ANTARCTIC KRILL SUSTAINABILITY

A Look Below the Surface

By Philip Trathan OBE, DSc | 2024
Based on a previous paper by Stephen Nicol, PhD

AKER BIOMARINE

About the author

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Philip Trathan OBE, DSc was previously the Head of Conservation Biology at the British Antarctic Survey where he published over 300 peer-reviewed scientific research papers. Until his retirement in 2022, he was the UK ecological lead for CCAMLR having worked with CCAMLR since 1992. Phil is now an Emeritus Fellow at BAS, an Honorary Fellow of Bangor University, and a visiting professor at the University of Southampton. He has undertaken 23 research deployments to the Antarctic, working on krill, krill-dependent predators, the krill fishery and climate change.

Based on a previous paper by

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Stephen Nicol has conducted research in Canada, South Africa, Australia and Antarctica, mainly on krill, the krill fishery and the Southern Ocean ecosystem. Steve worked at the Australian Antarctic Division from 1987 to 2011 as a research scientist and Program Leader and has published over 200 articles, including management papers, refereed articles, popular science and travel writing. Steve was on the Australian delegation to the Commission for the Conservation of Antarctic Marine Living Resources from 1987-2011. He led 4 major research voyages to the Antarctic and participated in a further five. He was awarded the Australian Antarctic Medal in 2011 in recognition of service to Australia's Antarctic Program.

Peer-reviewed scientific studies written by world-leading experts indicate that the commercial fishery for Antarctic krill is currently one of the most sustainably managed fisheries anywhere in the world. However, the fishery has become a source of controversy in recent years, primarily because it has been portrayed as potentially damaging to the Antarctic marine ecosystem.

Antarctic krill, *Euphausia superba*, is a crustacean and a member of the order Euphausiacea, which collectively comprises two families, ten genera and 86 species. Different species of krill occur in all of the world's oceans, with seven species occurring in the Antarctic. Antarctic krill is the largest of all the krill species, reaching a maximum size of ~6.5 cm and weighing up to 2 grams. Antarctic krill is one of the most abundant (multi-cellular) organisms on the planet with the largest biomass of any wild free-living species, somewhere in the range of 340 to 540 million tonnes, probably greater even than the biomass of humans (Greenspoon et al., 2023). The genome of Antarctic krill also reveals that the species has existed for millennia and has undergone environmental adaptation over geological timescales (Shao et al., 2023).

Antarctic krill often swim in vast, dense swarms that may stretch for miles (Miller and Hampton, 1989; Tarling and Fielding, 2016), making them a particularly appealing food source for larger animals such as penguins and whales. Swarming krill are also attractive to fishermen because they are large, rich in oil, easy to catch and hugely abundant.

"Antarctic krill is one of the most abundant organisms on the planet with the largest biomass of any wild free-living species, somewhere in the range of 340 to 540 million tonnes, probably greater even than the biomass of humans"

It is only Antarctic krill that are targeted by the commercial fishery in the Southern Ocean, which is managed under the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR is implemented by an international Commission (made up from the 26 Member States plus the European Union), following precautionary advice provided by a Scientific Committee. The commercial fishery for Antarctic krill is the largest fishery by mass of catch in the Antarctic.

The fishery is currently considered to be well-regulated by CCAMLR and is highly precautionary, as attested by many scientific peer-reviewed studies which report that the Antarctic krill fishery is actually one of the most sustainably managed fisheries in the world (see Constable, 2001; Constable and de la Mare, 1996; Constable et al., 2000). Moreover, in the Antarctic Peninsula region, where krill fishing is important, the feeding grounds of numerous krill-dependent predators are protected through voluntary action by the fishery (Trathan et al., 2022b; Godø and Trathan, 2022). Nevertheless, the fishery is sometimes portrayed as damaging to the marine ecosystem, as harvesting has the potential to undermine the Antarctic marine food-web, given that many species of fish, squid, seabird (including penguins) and marine mammal (including baleen whales) depend upon krill as a dietary food source, to a greater or lesser extent. However, within CCAMLR, work is underway to enhance management so that it remains precautionary should catches increase into the future (Trathan et al., 2018; Warwick-Evans et al., 2023c; Constable et al., 2023).

Where it all begins

Antarctic krill begin life as microscopic eggs that are spawned close to the ocean surface. A female krill can lay thousands of eggs, with several spawning episodes during the short Antarctic summer. The eggs sink to great depths as they develop and hatch, before the newly emerged larvae swim to the surface to begin feeding. When the larvae reach the ocean surface in autumn they must feed, so that they can survive the long Antarctic winter when the ocean is covered by sea ice.

