT STRATEGY	BYCATCH STRATEGY	RESEARCH AND MONITORING	ENFORCEMENT	INCLUSION	SCORE
Southern Ocean | Atlantic, Antarctic | Midwater trawls	Moderately Effective	Moderately Effective	Moderately Effective	Moderately Effective	Highly effective	**Yellow (3.000)**

Criterion 3 Assessment

SCORING GUIDELINES

Factor 3.1 - Management Strategy and Implementation

Considerations: What type of management measures are in place? Are there appropriate management goals, and is there evidence that management goals are being met? Do manages follow scientific advice? To achieve a highly effective rating, there must be appropriately defined management goals, precautionary policies that are based on scientific advice, and evidence that the measures in place have been successful at maintaining/rebuilding species.

Factor 3.2 - Bycatch Strategy

Considerations: What type of management strategy/measures are in place to reduce the impacts of the fishery on bycatch species and when applicable, to minimize ghost fishing? How successful are these management measures? To achieve a Highly Effective rating, the fishery must have no or low bycatch, or if there are bycatch or ghost fishing concerns, there must be effective measures in place to minimize impacts.

Factor 3.3 - Scientific Research and Monitoring
Considerations: How much and what types of data are collected to evaluate the fishery's impact on the species? Is there adequate monitoring of bycatch? To achieve a Highly Effective rating, regular, robust population assessments must be conducted for target or retained species, and an adequate bycatch data collection program must be in place to ensure bycatch management goals are met.

Factor 3.4 - Enforcement of Management Regulations
Considerations: Do fishermen comply with regulations, and how is this monitored? To achieve a Highly Effective rating, there must be regular enforcement of regulations and verification of compliance.

Factor 3.5 - Stakeholder Inclusion
Considerations: Are stakeholders involved/included in the decision-making process? Stakeholders are individuals/groups/organizations that have an interest in the fishery or that may be affected by the management of the fishery (e.g., fishermen, conservation groups, etc.). A Highly Effective rating is given if the management process is transparent, if high participation by all stakeholders is encouraged, and if there a mechanism to effectively address user conflicts.

Factor 3.1 - Management Strategy And Implementation

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderately Effective

Antarctic krill is managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR is an international commission with 25 member countries who agree on a set of conservation measures that determine fishery rules and limits. Krill management is carried out in accordance with the CCAMLR Convention. The objective of this convention is the conservation of marine living resources (Article KK.1). For the purpose of this Convention, the term "conservation" includes rational use. Any harvesting and associated activities in the area where the Convention applies are conducted in accordance with principles that include the prevention of a decrease in harvested populations below that which would ensure "stable recruitment" (Article II.3.a) and the maintenance of ecological relationships between fished species and the predators that depend on them. CCAMLR meets annually to determine the catch limits for each fishing season, based on recommendations from the Scientific Committee, although in practice the catch limit for krill in Subareas 48.1 to 48.4 has been fixed at the trigger level since 1991.

To prevent fishing activity from being too concentrated in one subarea, CCAMLR introduced a trigger catch level, above which the fishery cannot proceed unless it has established a mechanism to distribute catches among subareas (CCAMLR 2015a). To allow for the needs of predators that forage at smaller scales, the trigger level is further subdivided: catches in any one season are not allowed to exceed 25% of the trigger level (155,000 MT) in Subarea 48.1, 45% (279,000 MT) each in Subareas 48.2 and 48.3, and 15% (93,000 MT) in Subarea 48.4 (Conservation Measure 51-07). The trigger level as of 2015 is not linked to the assessment of krill biomass, so the trigger level was not changed in 2010 even though the precautionary catch limit changed (CCAMLR 2015a). Whether the subarea scale is the appropriate scale for spatial management is a significant source of uncertainty (e.g., (Plaganyi and Butterworth 2012)).

Because krill recruitment variability is expected to increase with climate change, the Scientific Committee has recommended that the decision rule for maintaining stable recruitment should be studied further (CCAMLR 2015a). While there are management measures in place to ensure the consistent recruitment of krill, it is unclear whether they are working due to the uncertainty over stock status (see the Abundance response in Criterion 1). Because of the need for more precaution, this fishery is ranked "moderately effective" for Management Strategy and Implementation.

Justification:

CCAMLR delegates include scientists, fishers, and NGOs. CCAMLR member countries are active in harvesting or research, contribute financially to CCAMLR, and have voting rights {Constable and De La Mar 2011}. As of 2011, there were 25 member countries and 9 contracting parties. CCAMLR receives advice from the Scientific Committee

(SC-CAMLR), as well as the Standing Committee on Implementation and Compliance and the Standing Committee on Administration and Finance. SC-CAMLR comprises several working groups, including Fish Stock Assessment, Ecosystem Monitoring and Management, Incidental Mortality Arising from Fishing, and Statistics, Assessments and Modelling {Constable and De La Mar 2011}.

CCAMLR sets the yield limit based on an estimate of potential yield. This is calculated using life history parameters from the population, which are fed into a Generalized Yield Model (GYM; (de la Mare 1996) to estimate a range of possible krill population sizes at a range of possible exploitation rates, including a scenario in which there is no fishing, given some stochasticity in recruitment. Exploitation rates are selected by determining two potential exploitation rates: one with which there is a < 10% probability of spawning biomass dropping below 20% of the median pre-exploitation spawning biomass over a 20-year harvesting period, and one that makes it so that the median escapement at the end of a 20-year period is at least 75% of the median pre-exploitation spawning biomass (this 75% escapement rule is made to account for the needs of krill predators). The lower of these two potential harvest rates is then multiplied by the estimated pre-exploitation biomass B0 to determine total allowable catch.

CCAMLR guidelines have also been effective at preventing intense fishing in a single management area. CCAMLR has set Conservation Measure 51-07 in order to spatially distribute catch, which has been successful at regulating localized concentrations of catch in the past 5 years. The trigger point for Subarea 48.1 has been reached a few times during that period, and each time the fishery has been closed. Although it is still debated whether the spatial rules are precautionary enough (a great deal of the fishery in Subarea 48.1 still takes from a single area in Bransfield Strait), CCAMLR has demonstrated the capacity to prevent hyper-localized fishing.

Whether spatial management is occurring at a proper scale for predators is still a scientific debate within the Scientific Committee (CCAMLR 2015c); see Criterion 4 for more information).

