

Protect global values of the Southern Ocean ecosystem

Climate change and fishing present dual threats

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The Southern Ocean, which comprises ~10% of the global ocean, is critically important to the homeostasis of the Earth system, exhibits distinctive marine biodiversity, and has tremendous scientific, diplomatic, and wilderness value. Yet, the region and its suite of global values are critically threatened by climate change, which is exacerbated by commercial fishing, an activity that provides value for relatively few industrial actors and compromises the greater values that the Southern Ocean ecosystem provides to the world. The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), the arm of the Antarctic Treaty System responsible for managing Southern Ocean marine living resources, meets in October–November 2022 and is under pressure to strengthen fisheries management, especially toward climate change resilience. We encourage improved management practices that account for the environmental externalities arising from trade-offs between fishing and the global contribution of the Southern Ocean ecosystem, including under a changing climate.

With sovereignty suspended under the Antarctic Treaty, Antarctica and the Southern Ocean serve as an international space with immense global value. The Antarctic is celebrated for its rich history of exploration, vast wilderness and extraordinary austere beauty, exceptional governance prioritizing diplomacy and peace, and long history of international science collaboration (1). The Southern Ocean surrounding Antarctica supports exceptional marine biodiversity, including assemblages of endemic organisms and large populations of predators that rely on its rich waters (2). These waters harbor some of the healthiest large marine ecosystems left in the world (e.g., Ross Sea, Weddell Sea), which provide remarkable wilderness, scientific, and ecological value.

Recent assessments have highlighted the immense global value of the Southern Ocean and how those values are immediately threatened by climate change, calling for a critical evaluation of trade-offs in management, including a better understanding of the risks posed by fishing (1–5). Antarctic waters affect the Earth's climate, moderate sea level, and play a strong role in global ocean circulation and nutrient cycling. The Southern Ocean

disproportionately absorbs global carbon dioxide and heat, thus helping to regulate temperature and buffering global impacts of climate change (5). The Southern Ocean biosphere also contributes to climate regulation and oxygen production through its primary production of seasonal phytoplankton blooms (3, 5). In addition, the Antarctic seafloor stores extensive amounts of carbon (3). Antarctic krill (*Euphausia superba*) play a critical role both as a central species in the Southern Ocean food web (5) and in biogeochemical cycles, stimulating primary production and influencing the drawdown of atmospheric carbon to the deep sea (6). A host of seasonally migrating iconic marine mammals and birds depend on the Southern Ocean to supply their energetic needs (4).

With no Indigenous Peoples in Antarctica, and no local fishing communities, exploitation of the waters surrounding Antarctica has always been the result of industrial distant water activities. Historically, prior to the existence of CCAMLR, these activities led to over-exploitation and near extirpation of whales, seals, and some finfish populations (2). CCAMLR came into force in 1982 to regulate Southern Ocean fisheries with a mandate to ensure that fishing does not cause irreversible harm to target and nontarget populations or the marine ecosystem and to account for environmental change. Currently, fishing is restricted to CCAMLR members (comprising 25 nation states plus the European Union), and in principle any state can go through the process to join CCAMLR.

SOCIAL AND ECOLOGICAL TRADE-OFFS

Today, Southern Ocean fisheries are conducted by only ~12 countries, do not contribute to food security, and threaten the Southern Ocean ecosystem. The primary targeted species include toothfish (*Dissostichus eleginoides* and *D. mawsoni*), the region's top fish predator, and Antarctic krill, with a minor contribution of mackerel icefish (*Champsocephalus gunnari*). Although the Food and Agriculture Organization of the United Nations has suggested that Antarctic krill are underfished, with potential to contribute to food security (7), the krill caught are not used as a direct food source for people but as fishmeal for farmed salmon and shrimp, as well as in premium priced krill oil supplements (8–10). Overall, these products make up <1% of the global fishmeal and supplements markets (3). Toothfish are processed for human consumption, but sold as Chilean sea bass in high-end restaurants and stores in the United States, Europe, and Asia, with limited ability to reduce the food insecurity of malnourished people worldwide (10). There are other social consequences. Like other fisheries operating in international waters, some toothfish operations support forced labor on their vessels, and accidents with loss of life at sea are not uncommon (11). Finally, many of these fisheries continue to be economically viable only on account of government subsidies, which, as shown throughout the world, can contribute to overfishing (9, 11).

Fishing in the Antarctic benefits very few and comes at a high cost of increasingly compromising the ecosystem. The Antarctic krill fishery recently has seen record high catches (>450,000 tonnes) (12). Yet, though these catch levels fall within the precautionary total allowable catch, extraction is increasingly concentrated in nearshore predator "hotspots" frequented also by fish, birds, and mammals (e.g., Scotia Sea and the west coast of the northern Antarctic Peninsula; CCAMLR Area 48) (7, 13). Reductions in sea ice (due to climate change) in the prime krill fishing grounds have further enabled vessel access to previously inaccessible waters and allowed for fishing year round, leading to increased

competition with predators and removal of krill from the food web (13). Recent research indicates that the cumulative catch in some of these coastal regions can be greater than the amount consumed by local predators, and greater than the local replenishable population of krill (7).

This localized depletion has substantial potential consequences for predators, including visiting whale populations, which are still recovering from historic depletion (7, 13). As a result of direct competition at these hotspots, in 2021, the krill fishery for the first time incidentally killed three juvenile humpback whales (12). This was in addition to the incidental killing of at least 16 seals and 60 petrels and other seabirds over the last two seasons (12). CCAMLR's mandate stipulates maintenance of ecological relationships, such that fishing should consider impacts on predators, including whales. Yet there are insufficient measures in place to ensure that the fishery is not detrimentally competing with predators or to prohibit (or even limit) incidental catch of whales in the krill fishery.