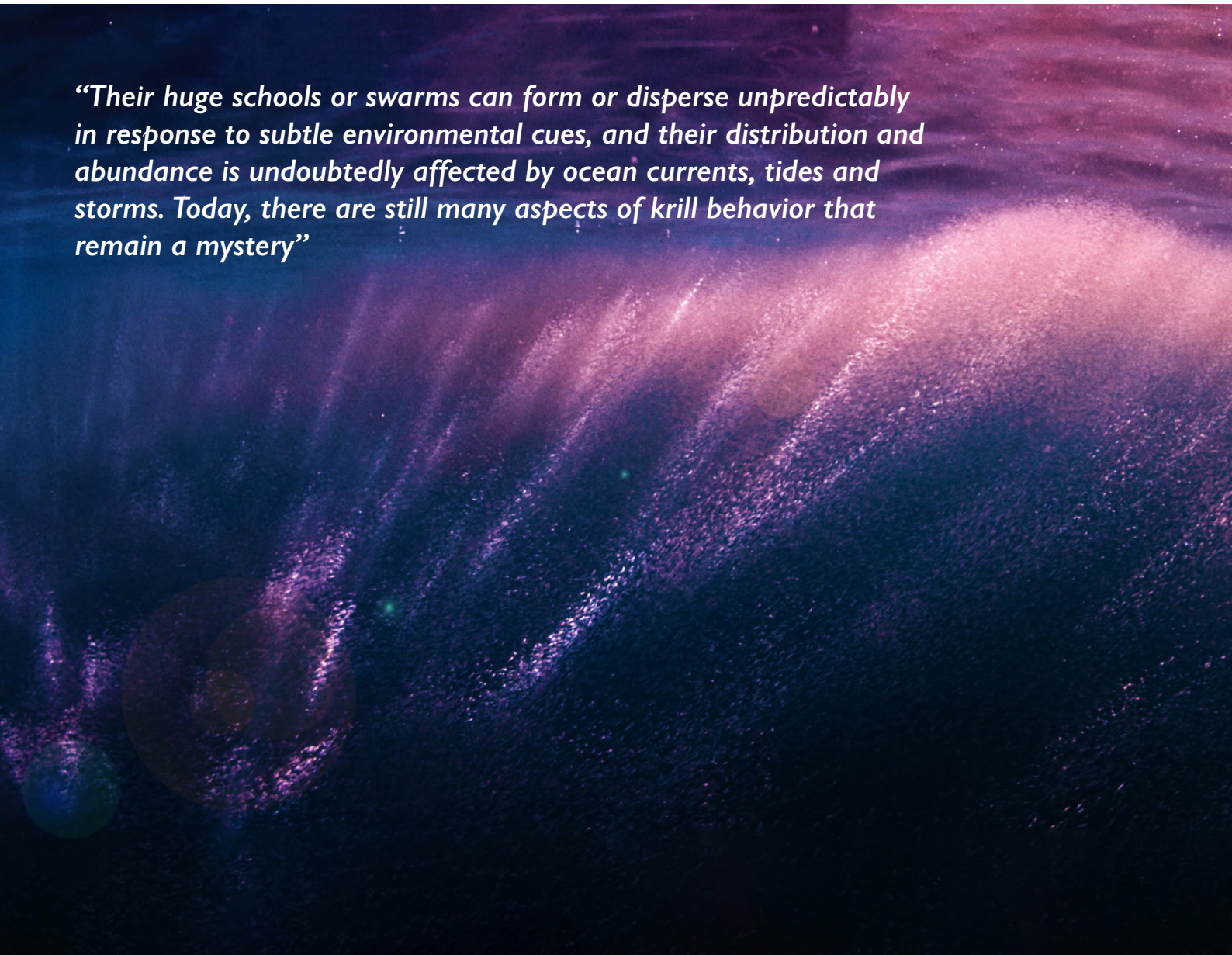
The larvae eat algae within the sea ice, using the complex under-ice habitat as a nursery ground. In the Antarctic spring, when the sea ice melts and the larvae – now juveniles – are released into the open ocean, they can form vast aggregations.

Antarctic krill have a complicated life history, changing size, shape and habitat as they grow (Miller and Hampton, 1989; Nicol, 2006). They mature at two years of age and can live for up to seven years, or even longer in laboratory conditions (see review by Reiss, 2018). Adult krill are now known to be capable of living anywhere in the Southern Ocean – from the very surface layers to the seafloor at abyssal depths, and from inshore areas to the deep open ocean. It is reported that about 87% of the krill population live over deeper oceanic waters. In some areas, Antarctic krill perform daily vertical migrations, approaching the ocean surface at night, and returning to darker, deeper waters during the day, where they can avoid air-breathing predators.

Antarctic krill exhibit complex behaviors in response to the changing seasonal environment. Through the Antarctic summer and autumn, they build body reserves as oil, to help sustain them through the Antarctic winter. They remain deeper in the ocean in winter than in the summer. In spring and early summer they are believed to migrate offshore to deeper waters to spawn (Perry et al., 2019), returning inshore later in the year (Siegel, 1988). Their huge schools or swarms can form or disperse unpredictably in response to subtle environmental cues, and their distribution and abundance is undoubtedly affected by ocean currents, tides and storms. Today, there are still many aspects of krill behavior that remain a mystery.

Environmental change and the impact on krill

Larvae of Antarctic krill are associated with sea ice during winter, which is thought to offer food and protection. However, these life stages are thought to be vulnerable to the impacts of climatic change, as the annual extent of sea ice is projected to decrease under most IPCC global warming scenarios, particularly in the winter; indeed, recent work suggests that various ecological indices are now changing at the Antarctic Peninsula, a major site for krill spawning (Cimino et al., 2023). Indeed, both larvae and juvenile krill



strongly benefit from heavier ice and colder temperatures in winter (Ryabov et al., 2023). Krill larvae are also sensitive to fluctuations in food availability (the adults can tolerate starvation for extended periods) and they have also been shown to be affected by increasing levels of acidity in the ocean (Kawaguchi et al., 2013), although mature krill may be more resilient to certain changes (Kawaguchi et al., 2024). Environmental changes that affect krill will doubtless have repercussions for the rest of the Antarctic marine food-web, so considerable research is underway to examine the potential effects of a warmer, more acidic ocean on the populations of krill in the Southern Ocean (Flores et al., 2012; Kawaguchi et al., 2024).

Antarctic krill exist within an ocean habitat that is estimated to be at least 19 million km^2 (around seven million square miles), equivalent to more than twice the area of the USA (Atkinson et al., 2009). As the area of habitat is so large it is challenging to measure how much krill exists at any given time. Also, since part of their habitat is covered by sea ice during much of the year, and also because the Southern Ocean is the stormiest in the world, it is impossible to measure all parts of the population at the same time (see Hill et al., 2024). However, recent advances in bio-acoustic science mean that those parts of the population that can be measured, can be done so reliably (Demer and Conti, 2003, Fielding et al., 2011; Krafft et al., 2021). Nevertheless, it remains challenging to determine whether the krill population is increasing or decreasing. However, a number of small-scale local scientific surveys are carried out on an annual basis, which provide confidence that although local abundance is variable between seasons and between years, there has been no long-term decline over the past three decades (Reiss et al., 2008; Fielding et al., 2014; Trathan et al., 2021; Skaret et al., 2023). Further, larger ocean basin-scale scientific surveys have shown that the overall abundance of krill has not changed since at least the year 2000 (Fielding et al., 2011), even though the spatial distribution varies over time (Krafft et al., 2021).

Has the krill population changed over time?

The long-term status of the Antarctic krill population has been the focus of an intense debate over the past two decades. This began with a suggestion that there had been a long-term decline in krill in the southwest Atlantic since the 1970s (Atkinson et al., 2004). However, this has been hotly contested (Cox et al., 2018; Cox et al., 2019; Hill et al., 2019; Candy, 2021; Kawaguchi et al., 2024). Understanding the population dynamics of krill is complex, especially with the sparse historical data available in most areas. Complete understanding probably needs to consider not just krill, but also the physical and biological environments of the Antarctic, including the demands of krill predators.