CCAMLR responds internally to review. In 2007, CCAMLR undertook a performance review that was carried out by a panel of nine people with expertise in a range of relevant disciplines, including fisheries science and law. The performance review recommendations provided guidance and suggested improvements on several measures, and the review of these recommendations has been incorporated into the annual fishery review process (CCAMLR 2015a).

Factor 3.2 - Bycatch Strategy

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderately Effective

All member countries in CCAMLR are required to have the same bycatch reduction measures. The most recent modifications to the bycatch reduction measures in the Antarctic trawl fisheries were adopted in 2011 {CCAMLR CM 25-03; 2011). They had adopted the following bycatch reduction measures as of 2011: forbidding the use of net monitor cables, minimizing light directed out of the vessel, prohibiting the discarding of waste and offal during shooting or hauling of trawl gear, cleaning nets before shooting to remove items that are attractive to birds, minimizing the time that the trawl net is at the surface of the water (where it can present an entangling hazard to seabirds and mammals), and developing gear configurations that minimize the chances that birds will interact with the net where they are most vulnerable (CCAMLR 2011). Because krill are either frozen or processed *en masse* aboard vessels and tows, those with the highest proportion of krill are the most valuable, so vessels targeting krill also have an economic incentive to avoid bycatch (pers. comm., K. Reid 2016).

Bycatch is low according to observer data, which would indicate that CCAMLR's management strategy is effective, but bycatch reporting by vessels is often different from the bycatch recorded by scientific observers, and varies widely between member countries. For this reason, the Antarctic krill fishery is ranked "moderately effective" for bycatch management.

Justification:

According to the most recent CCAMLR krill fishery report in 2015, the *reported* frequency of occurrence of bycatch in the commercial fishery has increased over the past three seasons, from 1.34% of hauls in 2013 to 3.76% in 2014 and 12.88% in 2015 (although the 2015 season was incomplete at the time of the report, so 12.88% is likely a lower bound on the true proportion of bycatch). These proportions are much lower than the numbers reported by the Scheme of International Scientific Observation (SISO) program for the same period (39.14%, 48.48%, and 56.46% for 2013, 2014, and 2015, respectively). This discrepancy between observed and reported bycatch rates has been the focus of suggested improvements to observer coverage and vessel reporting requirements.

Factor 3.3 - Scientific Research And Monitoring

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderately Effective

The managers of the krill fishery often follow the advice of the CCAMLR Scientific Committee. The Scientific Committee meets regularly to discuss sources of uncertainty in the fishery, and data reported at scientific meetings are shared online. The data used to estimate the standing stock biomass of krill come from a comprehensive acoustic survey of biomass in Subareas 48.1–48.4 in 2000, and model estimates from population projections. The survey in 2000 was the most recent, and it is more than 15 years old. In-season catch reporting as well as observer data are used to determine total catch within the season and to estimate impacts on non-target species. Discrepancies between observer data and vessel trip reports have been an issue, and observer coverage is still not always 100% on member vessels (CCAMLR 2015a). Member countries follow their own observer regulations in addition to CCAMLR regulations, but differences between member countries in observer coverage and total catch are not publicly available (pers. comm., K. Reid 2016). Because regulations around scientific research and monitoring are rigorous but there is not strong evidence that they are consistently followed, and observer coverage is expected to improve, the krill fishery is ranked “moderately effective.”

Justification:

During the 2013 and 2014 seasons, 15 vessels fished for krill. The combined fleet had 80% observer coverage across both years, with minimum coverage of 58% in the summer and 63% in the winter (Krafft et al. 2015). The number of observers on krill-targeting vessels has increased since 2010, after CM 51-06 was adopted in 2009. But the Working Group on Ecosystem Monitoring and Management still recommends a higher observer sampling frequency and more training so that observers can identify fish bycatch to the family level (Krafft et al. 2015).

In addition to the observer program, catch and effort in the krill fishery are reported on a monthly basis. Once the catch in a management area exceeds 80% of the catch limit for that area, then catches are required to be reported every 5 days. When this happens in a single area in one season, the threshold at which catches are reported every 5 days becomes 50% instead of 80% (CCAMLR 2015a). This adaptive approach is intended to increase the ability of CCAMLR to announce spatial closures earlier.

Factor 3.4 - Enforcement Of Management Regulations

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderately Effective

CCAMLR member states implement several tools that increase compliance with CCAMLR regulations, including vessel licensing (Conservation Measure 10-02), monitoring of vessel movements (Conservation Measure 10-04), monitoring of vessel transshipments (Conservation Measure 10-09), a vessel monitoring system (VMS; Conservation Measure 10-04), and Catch Documentation (Conservation Measure 10-05). CCAMLR also has a Standing Committee on Implementation and Compliance (SCIC), which meets annually to review compliance systems and conservation measures. CCAMLR keeps track of vessels that violate any of these. The degree of compliance has not yet been quantified and there is no information currently available on the differences in compliance among member countries, but the aforementioned tools make verification and enforcement possible. Because the framework for monitoring compliance exists but compliance data are not available, the krill fishery is considered “moderately effective” for enforcement of management regulations.

Factor 3.5 - Stakeholder Inclusion

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Highly effective

Decisions in CCAMLR are taken by consensus by all member countries in CCAMLR (e.g., decisions on catch limits, seasonal or area closures, and other conservation measures with other members). A recent analysis found that the fishing industry, conservation-focused NGOs, and scientists generally agreed that maintenance of ecosystem health was a priority, recognized that setting management objectives was a priority, and thought that the ecosystem was capable of sustaining current catch levels (Cavanagh et al. 2016). Stakeholders and NGOs are present at CCAMLR meetings so that the transparency of the decision-making process is maintained, but they do not have voting privileges. Summary reports of meetings are publicly available, and mechanisms for addressing stakeholder concerns are built into the regulatory structure of CCAMLR. Because the decision-making process is inclusive of stakeholders and fully transparent, it is rated “highly effective” for stakeholder inclusion.