The over-exploitation of baleen whales during the 20th century depleted populations which would otherwise have consumed a conservative estimate of 150 million tonnes of krill per year (Laws, 1977). Subsequently, this reduction in demand may have then allowed populations of other predator species, such as seals and penguins, to increase given the more abundant food supplies (Ballance et al., 2006; Trivelpiece et al., 2011; Trathan et al., 2012; Palin et al., 2023). However, evidence for some species is better than for others (Ballance et al., 2006; Trivelpiece et al., 2011; Trathan et al., 2012), and now, given the passage of time and the incomplete historical record, further evidence will be difficult to accumulate. Nevertheless, as populations of baleen whales recover, marine ecosystems are likely to change.

More recent work has also suggested that overall, the Antarctic marine ecosystem may actually become more productive as populations of baleen whales recover (Nicol et al., 2010; Ratnarajah et al., 2016). This is based on the recognition that whale faeces contains iron, which is a limiting nutrient in the Southern Ocean, and that historically, defecation by baleen whales could have been a major mechanism for recycling iron and fertilizing the ocean. Pre-exploitation populations of whales and krill must have stored larger quantities of iron than today and so they would have also recycled more iron in surface waters, enhancing overall ocean productivity through a positive feedback loop. Thus, allowing the great whales to recover might actually increase Southern Ocean productivity through enhancing iron levels in the surface layers. However, evidence to support this hypothesis still remains incomplete.

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Each of these differing hypotheses reflects debates amongst parts of the scientific community, and highlights the need that scientists should attempt to develop a unified view related to the history of krill and its dependent predators.

It is highly likely that any unified view will require detailed historical information about both krill and about the major consumers of krill, that is whales, seals, penguins and fish. Given the serial exploitation of different predator species over time, this may now be challenging. However, detailed observations over the coming decades may help resolve parts of the discussion, particularly as whale populations recover.

Whatever the historical situation, the regular acoustic surveys of krill biomass at South Georgia (Fielding et al., 2014; Trathan et al., 2021), at the South Orkney Islands (Skaret et a., 2023) and at the Antarctic Peninsula (Reiss et al., 2008) have failed to detect any systematic change in the krill population over the past 30 years. Variability exists in both space and time, but there has been no evidence of a decline since these surveys were initiated.

Today, most of the predators that depend upon krill as a food source have relatively healthy populations, albeit with some species, such as Adélie penguins, Antarctic fur seals and humpback whales, increasing dramatically in some places over the last 50 years (Southwell et al., 2015; Lynch et al., 2016; Forcada et al., 2005; Trathan et al., 2022b; Jackson et al., 2015). However, other species in some areas, such as chinstrap penguins, have undergone declines (Trivelpiece et al., 2011; Strycker et al., 2020). The factors that result in changes in the population sizes of some species are complex, including competition and density dependence (Trathan et al., 2021), and the environment (Forcada et al., 2008), and are not related in any simple way to food supply or to fisheries.

There is no evidence to suggest that the krill fishery is depleting the krill population to the extent that populations of whales, seals or penguins are suffering.

Locally, krill population size can vary naturally from year to year, and in extreme circumstances krill shortages do occur, such as at South Georgia; this in turn has been shown to affect the breeding success of seals and penguins (Trathan et al., 2022a). Ultimately, physical drivers (Trathan and Murphy, 2003) and the movement of krill within ocean currents has been linked to these krill shortages (Murphy et al., 2004; Trathan et al., 2022a).

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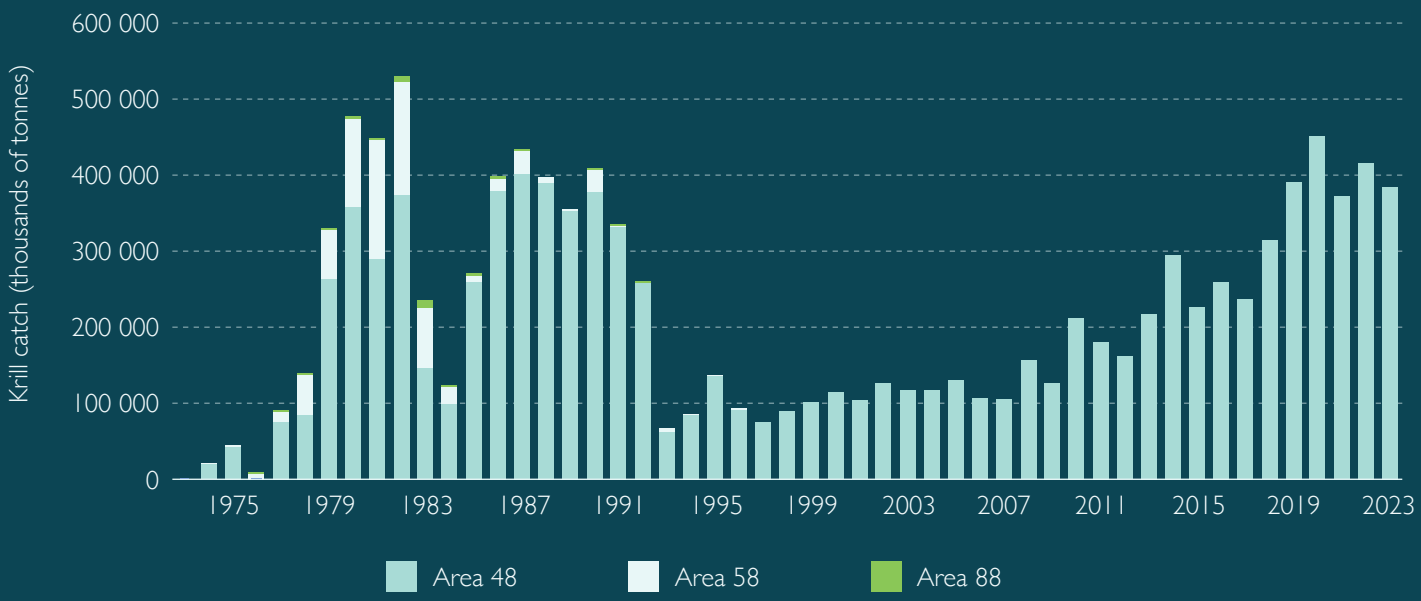
In other parts of the Antarctic it has been much more difficult to directly link seasonal or annual fluctuations of krill abundance to the health of seal and penguin populations. In these regions, the recent resurgence of humpback whales, such as at the Antarctic Peninsula, argues that krill have been readily available. However, some studies have identified the importance of the environment with possible impacts on penguins when krill populations are low (Watters et al., 2020), although Lowther et al., (2020) and Oosthuizen et al., (2022) argued that such analyses must also include other major krill predators if conclusions are to be robust.

Further, the recent voluntary designation of seasonally closed coastal areas to protect penguin feeding grounds during the breeding season (Godø and Trathan, 2022), suggests that such concerns might now be of much lesser consideration.

Figure 1: 40 years of Krill Harvesting (source CCAMLR)



Establishing the modern-day krill fishery

Due to uncertainties over the total circumpolar stock size of krill, the fishery is managed using regional estimates of abundance that are highly conservative, so that any catch allocation is highly precautionary (Hewitt et al., 2004; Fielding et al., 2011; Pauly et al., 2000; Nicol et al., 2000; Jarvis et al., 2010; Skaret et al., 2023).

The krill fishery has been operating since the early 1960s, firstly as an exploratory research fishery. Subsequently, as the fishery developed, catches increased, peaking in the early 1980s with Japanese and Soviet vessels catching over half a million tonnes a year (see Figure 1). With the breakup of the former Soviet Union, catches collapsed, but are now increasing once again. It has generally been difficult to develop marketable products from krill, as it requires innovative technology to process the catch, which needs to be done very quickly. Further, harvesting has always been very expensive given the remoteness of the fishing grounds. Economic factors have therefore always been key to the successful operation of the krill fishery (Foster et al., 2011), including global commodity prices of related fishmeal products. Illegal, Unreported and Unregulated (IUU) fishing for krill has never been reported to date.

When the krill fishery began, there were concerns that it might cause irreversible damage to the Antarctic ecosystem, so a unique international convention, CCAMLR, was agreed to ensure that the fishery would be managed using an approach that took into account the requirements of the entire Antarctic marine ecosystem. CCAMLR remains part of the Antarctic Treaty System and enshrines the ecosystem approach to fisheries management. It was the first major international management agreement to adopt this foresighted approach to harvesting.

The high catch levels of the Soviet era were not sustained and annual catches dropped to less than 100,000 tonnes in the mid-1990s. Since then, krill catches have slowly increased. Today, over 400,000 tonnes are caught from the southwest Atlantic, largely by Norwegian vessels, producing high quality aquaculture feed and krill oil supplements for human consumption. Other krill-fishing nations include Chile, China, South Korea and Ukraine. In 2024, Russia once again started to fish for krill.

After forty years of krill harvesting in the southwest Atlantic, the total catch is still less than double the annual precautionary catch limit of 5.61 million tonnes.

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How (and why) catch limits are strictly regulated

No commercially harvested marine species has such a large biomass as krill, or such an extensive habitat range. Therefore, whilst the krill fishery is the largest by catch mass in the Southern Ocean, it remains relatively small by world standards. According to FAO statistics (FAO, 2022), the krill fishery in 2020 was only the world's 19th largest fishery by mass (~445,000 tonnes), albeit the 2nd largest crustacean fishery. The world's top 13 fisheries each caught more than one million tonnes in 2020, of which the fishery for Peruvian anchovy (a species that occupies a similar ecological niche to krill), is the world's largest, with harvests of 4.9 million tonnes taken from much smaller areas of ocean.

As the krill stock is so enormous and so extensive, there have never been any concerns voiced over possible depletion of the stock. The primary concerns voiced have been about whether the aggregation of catches might deplete food resources for krill-dependent marine predators, especially those that breed on land and have a restricted foraging area. This is why CCAMLR has spent so much effort in developing robust management methods (Constable, 2001; Constable and de la Mare, 1996; Constable et al., 2000), including the development of a recent management framework that is currently being refined prior to possible implementation (Trathan et al., 2018; Warwick-Evans et al., 2023c; Constable et al., 2023).

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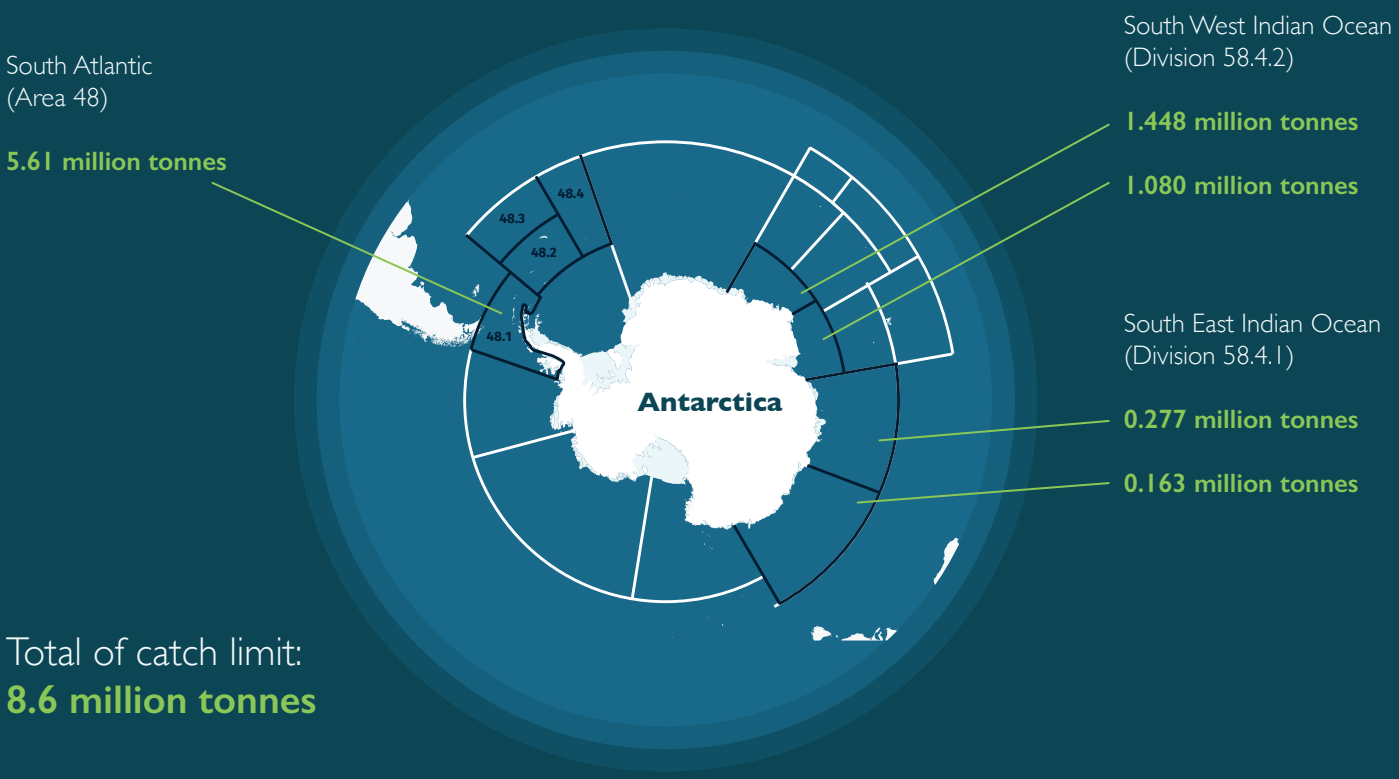
CCAMLR meets annually making decisions through consensus. It agrees Conservation Measures for all managed fisheries operating in the waters around Antarctica. For krill, the fishery is regulated through a series of Conservation Measures that specify how much biomass of krill can be caught, where it can be caught, acceptable levels of by-catch and other operational requirements. CCAMLR also adheres to a strict set of conservation principles that require that harvesting should not disrupt any ecological relationships between harvested, dependent and related populations, and that any changes that result from harvesting must be reversable within two or three decades. In practical terms, these principles ensure that a significant proportion of the unfished biomass of krill is left for dependent predators (75% in the case of krill).