Criterion 4: Impacts on the Habitat and Ecosystem

This Criterion assesses the impact of the fishery on seafloor habitats, and increases that base score if there are measures in place to mitigate any impacts. The fishery's overall impact on the ecosystem and food web and the use of ecosystem-based fisheries management (EBFM) principles is also evaluated. Ecosystem Based Fisheries Management aims to consider the interconnections among species and all natural and human stressors on the environment. The final score is the geometric mean of the impact of fishing gear on habitat score (factor 4.1 + factor 4.2) and the Ecosystem Based Fishery Management score. The Criterion 4 rating is determined as follows:

- ***Score >3.2=Green or Low Concern***
- ***Score >2.2 and ≤3.2=Yellow or Moderate Concern***
- ***Score ≤2.2 = Red or High Concern***

GUIDING PRINCIPLES

- Avoid negative impacts on the structure, function or associated biota of marine habitats where fishing occurs.
- Maintain the trophic role of all aquatic life.
- Do not result in harmful ecological changes such as reduction of dependent predator populations, trophic cascades, or phase shifts.
- Ensure that any enhancement activities and fishing activities on enhanced stocks do not negatively affect the diversity, abundance, productivity, or genetic integrity of wild stocks.
- Follow the principles of ecosystem-based fisheries management.

Rating cannot be Critical for Criterion 4.

Criterion 4 Summary

FISHERY	FISHING GEAR ON THE SUBSTRATE	MITIGATION OF GEAR IMPACTS	ECOSYSTEM-BASED FISHERIES MGMT	SCORE
Southern Ocean | Atlantic, Antarctic | Midwater trawls	5	0	Moderate Concern	**Green (3.873)**

Criterion 4 Assessment

SCORING GUIDELINES

Factor 4.1 - Physical Impact of Fishing Gear on the Habitat/Substrate
Goal: The fishery does not adversely impact the physical structure of the ocean habitat, seafloor or associated biological communities.

- *5 - Fishing gear does not contact the bottom*
- *4 - Vertical line gear*
- *3 - Gears that contacts the bottom, but is not dragged along the bottom (e.g. gillnet, bottom longline, trap) and is not fished on sensitive habitats. Or bottom seine on resilient mud/sand habitats. Or midwater trawl that is known to contact bottom occasionally. Or purse seine known to commonly contact the bottom.*
- *2 - Bottom dragging gears (dredge, trawl) fished on resilient mud/sand habitats. Or gillnet, trap, or bottom longline fished on sensitive boulder or coral reef habitat. Or bottom seine except on mud/sand. Or there is known trampling of coral reef habitat.*
- *1 - Hydraulic clam dredge. Or dredge or trawl gear fished on moderately sensitive habitats (e.g., cobble or boulder)*
- *0 - Dredge or trawl fished on biogenic habitat, (e.g., deep-sea corals, eelgrass and maerl)*
  Note: When multiple habitat types are commonly encountered, and/or the habitat classification is uncertain, the score will be based on the most sensitive, plausible habitat type.

Factor 4.2 - Modifying Factor: Mitigation of Gear Impacts

Goal: Damage to the seafloor is mitigated through protection of sensitive or vulnerable seafloor habitats, and limits on the spatial footprint of fishing on fishing effort.

- *+1 —>50% of the habitat is protected from fishing with the gear type. Or fishing intensity is very low/limited and for trawled fisheries, expansion of fishery's footprint is prohibited. Or gear is specifically modified to reduce damage to seafloor and modifications have been shown to be effective at reducing damage. Or there is an effective combination of 'moderate' mitigation measures.*
- *+0.5 —At least 20% of all representative habitats are protected from fishing with the gear type and for trawl fisheries, expansion of the fishery's footprint is prohibited. Or gear modification measures or other measures are in place to limit fishing effort, fishing intensity, and spatial footprint of damage caused from fishing that are expected to be effective.*
- *0 —No effective measures are in place to limit gear impacts on habitats or not applicable because gear used is benign and received a score of 5 in factor 4.1*

Factor 4.3 - Ecosystem-Based Fisheries Management
Goal: All stocks are maintained at levels that allow them to fulfill their ecological role and to maintain a functioning ecosystem and food web. Fishing activities should not seriously reduce ecosystem services provided by any retained species or result in harmful changes such as trophic cascades, phase shifts or reduction of genetic diversity. Even non-native species should be considered with respect to ecosystem impacts. If a fishery is managed in order to eradicate a non-native, the potential impacts of that strategy on native species in the ecosystem should be considered and rated below.

- *5 — Policies that have been shown to be effective are in place to protect species' ecological roles and ecosystem functioning (e.g. catch limits that ensure species' abundance is maintained at sufficient levels to provide food to predators) and effective spatial management is used to protect spawning and foraging areas, and prevent localized depletion. Or it has been scientifically demonstrated that fishing practices do not have negative ecological effects.*
- *4 — Policies are in place to protect species' ecological roles and ecosystem functioning but have not proven to be effective and at least some spatial management is used.*
- *3 — Policies are not in place to protect species' ecological roles and ecosystem functioning but detrimental food web impacts are not likely or policies in place may not be sufficient to protect species' ecological roles and ecosystem functioning.*
- *2 — Policies are not in place to protect species' ecological roles and ecosystem functioning and the likelihood of detrimental food impacts are likely (e.g. trophic cascades, alternate stable states, etc.), but conclusive scientific evidence is not available for this fishery.*
- *1 — Scientifically demonstrated trophic cascades, alternate stable states or other detrimental food web impact are resulting from this fishery.*

Factor 4.1 - Impact of Fishing Gear on the Habitat/Substrate

Southern Ocean | Atlantic, Antarctic | Midwater trawls

5
The midwater trawls used to catch krill do not have contact with the seafloor, so they have a score of 5 for this criterion.

Factor 4.2 - Modifying Factor: Mitigation of Gear Impacts

Southern Ocean | Atlantic, Antarctic | Midwater trawls

0
Score: 0 (gear does not contact the substrate)

Factor 4.3 - Ecosystem-based Fisheries Management

Southern Ocean | Atlantic, Antarctic | Midwater trawls

Moderate Concern
Antarctic krill is an important forage species for predators in the Southern Ocean. CCAMLR is broadly recognized as a progressive management entity for its incorporation of ecosystem- based management principles into its convention instead of having to move from a single- species to a multispecies approach (Constable 2011)(Nilsson et al. 2016). Article II of the Convention on the Conservation of Antarctic Living Marine Resources describes the ecosystem approach to fishery management and CCAMLR's intention to maintain target stocks at productive levels and maintain species that are dependent and related. It also describes CCAMLR's precautionary approach with respect to the krill stock (Constable 2011). The most prevalent concerns about ecosystem-based fishery management in this fishery are 1) the spatial resolution of management units, and 2) uncertainty about the performance of current fishery management rules in the face of climate change and potential expansion of the fishery.

CCAMLR has several management guidelines in place to protect predators from prey depletion, including setting catch limits to a fraction of the amount dictated by the trigger level and subdividing the management area into subareas. In 2003, CCAMLR agreed to the subdivision of management areas in 15 small-scale management units (SSMUs) based on the distribution of krill, krill predators, and the fishery (CCAMLR 2015a); Figure 6). But catch has not been allocated separately for each SSMU (CCAMLR 2015a). Area-specific trigger and catch limits are intended to protect predators from local depletion, and catch limits are conservative with the intent to leave enough krill biomass for predator needs in each subarea. Several studies have addressed ecosystem-based management objectives, using ecosystem models and studies of predator-prey interactions for the Antarctic krill fishery. But these studies have never been fully integrated into the decision-making process; instead, they provide context for current management strategies (Collie et al. 2016). Ecosystem models have not yet been used to determine fishing mortality. Currently, SC-CAMLR is using ecosystem models and fishery data to determine the optimal spatial scale of management for krill predators and to provide advice about subdividing krill catch in the southwest Atlantic (Constable 2011).

Future changes in the extent of sea ice and in melt time, along with increased participation in the fishery, could cause sweeping changes to food web structure and krill availability for predators. Low sea-ice extent is associated with years of poor recruitment for krill, which often causes decreases in total abundance (Fraser and Hofmann 2003). The current management plan for krill does not include any feedback for ensuring that ecosystem requirements are fulfilled, and CCAMLR could improve the robustness of its management plan by evaluating the risks and uncertainties of different possible impacts of climate change (Trathan and Agnew 2010). A major concern for the krill fishery is that climate change will cause a regime shift that will make the population vulnerable even at the current catch levels.

Although CCAMLR's management scheme follows the principles of EBFM, CCAMLR has not yet defined operational objectives for ecosystem-based management of the krill fishery (Cavanagh et al. 2016). Because detrimental impacts on the food web are possible due to krill's importance as a forage species but the policies that are currently in place may not be robust to respond to future changes in the fishery, Seafood Watch considers krill to be of "moderate" concern for Ecosystem-Based Fisheries Management.

Justification:

Krill is a key forage species for predators in the Southern Ocean and is preyed upon by finfish, albatross, penguins (chinstrap, Adélie, emperor, gentoo, macaroni, king, and rockhopper), and marine mammals (baleen whales, as well as fur, crabeater, Weddell, elephant, and leopard seals). These are mostly spatially restricted foragers, which feed in the same areas where the krill fishery occurs (Watters et al. 2013). They also have significant needs in terms of krill biomass: a study by Hill et al. {Hille t al. 2007} found that fish consume more krill than do penguins and whales combined. Because of the importance of krill to predator diets, CCAMLR has included ecosystem considerations in its management objectives, and biological models that include spatial considerations have been developed to examine the impacts of local prey depletion on predators (e.g., (Plaganyi and Butterworth 2012). CCAMLR uses diet composition and other indicators to detect changes in the relative consumption of krill by predators (CCAMLR 2015a). Estimates of predator-prey interaction strength have been considered highly uncertain, so this information is currently used by CCAMLR only to provide context for other management decisions, and CCAMLR has not yet defined predator reference points.

Although the catch limit for krill is precautionary for each management area in the Southern Ocean, much of the fishing for krill occurs in a relatively small area (Area 48), and localized depletion is a concern for predators, including fish, penguins, and whales. In recognition of this possibility, CCAMLR has a "trigger level" (currently set at 620,000 MT, or the maximum combined historical catch), above which the fishery cannot proceed without an agreed-upon mechanism to distribute catches more evenly among the subareas. Each season, catches in any one subarea are not allowed to exceed 25% of the trigger level (a defined percentage for Subarea 48.1, 45% for Subarea 48.2, 45% for Subarea 48.3, and 15% for Subarea 48.4). In 2003, CCAMLR agreed to a subset of small-scale management units (SSMUs) within Area 48 that are based on the distribution of krill and krill predators (Figure 6). Although these units have been established, there has not been agreement on the allocation of catches at that scale. Spatial allocations of catch have been demonstrated to be less sensitive to choices of predator reference points and predator groupings; however, high certainty around predator reference points and predator groupings may not be necessary in order to have effective spatial management (Hill 2013b).

The central debate in krill fishery management recently has been the spatial allocation of trigger levels. Subarea 48.1 is a good example of this debate. The trigger limit for Subarea 48.1 has been reached several times in the past 5 years, and the krill fishery was closed each time — without Conservation Measure 51-07, the fishery would have continued fishing in this relatively small area. But the majority of the catch *within* Subarea 48.1 was taken from the Bransfield Strait, suggesting that trigger limits may need to be set at an even more local scale. There is currently a debate within CCAMLR as to whether having trigger biomass distributed at the subarea scale is sufficiently precautionary.

The CCAMLR Ecosystem Monitoring Program (CEMP) was established in 1985 to detect changes in the krill-based ecosystem in the Southern Ocean, in order to provide recommendations for an "ecosystem approach" to management. The program is intended to "detect and record significant changes in critical components of the ecosystem" and to "distinguish between changes due to the harvesting of commercial species and changes due to environmental variability, both physical and biological" (CCAMLR 2015a). Despite this solid institutional basis for EBFM, there are several areas in which CCAMLR can improve the implementation of EBFM and include ecosystem objectives in its decision of catch limits.

The association of krill with sea ice makes krill particularly vulnerable to climate change, specifically changes in the timing and extent of sea ice in the Antarctic. Krill tends to congregate in the Bransfield Strait during the winter, an area that is becoming ice-free more frequently. This makes them more vulnerable to fisheries in the autumn and winter (Jones et al. 2015), where they are heavily targeted (CM 51-07 is designed to prevent local depletion, and the Bransfield Strait is one place where localized depletion is a concern). Additionally, predators such as chinstrap and Adélie penguins are likely to face additional pressure when ocean warming combines with increases in the abundance of their competitors for krill in coming years (Trivelpiece et al. 2011). The Scientific Committee has agreed that climate change and the ensuing changes in water temperature and ice melt timing are important to consider when producing recommendations for the Commission (Jones et al. 2015).