In implementing this, CCAMLR has sought to limit the amount of krill that can be caught in any management period. This was initially based on a bio-acoustic survey undertaken in 1981 (Trathan et al., 1995), but this was subsequently updated following the acoustic survey carried out in the year 2000 (Fielding et al., 2011). Based on the biomass of krill recorded, precautionary catch limits were set that are far more conservative than for any other fishery quotas, given the necessary levels of escapement needed for natural predators. The acoustic survey carried out in 2019 found a similar biomass of krill to that reported in the year 2000 (Krafft et al., 2021), providing confidence that the available biomass of krill has not changed in recent decades.

Figure 2: Precautionary Catch Limits (PCLs) of Antarctic Krill (source CCAMLR)



In the southwest Atlantic (FAO Area 48), the precautionary catch limit for Antarctic krill is currently set at 5.61 million tonnes and amounts to less than 10% of the total estimated biomass in the area, which is 60.3 million tonnes (Fielding et al., 2011). However, until there is agreement about where and when such a large catch can be caught without impacting the natural ecosystem, CCAMLR has imposed an even more stringent interim catch limit. The interim catch is therefore limited to 620,000 tonnes in any one fishing season, or approximately 1% of the total biomass. Furthermore, CCAMLR has also spatially subdivided the interim catch limit amongst four FAO Subareas (48.1, 48.2, 48.3 and 48.4, respectively 155,000, 279,000, 279,000 and 93,000 tonnes) within the southwest Atlantic, to prevent the potential aggregation of the fishery with associated concentration of catches. Though highly precautionary, CCAMLR is working to replace this interim catch limit with a more scientifically justified catch limit.

The krill fishery in the southwest Atlantic, where all harvesting currently takes place, is limited to 620,000 tonnes a year, or approximately 1% of the current biomass, which is a highly precautionary catch limit when compared with all other fisheries.

The current interim catch limit in the southwest Atlantic is highly precautionary when compared with other fisheries. For example, the Lenfest Forage Fish Task Force recommends that the biomass of lower trophic level species should not be allowed to fall below 30-80% of the unfished biomass depending upon the level of ecosystem knowledge (Pikitch et al., 2012). CCAMLR's precautionary limit of less than 10% of the current krill biomass far exceeds this level of precaution, whilst the interim limit at approximately 1% of biomass shows an even higher level of precaution.

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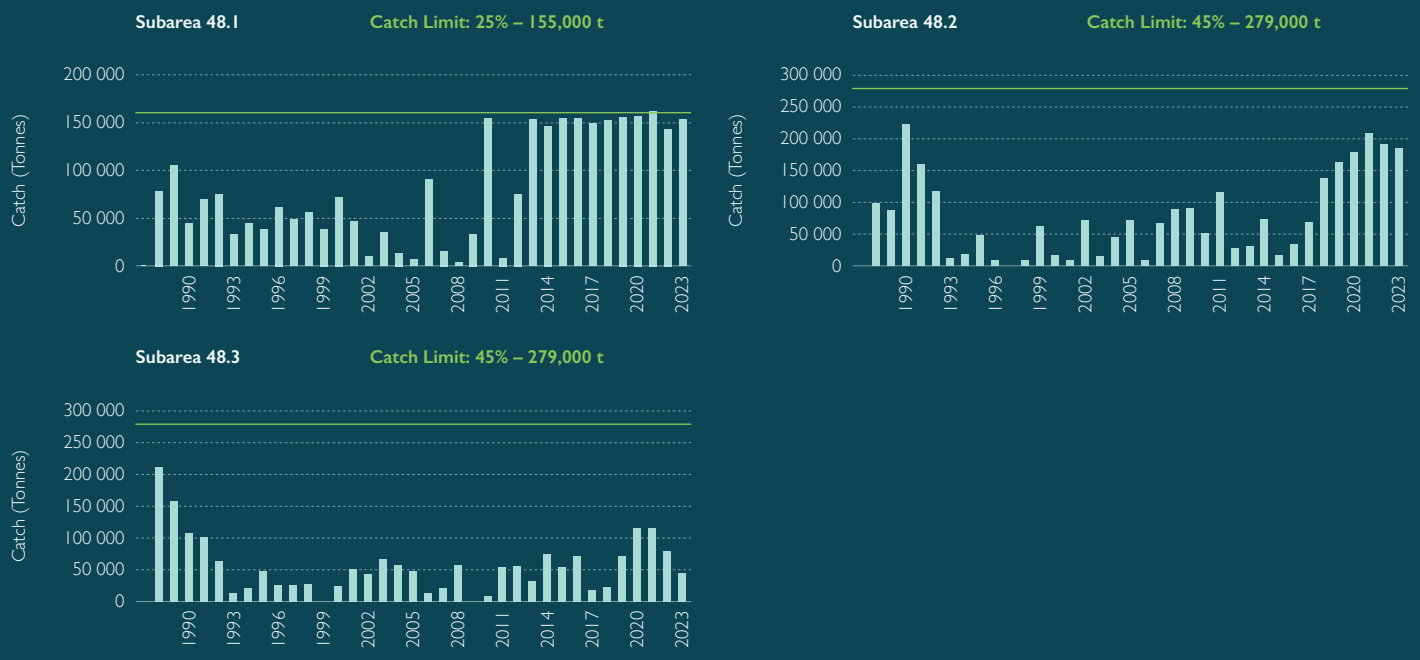
Beyond the southwest Atlantic, precautionary catch limits have been set for two areas in East Antarctica. The total precautionary catch of Antarctic krill in FAO Statistical Division 58.4.1 is limited to 440,000 tonnes in any fishing season, whilst the total catch in FAO Statistical Division 58.4.2 is limited to 2.528 million tonnes. Together with Area 48, these sum to just under 8.6 million tonnes per

Figure 3: Catch history for Antarctic krill in the southwest Atlantic, with the interim catch allocation shown for each FAO Subarea



year. Each of these catch limits are further subdivided into smaller areas in order to ensure that large proportions of the permitted catch do not aggregate in small areas to the detriment of the ecosystem.