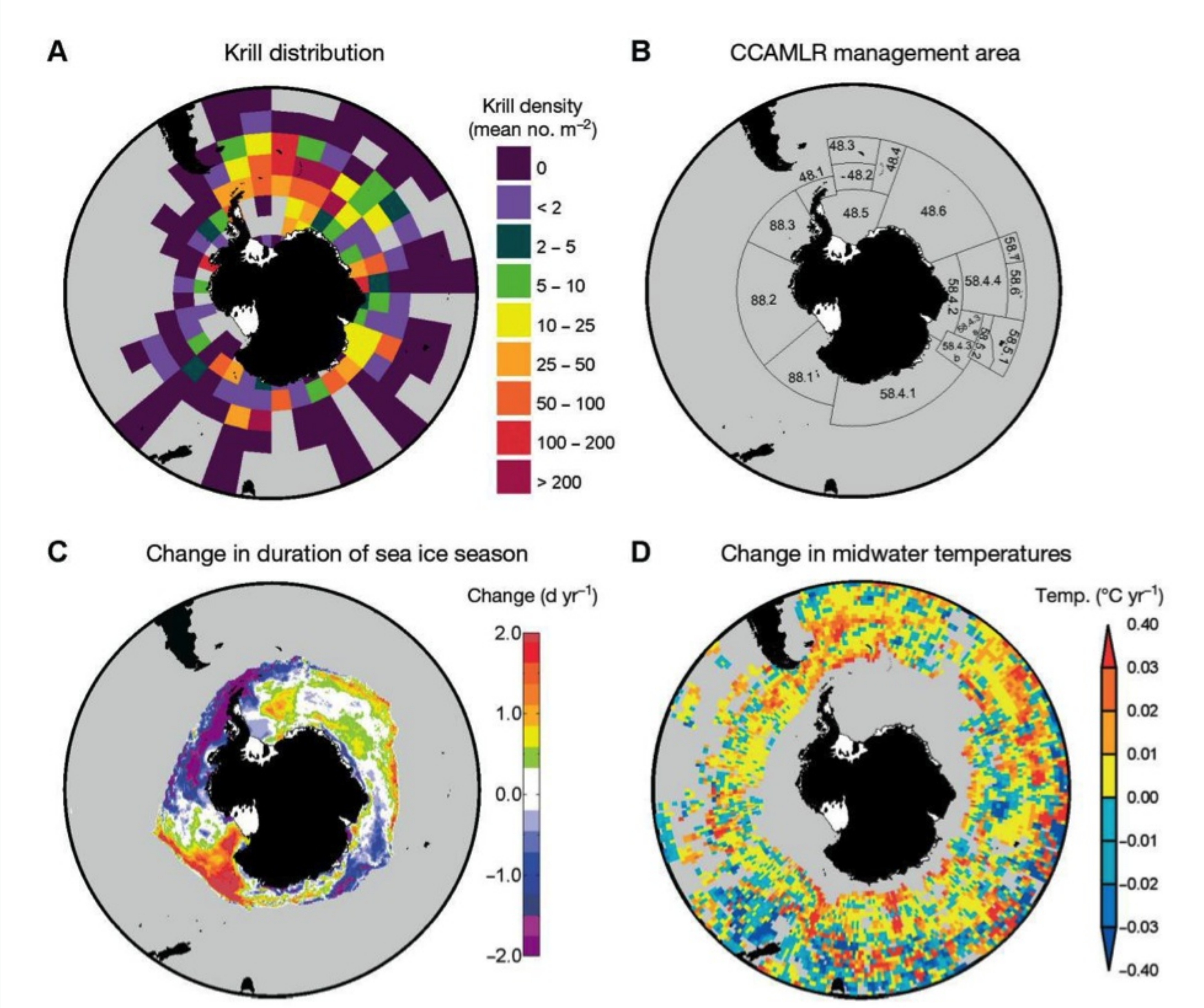


Figure 7: This image and caption are reproduced from Flores et al. (Flores et al. 2012). (A) Circumpolar distribution of post-larval Antarctic krill (re-drawn from {Atkinson et al. 2008}). The plot shows arithmetic mean krill densities (ind. m-2) within each 5° latitude by 10° longitude grid cell derived from KRILLBASE. (B) CCAMLR convention area, with FAO statistical Subareas 48.1 to 88.3. (C) Trends of change in ice season duration between 1979 and 2006 in d yr-1 (provided by E. Maksym, British Antarctic Survey). Trends were calculated from satellite-based daily sea ice concentration data provided by the National Snow and Ice Data Center (University of Colorado at Boulder, http://nsidc.org), using the methodology described by Stammerjohn et al. (2008). (D) Trend of midwater ocean temperature change during the period 1930 to 2000 in °C yr-1 (modified from Gille 2002, with permission). The analysis was based on archived shipboard measurements (1930-1990) and Autonomous Lagrangian Circulation Explorer (ALACE) float data (1990-2000) from 700 to 1100 m depth (© American Association for the Advancement of Science 2002).

Scientific review does not constitute an endorsement of the Seafood Watch® program, or its seafood recommendations, on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

Acknowledgements

Seafood Watch would like to thank the consulting researcher and author of this report, Gabe Andrews from The Safina Center, as well as several anonymous reviewers for graciously reviewing this report for scientific accuracy.

References

Atkinson A, V. Siegel, E.A Pakhomov, et al. 2009. A re-appraisal of the total biomass and annual production of Antarctic krill. Deep Sea Res Part Oceanogr Res Pap 56, 727–740. doi: 10.1016/j.dsr.2008.12.007.

Atkinson, A, SL Hill, EA Pakhomov, V Siegel, CS Reiss, VJ Loeb, DK Steinberg, K Schmidt, GA Tarling, L Gerrish, and SF Sailley. 2019. Krill (Euphausia superba) distribution contracts southward during rapid regional warming. Nature Climate Change, 9: 142-147.

B. Roel and J. Rios. 2020. DERIS, S.A. –Pesca Chile- Antarctic krill fishery First Surveillance Audit Report, January 2020. Available at: https://fisheries.msc.org/en/fisheries/deris-s.a.-pesca-chile-antarctic-krill-fishery/@@view

Bibik V.A., N. Zhuk. 2008. State Of Antarctic Krill (Euphausia Superba) Fisheries In Statistical Subarea 48.2. CCAMLR.

Brierly, A.S. & Proud.R. 2018. On the very high likelihood of bycatch of ice krill (Euphausia crystallorophias) in the present-day fishery for Antarctic krill (E. superba). WG-EMM-18/05

Brooks C.M., A.H. Andrews, J.R. Ashford, et al. 2011. Age estimation and lead–radium dating of Antarctic toothfish (Dissostichus mawsoni) in the Ross Sea. Polar Biol 34:329–338. doi: 10.1007/s00300- 010-0883-z.

Cavanagh R.D., S.L. Hill, C.A. Knowland, S.M. Grant .2016. Stakeholder perspectives on ecosystem-based management of the Antarctic krill fishery. Mar Policy 68:205–211. doi: 10.1016/j.marpol.2016.03.006.

CCAMLR. 1980. Convention on the Conservation of Antarctic Marine Living Resources. Canberra.

CCAMLR. 2011. Conservation Measure 25-03: Minimisation of the Incidental Mortality of Seabirds and Marine Mammals in the Course of Trawl Fishing in the Convention Area.

CCAMLR. 2014a. Conservation Measure 51-07: Interim distribution of the trigger level in the fishery for Euphausia superba in Statistical Subareas 48.1, 48.2, 48.3 and 48.4.

CCAMLR. 2014b. Conservation Measure 51-06 (2014). CCAMLR.

CCAMLR. 2015a. Krill fishery report 2015.

CCAMLR. 2015b. Report of the Working Group on Fish Stock Assessment. CCAMLR, Hobart, Australia.

CCAMLR. 2015c. Report of the thirty-fourth meeting of the scientific committee. CCAMLR, Hobart, Australia.

CCAMLR. 2016. Conservation Measure 51-07 (2016) Interim distribution of the trigger level in the fishery for Euphausia superba in Statistical Subareas 48.1, 48.2, 48.3 and 48.4.

CCAMLR. 2018b. Report of the Working Group on Ecosystem Monitoring and Management (Cambridge, UK, 9 to 13 July 2018). Available at: https://www.ccamlr.org/en/system/files/e-sc-xxxvii-a8.pdf

CCAMLR. 2019. Report of the Thirty-Eighth Meeting of the Commission Hobart (CCAMLR-38), Australia 21 October – 1 November 2019. Available at: https://www.ccamlr.org/en/system/files/e-cc-38_1.pdf

Collie J.S., L.W. Botsford, A. Hastings, et al. 2016. Ecosystem models for fisheries management: finding the sweet spot. Fish Fish 17:101–125. doi: 10.1111/faf.12093.

Constable A, W.K. de la Mare. 2011. Generalised model for evaluating yield and the long-term status of fish stocks under conditions of uncertainty - ScienceBase-Catalog. Available at: https://www.sciencebase.gov/catalog/item/5053f5afe4b097cd4fcf82eb. Accessed 25 Apr 2016.

Constable A.J. 2011. Lessons from CCAMLR on the implementation of the ecosystem approach to managing fisheries. Fish Fish 12:138–151. doi: 10.1111/j.1467-2979.2011.00410.x.

Cossio A, C> Reiss, R. Driscoll. 2011. A re-analysis and update of the Antarctic krill biomass in the South Shetland Islands through 2011. CCAMLR.

Cox, M.J., Candy, S., de la Mare, W.K., Nicol, S., Kawaguchi, S. and Gales, N. 2018. No evidence for a decline in the density of Antarctic krill Euphausia superba Dana, 1850, in the Southwest Atlantic sector between 1976 and 2016. Journal of Crustacean Biology 38: 656-661

de la Mare, W.K. 1996. Some recent developments in the management of marine living resources. In: Frontiers of Ecology. CSIRO Publishing, Melbourne, pp 599–616.

Eagle B.E., C. Faux, S. Kawaguchi, et al. 2015. Antarctic krill population genomics: apparent panmixia, but genome complexity and large population size muddy the water. Mol Ecol 24:4943–4959. doi: 10.1111/mec.13370.

Eastman J.T, A.L.DeVries. 2000. Aspects of body size and gonadal histology in the Antarctic toothfish, Dissostichus mawsoni, from McMurdo Sound, Antarctica. Polar Biol 23:189–195. doi: 10.1007/s003000050026.

Everyone I., A. Neyelov, Y.E. Permit in. 1992. Bycatch of fish in the South Atlantic krill fishery. Antarct Sci 4:389–392. doi: 10.1017/S0954102092000579.

Fielding S., J.L. Watkins, M.A. Collins, et al. 2012. Acoustic determination of the distribution of fish and krill across the Scotia Sea in spring 2006, summer 2008 and autumn 2009. Deep Sea Res Part II Top Stud Oceanogr 59–60:173–188. doi: 10.1016/j.dsr2.2011.08.002.

Fielding S., J.L. Watkins, P.N. Trathan, et al. 2014. Interannual variability in Antarctic krill (Euphausia superba) density at South Georgia, Southern Ocean: 1997-2013. ICES J Mar Sci 71:2578–2588. doi: 10.1093/icesjms/fsu104.

Flores H., A. Atkinson, S. Kawaguchi, et al. 2012. Impact of climate change on Antarctic krill. Mar Ecol Prog Ser 458:1–19. doi: 10.3354/meps09831.

Fraser W.R., E.E. Hofmann. 2003. A predator's perspective on causal links between climate change, physical forcing and ecosystem response. Mar Ecol Prog Ser 265:1–15. doi: 10.3354/meps265001.

Gjosaeter J., K. Kawaguchi. 1980. Gjøsaeter, J. and K. Kawaguchi, 1980. A review of the world resources of mesopelagic fish. FAO.

Gomez-Gutierrez, J. and Robinson, C.J. 2005. Embryonic, early larval development time, hatching mechanism and interbrood period of the sac-spawning euphausiid Nyctiphanes simplex Hansen. Journal of Plankton Research 27(3): 279-295.

Hanchet .S, A. Dunn, S. Parker, et al. 2015. The Antarctic toothfish (Dissostichus mawsoni): biology, ecology, and life history in the Ross Sea region. Hydrobiologia 761:397–414. doi: 10.1007/s10750-015-2435-6.

Hanchet S.M., G.J. Rickard, J.M. Fenaughty, et al. 2008. A hypothetical life cycle for Antarctic toothfish (Dissostichus mawsoni) in the Ross Sea Region.

Hill S.L. 2013b. From strategic ambiguity to technical reference points in the Antarctic krill fishery: the worst journey in the world? Environ Conserv 40, 394–405. doi: 10.1017/S0376892913000088.

Hill S.L., K. Reid, S.E Thorpe, et al. 2007. CCAMLR Science, Volume 14 (2007): 1–25. CCAMLR.

Hill, S.L. 2013a. Prospects for a Sustainable Increase in the Availability of Long Chain Omega 3s: Lessons from the Antarctic Krill Fishery. In: Meester FD, Watson RR, Zibadi S (eds) Omega-6/3 Fatty Acids. Humana Press, pp 267–296.