All areas fished for krill as well as most areas where krill fishing occurred in the past are now covered by precautionary catch limits. Only very limited experimental fishing is allowed outside these areas, primarily because krill stocks have not been adequately surveyed and there is no established catch limit.

The krill fishery in the southwest Atlantic, where all harvesting currently takes place, is limited to 620,000 tonnes a year, or approximately 1% of the current biomass, which is a highly precautionary catch limit when compared with all other fisheries.

Moving towards revised scientifically-based catch limits for the southwest Atlantic

CCAMLR's management principles determine that at least 75% of the unfished biomass of krill should be left for natural predators. However, ensuring that krill is not harvested beyond this limit requires agreement about the spatial and temporal scales of measurement needed. It is not logistically feasible to undertake large-scale surveys every year; however, small-scale research surveys each year do provide confidence about the status of the krill stock.

There is little concern about the abundance of krill at larger-scales, therefore the major focus for krill fisheries management within CCAMLR has been to distribute the catch in space and time so that krill-dependent predators, such as penguins and seals, are not affected by aggregations of catches into small areas (Trathan et al., 2022b). This is an important issue within CCAMLR, particularly for penguins and seals, which must return to land on a regular basis in order to provision their offspring. Whilst feeding their young, penguins and seals can only travel relatively short distances, which means that any aggregation of catches in the vicinity of their breeding sites must be carefully regulated.

> ***"The revised krill fishery management framework is intended to specifically account for the needs of krill-predators across both space and time"***

Developments in krill fishery management are discussed every year at the annual CCAMLR meetings which, as well as the 27 Members, are attended by a range of other interested parties, including environmental NGOs (non-governmental organizations), fishing industry associations, and other international bodies that have a stake in the conservation of the Antarctic ecosystem. A number of stakeholders focus their attention upon the needs of dependent predators that feed upon krill.

Consequently, over the past few years CCAMLR has been working to develop a robust scientifically based approach for krill fishery management in Area 48 (e.g. Trathan et al., 2018; 2022b; Warwick-Evans et al., 2022a; 2022b; 2022c; Constable et al., 2023). The revised krill fishery management framework is intended to specifically account for the needs of krill-predators across both space and time. This revised framework has now been under development since 2019, including with a pilot analytical study focused on the Antarctic Peninsula (Warwick-Evans et al., 2022a; 2022b; 2022c).

The revised framework relies upon the development of three core elements (CCAMLR, 2019, paragraph 5.17 to 5.19):

1. A krill stock assessment to estimate precautionary harvest rates;
2. Regular updates of krill biomass estimates, potentially at multiple scales; and,
3. A risk assessment framework to inform the spatial allocation of krill catch.

CCAMLR has also agreed that appropriate ecosystem monitoring is needed, as well as spatial management tools agreed to ensure that biodiversity is adequately maintained, especially given regional climate change (see also Trathan, 2023).

Once fully implemented and tested, the pilot project could be rolled out for other locations, providing a scientifically robust precautionary krill fishery management framework for the whole of Area 48. Field testing and implementation will be contingent upon reaching consensus within CCAMLR. If CCAMLR cannot reach agreement, or if the pilot project fails for any reason, the existing highly precautionary management framework should remain in place.

International scientific collaboration to ensure history doesn't repeat itself

In the 1970s, there was great concern amongst scientists, policymakers and environmental NGOs, that the developing krill fishery could undermine the stability of the Antarctic marine ecosystem, if krill catches were not well managed. Such concerns were predicated upon the history of exploitation in the Antarctic where serial over exploitation had decimated populations of seals, whales and fish. Such concerns led to the establishment of CCAMLR, even though this was during the height of the 'Cold War'.

When CCAMLR was signed in 1980, it was hailed as a groundbreaking approach to resource management because it sought to ensure the sustainable harvesting of marine resources using an ecosystem approach. CCAMLR has since overseen the management of the krill fishery.

The Conservation Measures that now regulate the Antarctic krill fishery make up a regime that would be considered comprehensive and innovative in any other environment. Still, because the Antarctic is such a sensitive place and Antarctic krill is such an important component of the marine food-web, the fishery is always under intense scrutiny.

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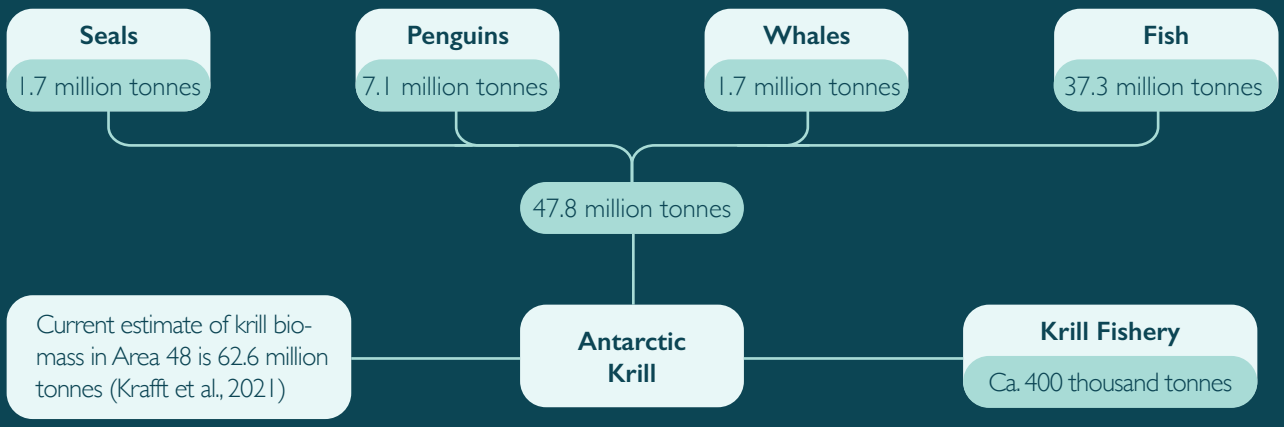
A broad range of Conservation Measures govern the operation of the krill fishery, including: notification rules, environmental stipulations, observer requirements and the establishment of spatial catch limits and by-catch

Figure 4: Estimated predator demand for krill in FAO Area 48: Total krill demand (thousand tonnes) by taxonomic group. From Hill et al., (2007).



regulation (e.g. Krafft et al., 2022). Additionally, CCAMLR has implemented an ecosystem monitoring program (Agnew, 1997) to detect changes in the status of species that are dependent upon krill and to determine whether any observed changes might be as a result of fishing activity. The ecosystem monitoring program was developed during the nadir of baleen whale population abundance (following their historical over exploitation). Now, with resurgent whale populations, CCAMLR is revising the monitoring programme to include baleen whales; it is also working to ensure that the revised monitoring programme also supports the new revised krill fishery management framework.

The new revised krill management framework requires information about the seasonal distribution of krill and the seasonal consumption of krill by a range of marine predators. Fishing companies are contributing to this through regular surveys for krill (e.g. Skaret et al., 2023) and the Antarctic Wild Life Research Fund (antarcticfund.org). According to Atkinson et al., (2009), approximately 28% of the global krill biomass occurs in the southwest Atlantic, the same area where krill-dependant predators are also most abundant. Hill et al., (2007) estimate that collectively, across the southwest Atlantic, fish, penguins, seals and whales consume approximately 47.8 million tonnes of krill each year (see Figure 3). Work is underway to revise these estimates, given the fact that some predator populations are now known to be increasing, whilst others are decreasing.

Compared to the levels of natural krill consumption by predators, the amount currently harvested by the commercial fishery is very low. Under the revised krill fishery management framework, catches will increase, but be distributed in space and time so that there is increased certainty that predators will not be impacted, even when catches increase above the interim catch limit.

Third party sustainability verification

There has been a trend in the last two to three decades to use independent third party certification to confirm the sustainability of seafood products. The Marine Stewardship Council (MSC) is the premier certifying organization known for its rigorous assessment process and credible standards for sustainable fishing and seafood traceability. MSC is an independent, third-party certification that is uncompromising on environmental standards; their full assessment process is rigorous and scientific and looks at fisheries based on three principles: 1 - Sustainable fish stocks; 2 - Minimizing environmental impact; and 3 - Effective management; MSC also operate a reliable chain of custody certification program (see recent review by Matthews, 2023). MSC certification allows products to carry the distinctive MSC blue eco-label, no other companies are eligible to display this label.

The krill fishery operated by Aker BioMarine was the first to be certified as sustainable and 100% traceable in 2010, and was subsequently recertified for a further five years in 2013 and again in 2019. In addition, since 2016, Aker BioMarine has also been certified by Friends of the Sea (https://friendofthesea.org/). This certification is subject to

regular surveillance audits to ensure Sustainable Seafood, Fisheries and Aquaculture Products. Only two other krill fishing companies currently hold MSC certification.

The need for cooperative research

MSC certification carries with it several responsibilities, including a commitment to undertake any research necessary to ensure sustainable management of the resource. The krill fishing industry therefore works constructively with various stakeholders, including environmental NGOs that play an important role within CCAMLR, given their focus on precautionary ecosystem management, environmental protection, and on the sustainability of the region's fisheries. The largest krill fishing company, Aker BioMarine, pioneered an initiative in 2012 to form an industry collective to help ensure CCAMLR's goals are being met. Virtually all (9 out of 11) krill fishing companies are now part of this collective – the Association of Responsible Krill (ARK) Harvesting Companies (ark-krill.org). ARK brings together krill fishing companies from four CCAMLR Member States (Chile, China, Norway and South Korea). The combined fishing capacity of ARK represents over 90% of all krill catches. ARK aims to ensure that the industry develops sustainably in support of the long-term viability of the krill stocks and dependent predators.

An initiative of ARK is to conduct annual krill acoustic surveys in areas that are logistically difficult for scientific researchers to access

There are very few scientific research vessels operating around Antarctica and they are only present in the region for short periods each year. In contrast, krill fishing vessels operate on the fishing grounds for most of the year and are extremely well positioned to collect scientific data that can be used in the management of the fishery. Most fishing vessels have the equipment and the capacity to carry out valuable research, which can be used to better understand the biology of krill and provide information on changes in krill stocks.

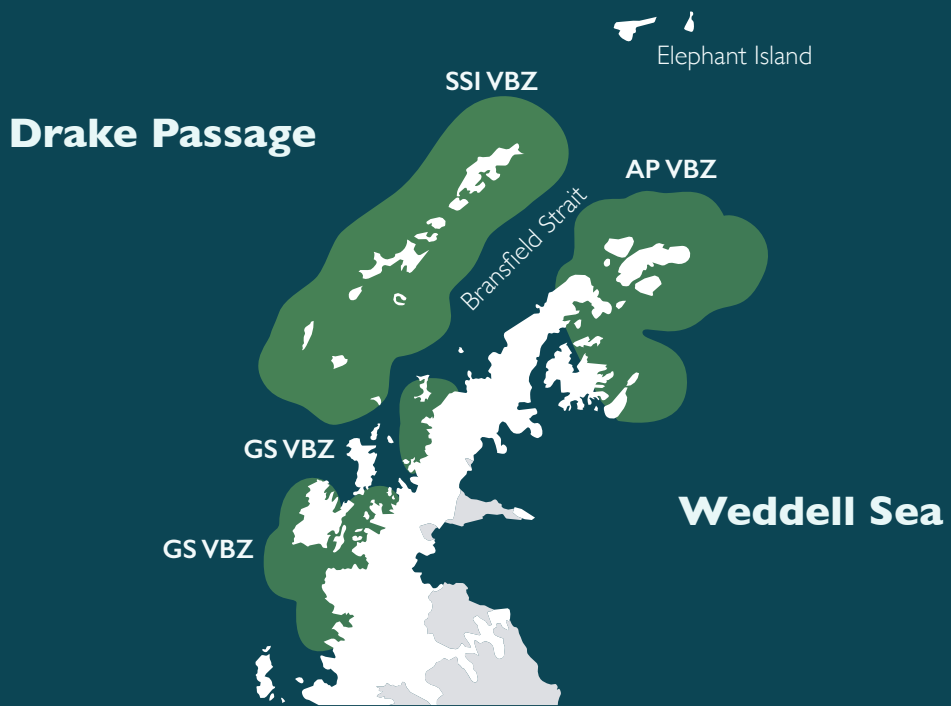
An initiative of ARK is to conduct annual krill surveys in areas that are not generally accessible to researchers and to encourage the collection of scientific data from fishing vessels. The active involvement of the fishing industry in research is of considerable benefit to fishers, managers and scientists. Organizations such as ARK now assist with communication between the fishing industry and CCAMLR, so that management actions can be adopted seamlessly.