Hill, S.L., Atkinson, A., Pakhomov, E.A. and Siegel, V. 2019. Evidence for a decline in the population density of Antarctic krill Euphausia superba Dana, 1850 still stands. A comment on Cox et al. Journal of Crustacean Biology 39: 316-322

Hill, SL, A. Atkinson, C. Darby, S. Fielding, BA Krafft, OR Gordo, G Skaret, PN Trathan, and JL Watkins. 2016. Is current management of the Antarctic krill fishery in the Atlantic sector of the Southern Ocean precautionary? CCAMLR Sci. 23, 31–51.

Hill, SL, J Hinke, S Bertrand, L Fritz, RW Furness, JN Ianelli, M Murphy, R Oliveros-Ramos, L Pichegru, R Sharp, RA Stillman, PJ Wright, and N Ratcliffe. 2020. Reference points for predators will progress ecosystem-based management of fisheries. Fish and Fisheries 21 (2): 368-378.

Ikeda T.,P. Dixon, J. Kirkwood. 1985. Laboratory Observations of Molting, Growth and Maturation in Antarctic Krill (Euphausia superba Dana). Polar Biol 4:1–8. doi: 10.1007/BF00286811.

IUCN. 2008. Arctocephalus gazella: Hofmeyr, G.: The IUCN Red List of Threatened Species 2014: e.T2058A45223888.

Jones C.J., K. Reid, D. Ramm. 2015) SC-CAMLR-XXXIV: Thirty-fourth Meeting of the Scientific Committee. CCAMLR, Hobart, Australia

Kawaguchi S., S. Nicol. 2007. Learning about Antarctic krill from the fishery. Antarct Sci 19:219–230. doi:10.1017/S0954102007000296.

Kawaguchi S., S. Nicol. 2015. Euphausia superba. The IUCN Red List of Threatened Species 2015.

Kinzey D., G. Watters, C.S. Reiss. 2013. Effects of recruitment variability and natural mortality on generalised yield model projections and the CCAMLR decision rules for Antarctic krill. 20, 81–96.

Kock, K.H., E. Barrera-Oro, M. Belchier, M.A Collins, G. Duhamel, S. Hanchet, L. Pshenichnov, D. Welsford, R. Williams. 2012. The role of fish as predators of krill (Euphausia superba) and other pelagic resources in the Southern Ocean. CCAMLR Science, 19, 115–169.

Krafft B.A., L.A. Krag, B. Hermann, et al. 2015. Antarctic krill; assessment of mesh size selectivity and escape mortality from trawls. CCAMLR.

LaMesa M., A. De Felice, C.D. Jones, K.H. Kock. 2009. Age and growth of spiny icefish (Chaenodraco wilsoni regan, 1914) off Joinville-D'Urville Islands (Antarctic Peninsula). Available at: https://www.researchgate.net/publication/287919488_Age_and_growth_of_spiny_icefish_Chaenodraco_wilsoni_regan_1914_off_Joinville-D'Urville_Islands_Antarctic_Peninsula. Accessed 22 Jul 2016.

Leonori, L., De Felice, A., Canduci, G., Costantini, I., Biagiotti, I., Giuliani, G., and Budillon, G. 2017. Krill distribution in relation to environmental parameters in mesoscale structures in the Ross Sea. Journal of Marine Systems 166: 159-171.

Loeb V.J., A.K. Kellermann, P. Koubbi, et al. 1993. Antarctic Larval Fish Assemblages: A Review. Bull Mar Sci 53:416–449.

Meyer, B., Atkinson, A., Bernard, K.S., Brierley, A.S., Drsicoll, R., Hill, S.L., Marschoff, E., Maschette, D., Perry, F.A., Reiss, C.S., Rombola, E., Tarling, G.A., Thorpe, S.E., Trathan, P.N., Zhu, G., and Kawaguchi, S. 2020. Successful ecosystem-based management of Antarctic krill should address uncertainties in krill recruitment, behaviour and ecological adaptation. Commun Earth Environ 1, 28 (2020). https://doi.org/10.1038/s43247-020-00026-1.

MRAG (2009) Finfish by-catch estimates during continuous trawling for krill in CCAMLR Areas 48.1, 48.2 and 48.3

between December 2006 and September 2008.

Murphy E.J., J.L. Watkins, K. Reid, et al. 1998. Interannual variability of the South Georgia marine ecosystem: biological and physical sources of variation in the abundance of krill. Fish Oceanogr 7:381–390. doi: 10.1046/j.1365-2419.1998.00081.x.

Nicol S., J. Foster, S. Kawaguchi. 2012. The fishery for Antarctic krill – recent developments. Fish Fish 13:30–40. doi: 10.1111/j.1467-2979.2011.00406.x.

Nicol, S. 1990. A standardised sampling procedure for commercial krill catches. CCAMLR.

Nicol, S. 2006. Krill, currents, and sea ice: Euphausia superba and its changing environment. Bioscience 56:111–120. doi: 10.1641/0006-3568(2006)056[0111:KCASIE]2.0.CO;2.

Nilsson J.A., E.A. Fulton, M. Haward, C. Johnson. 2016. Consensus management in Antarctica's high seas – Past success and current challenges. Mar Policy 73:172–180. doi: 10.1016/j.marpol.2016.08.005.

Pakhomov, E.A. and R. Perissinotto. 1996. Antarctic neritic krill Euphausia crystallorophias: spatio-temporal distribution, growth and grazing rates. Deep Sea Research Part I: Oceanographic Research Papers 43 (1): 59-87.

Parker S.J., P.J. Grimes. 2010. Length- and age-at-spawning of Antarctic toothfish (Dissostichus mawsoni) in the Ross Sea. CCAMLR Sci 17, 53–73.

Pikitch, E., P.D. Boersma PD, I.L. Boyd, et al. 2012. Little Fish, Big Impact: Managing a crucial link in ocean food webs. Lenfest Ocean Program, Washington, D.C.

Piyanova S.P., A.F. Petrov, N.V. Kokorin. 2008. On the study of fecundity and egg size of Antarctic toothfish Dissostichus mawsoni Norman 1937. CCAMLR

Plaganyi E.E., D.S. Butterworth. 2012. The Scotia Sea krill fishery and its possible impacts on dependent predators: modeling localized depletion of prey. Ecol Appl 22, 748–761.

Post A. 1990. Paralepididae. In: Fishes of the Southern Ocean. J.L.B. Smith Institute of Ichthyology, Grahamstown, South Africa, pp 138–141.

Ross, R. and Quetin, L. 2000. Reproduction in Euphausiacea. Pages 150–181 in Everson I, ed. Ecology and Fisheries. Cambridge (United Kingdom): Blackwell

Sala, A., Massimo, A., and Russo, A. 2002. Krill of the Ross Sea: distribution, abundance and demography of Euphausia superba and Euphausia crystallorophias during the Italian Antarctic Expedition (January-February 2000). SCIENTIA MARINA 66 (2): 123-133.

Saunders R.A., M.A. Collins, P. Ward, et al. 2015. Distribution, population structure and trophodynamics of Southern Ocean Gymnoscopelus (Myctophidae) in the Scotia Sea. Polar Biol 38:287–308. doi: 10.1007/s00300-014-1584-9.

SCAR EGS. 2004. Scientific Commitee on Antarctic Research Expert Group on Seals (SCAR EGS): Scientific Committee for Antarctic Research- Expert Group on Seals Report.

SC-CAMLR. 2010. Report of the Twenty-ninth Meeting of the Scientific Committee, Hobart, Australia.

SC-CAMLR. 2015). WG-FSA-15 Working Group on Fish Stock Assessment.

Schwarz L.K., M.E. Goebel, D.P. Costa, A.M. Kilpatrick. 2013. Top-down and bottom-up influences on demographic rates of Antarctic fur seals Arctocephalus gazella. J Anim Ecol 82:903–911. doi: 10.1111/1365-2656.12059.

Siegel V. 2005. Distribution and population dynamics of Euphausia superba: summary of recent findings. Polar Biol 29:1–22. doi: 10.1007/s00300-005-0058-5.

Siegel V., C.S Reiss, K.S. Dietrich, et al. 2013. Distribution and abundance of Antarctic krill (Euphausia superba) along the Antarctic Peninsula. Deep Sea Res Part Oceanogr Res Pap 77:63–74. doi: 10.1016/j.dsr.2013.02.005.

Trathan P.N., D. Agnew . 2010. Climate change and the Antarctic marine ecosystem: an essay on management implications. Antarct Sci 22:387–398. doi: 10.1017/S0954102010000222.

Trathan P.N., J.L. Watkins, A.W.A Murray, et al. 2001. CCAMLR Science, Volume 8 (2001):1–23. CCAMLR. Available at: https://www.ccamlr.org/en/publications/science_journal/ccamlr-science-volume-8/ccamlr- science-volume-81-24. Accessed 23 May 2016.

Trivelpiece W.Z., J.T. Hinke, A.K. Miller, et al. 2011. Variability in krill biomass links harvesting and climate warming to penguin population changes in Antarctica. Proc Natl Acad Sci U S A 108:7625–7628. doi: 10.1073/pnas.1016560108.

Warren J.D., D.A. Demer. 2010. Abundance and distribution of Antarctic krill (Euphausia superba) nearshore of Cape Shirreff, Livingston Island, Antarctica, during six austral summers between 2000 and 2007. Can J Fish Aquat Sci 67:1159–1170. doi: 10.1139/F10-042

Watkins J.L. 2000. Aggregation and vertical migration. In: Krill biology, ecology and fisheries. Oxford, pp 80–102.

Watters G. 1996. CCAMLR Science, Volume 3 (1996):111–123. CCAMLR. Available at: https://www.ccamlr.org/en/publications/science_journal/ccamlr-science-volume-3/ccamlr- science-volume-3111-123. Accessed 10 Mar 2016

Watters G.M., S.L> Hill, J.T. Hinke, et al. 2013. Decision-making for ecosystem-based management: evaluating options for a krill fishery with an ecosystem dynamics model. Ecol Appl Publ Ecol Soc Am 23:710–725.

Watters, GM, JT Hinke, and CS Reiss. 2020. Long-term observations from Antarctica demonstrate that mismatched scales of fisheries management and predator-prey interaction lead to erroneous conclusions about precaution. Scientific Reports 10 (2314).

Zane L., L. Ostellari, L. Maccatrozzo, et al. 1998. Molecular evidence for genetic subdivision of Antarctic krill (Euphausia superba Dana) populations. Proc R Soc Lond B Biol Sci 265:2387–2391. doi: 10.1098/rspb.1998.0588

Appendix

Updates to Antarctic Krill (Southern Ocean) Report : Updates to the January 8, 2017 Antarctic krill report were made on November 13, 2020:

Overall Recommendations for Antarctic krill caught with midwater trawls in the Southern Ocean remain unchanged, but there were updates described below.

Antarctic krill biomass and mortality estimates
In 2019, a large-scale survey was taken of krill resources in Area 48. This is only the second such survey, with the first occurring in 2000. The biomass estimate for Area 48 was 62.6 MT, which is slightly higher than the 2000 estimate. Analyses of krill abundance at regional spatial scales show conflicting trends (Meyer et al. 2020). The total catch in 2019 remained below the TAC, but reached the highest levels since the early 1990s. The information for C1 was updated, but the scores for abundance and fishing mortality remain unchanged.

Ice Krill Bycatch
During the Commission for the Conservation of Antarctic Marine Living Resources' (CCAMLR) 2018 meeting of the

Working Group on Ecosystem Monitoring and Management, researchers suggested that ice krill (*Euphausia crystallorophias*) is likely caught in the Antarctic krill fishery without being documented. According to Brierley and Proud (2018), the fishery operates in areas that are known to contain ice krill, this species inhabits similar depths in the water column as Antarctic krill, and the two species are morphologically similar; the researchers therefore argue that the likelihood of ice krill bycatch "...is effectively 100%." However, fishery observers are not currently equipped with the tools needed to identify ice krill in routine observations (CCAMLR 2018b) and research in the Ross Sea suggests that ice krill and Antarctic krill occupy different habitats that are defined by different environmental characteristics {Davis et al. 2017} (Leonori et al. 2017).

There is conflicting information as to whether ice krill are likely to be caught in the Antarctic krill fishery. However, because management of this fishery is highly precautionary (e.g. precautionary catch level (PCL) is 9.3% of B_0 and the TAC is 11% of the PCL), impacts to ice krill populations are expected to be minimal. Seafood Watch has determined that current information does not warrant the inclusion of ice krill as a C2 species, nor would inclusion of ice krill change the overall recommendation for Antarctic krill. More consideration will be given to this issue during the full report update in 2021 or 2022.