ARK's voluntary precautionary protection of land breeding predators

A further ARK initiative has been to designate a series of voluntary buffer zones (VBZ) around major penguin colonies to provide precautionary protection with seasonal no-take fishery zones for important penguin foraging areas during breeding (Godø and Trathan, 2022). These were first implemented in 2018 and there has been full compliance every year since. The VBZ include the majority of the penguin foraging habitat during chick rearing for colonies within FAO Subarea 48.1, encompassing approximately 74.3% of all chinstrap, 97.5% of gentoo, and 91.4% of Adélie penguin colonies (Trathan et al., 2022b). Importantly, the VBZ focus protection in coastal areas near to land-based predator breeding sites, something that CCAMLR has previously identified as important. The VBZ weight different penguin species equally, and do not down-weight less common species such as gentoo penguins. The VBZ, in addition to protecting penguin foraging habitat, also provide protection for feeding baleen whale species (Trathan et al., 2022b). When the VBZ were agreed, ARK also undertook that all ARK vessels would commit to agreed standards for trans-shipment, and all ARK vessels would comply with the Torremolinos International Convention for the Safety of Fishing Vessels (imo.org).

Krill fishing companies are also working in other ways to ensure scientific research information is available to inform

Figure 5: The Association of Responsible Krill Harvesting Companies Voluntary Buffer Zones (VBZ) in FAO Subarea 48.1; GS VBZ: Gerlache Strait; SSI VBZ: South Shetland Islands; AP VBZ: Antarctic Peninsula. ARK companies do not fish for krill within the VBZ during the penguin breeding season.



management of the krill fishery. Aker BioMarine has set up the Antarctic Wild Life Research Fund in 2015 to help fund research into krill, its predators and the Antarctic marine ecosystem (AWR; antarcticfund.org). The principal aims of the AWR research plan are to: contribute to CCAMLR's work on the development of a management system for the commercial fishery for Antarctic krill; design and implement a series of candidate scientific reference areas to monitor natural variability and long term change; design field and analytical methods for providing early warning signals about future ecological change, and; observe and evaluate signals of ecological change with a view to determining, to the extent possible, the causes of change, whether natural or anthropogenically induced. In its first 10 years, AWR has provided more than US$1,500,000 in science funding, spread across 24 projects implemented by various research institutions.

Ensuring fishing practices are fit for use within sensitive ecosystems

A recent innovation in krill fishing was the development of the continuous fishing system, first introduced by Aker BioMarine, and termed Eco-Harvesting®. Other companies are now looking to introduce similar systems which use a specially designed beam trawl system and direct hose connection between the trawl and the vessel. The system reduces the need for multiple trawl deployments, each of which would otherwise have the potential to add to incidental mortality of seabirds. In terms of its operation, the equipment stays deployed whilst the vessel fishes, with a continuous flow of water passing through the hose, bringing live krill directly into the factory. This allows for immediate processing of fresh raw material with superior product quality.

Continual revision of fishing practices is necessary, given the complexity of the Antarctic marine ecosystem. For example, Aker BioMarine was the first krill fishing company to require seal exclusion devices on all its nets, preventing seals from becoming trapped and drowned. Aker BioMarine was also the first company to fit whale exclusion devices, recognising that baleen whale populations are now recovering. Both practices have now been mandated by CCAMLR.

An important component of CCAMLR's management, is the requirement for Fisheries Observers to monitor fishing activities. Aker BioMarine was the first company to implement 100% International Observer coverage. This was subsequently implemented by CCAMLR, though some

companies only carry National Observers. Most recently, Aker BioMarine has begun trials with video observation of trawl gear, the first in the krill fleet to do so. If successful, video recordings may provide long-term records that augment human observers, something particularly valuable for recording fishing activities during the night, and something potentially important for recording seabird incidental mortality.

Going above and beyond - why are all these efforts necessary?

The Antarctic is a special place and industries that work there have a responsibility to ensure its protection and conservation.There have been major ecological catastrophes as a result of earlier harvesting activities (i.e., whales, seals and fish), so it is essential that current and future fishing is undertaken in a responsible and sustainable manner.

CCAMLR provides an international framework that ensures the fishery for Antarctic krill is precautionary and sustainable. Nevertheless, based on the 'polluter pays principle', it is also important that the fishing industry assists with management to the greatest extent possible, including through operational transparency and the provision of additional voluntary actions where these aid management. It is also vital that industry helps through the delivery of science and data. ARK companies, led by Aker BioMarine, have committed to the delivery of sustainable harvesting, going above and beyond the requirements of CCAMLR.

About Aker BioMarine

Aker BioMarine is an integrated biotechnology company dedicated to the sustainable harvest of krill and development of krill-derived biotech products. The company supplies biomarine ingredients through a completely transparent value chain. Aker BioMarine's Superba™ Krill products are provided with 100% traceability from sea to shelf. Currently, Aker BioMarine is one of only three krill harvesting companies to hold the Marine Stewardship Council (MSC) certification (March, 2018) and is also Friends of the Sea certified (2016).

Since Aker BioMarine began harvesting Antarctic krill, it has maintained a range of active partnerships with the environmental NGO community. For example, Aker BioMarine, WWF Norway and the Antarctic and Southern Ocean Coalition (ASOC) are Board Members of AWR, with Pew Bertarelli Ocean Legacy also an Affiliated Member. Similarly, the ARK VBZ are reviewed annually by a Panel of Experts from the scientific community, reporting to a Review Panel where ARK Members, including Aker BioMarine, sit together with representatives from Greenpeace, Pew and WWF. Further, Aker BioMarine strives to maintain good working relationships with 10 other environmental NGO groups outside these more formal partnerships. Aker Biomarine considers that progress in CCAMLR requires broad collaboration and reconciliation of different stakeholder interests.

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