Ecosystem and target species' impacts from fishing are further compounded by climate change. Parts of the Southern Ocean, especially those adjacent to the western Antarctic Peninsula (where krill fishing is concentrated), are among the most rapidly changing regions in the world, with potential cascading impacts on the ecosystem (2, 3). Krill, in particular, owing to dependence on sea ice and vulnerability to acidification, are seen as extremely high risk from climate change (3). Benthopelagic-dwelling Antarctic toothfish, because of their limited thermal tolerance, are also at risk (2, 3). Antarctic finfish have shown to be easily overexploited even without the stress of climate change. For example, marbled rockcod (*Notothenia rossii*), which were severely overfished in the 1970s, remain at a fraction of their estimated pre-exploitation levels, despite ongoing regional fishery closures (14); bycatch of larval fish in the krill fishery may be impeding their recovery (8, 14). The population status of many toothfish fisheries remains unknown, including in some regions of the Southern Ocean that were heavily targeted by illegal, unregulated, and unreported fisheries in the 1990s (12). Meanwhile, ecosystem impacts of fishing toothfish remain largely unknown and debated. Fishing at current levels will likely exacerbate environmental impacts on toothfish and krill, along with the greater Southern Ocean ecosystem, including competing birds and mammals (3, 13).

Krill fishing, in particular, because of krill's critical role in the ecosystem and biogeochemical cycles, is predicted to negatively affect Southern Ocean ecosystem services (1–3), including reducing the carbon storage potentially provided by krill (6). Further, given that historic whale populations would have enhanced nutrient cycling, promoted productivity, and facilitated the drawdown of carbon and nutrients to the seafloor, allowing whales to recover (by limiting competition with fisheries) could lead to higher Southern Ocean productivity, increasing its powers of carbon sequestration (15). In addition, the incredible remoteness of the Antarctic means that fuel use by fishing vessels is high, leaving a disproportionate carbon footprint from fishing (8).

PROTECTING THE GLOBAL VALUES

This is a critical moment for the Southern Ocean, and for CCAMLR, which showed tremendous leadership in 2016 by adopting the Ross Sea region marine protected area (MPA), among the largest MPAs in the world, but which has since waned on adopting

further conservation initiatives beyond pre-existing fisheries measures. This comes at a time when the global community, through the United Nations, is close to negotiating a new treaty for conserving biodiversity on the high seas. CCAMLR thus stands to either serve as a leading model or be surpassed. Continuing to authorize the removal of key prey and predator species through fishing, by a relatively small industrial fleet, will further compromise ecosystem and biosphere regulating services (as has been shown elsewhere, e.g., Peru, and Benguela current forage fish extraction). Fishing also stands to create diplomatic conflict (e.g., current conflict over toothfish fisheries at South Georgia) and erode the wilderness value of the Antarctic, without contributing to food security. Although actions must continue to be taken through national governments toward reducing global carbon emissions, CCAMLR has the responsibility to embrace the ecosystem mandates in its convention and the competency to implement a variety of tools to help immediately.

Manage for ecological and climate resilience

For three decades, CCAMLR has discussed more sophisticated spatial management for Antarctic krill (e.g., at smaller scales), yet has not been able to adopt this into practice. Thus, CCAMLR has not yet moved beyond single-species stock assessments with a largescale static total allowable catch. Meanwhile, recent modeling has indicated that combined effects of krill fishing and climate change are potentially disastrous for populations of penguins and other predators (13). Historical trends suggest that the quantity of krill fished will further increase and grow more spatially concentrated in predator hotspots.

A suite of science-based tools exist for managing marine systems for ecological and climate resilience. These include using environmental and ecosystem indices to understand impacts of fishing and environmental change; considering future climate impacts on targeted species and the ecosystem; and employing adaptive management. Consideration of recovering whales and the provisioning needs of krill and toothfish predators must be accounted for in management, including in more refined spatial management and precautionary catch limits. All of these management ideas are being discussed among CCAMLR's Scientific Committee (which advises CCAMLR). However, data gaps and uncertainty, along with resistance to more stringent catch limits (spatially, and overall), have prevented progress. In 2022, the precautionary interim distribution of the "trigger" catch limit for krill expires. This presents a tremendous risk for fishing to be even more concentrated. Given the recent research demonstrating the risk to krill and their predators if the fishery continues under its current rules, CCAMLR has an immense opportunity and responsibility to adopt the spatially explicit precautionary management that it has been developing for decades.

Implement marine protection

Within CCAMLR's capabilities to exclude areas from fishing, MPAs, if well designed, can potentially promote adaptation to climate change and enhance Southern Ocean ecosystem resilience. MPAs can provide climate refugia and facilitate adaptation by alleviating the stressors on the ecosystem (e.g., fishing). CCAMLR's founding articles contain language that allows the closing of areas to manage fisheries, and at times it has exercised that power. Moreover, CCAMLR committed to an ecologically representative network of Southern Ocean MPAs. After adopting two MPAs (in 2009 and 2016), it has since lacked the renewed political will to move forward, with Russia and China not yet joining in consensus for the existing Southern Ocean MPA proposals under negotiation. These MPA proposals are

grounded in extensive science, but likely need high-level diplomacy, one of the key facilitators of the adoption of the Ross Sea region MPA. We encourage CCAMLR states to work together to find common ground on the MPAs, which can serve as a tool for both conservation and international diplomacy, emblematic of the spirit of the Antarctic Treaty System.

Consider the full suite of values for future generations

As an international space, the Southern Ocean must be valued beyond its direct economic (extractive) value, which benefits a small number of nations (including the wealthiest on Earth) in the short term. These activities are likely also harming the wider values and functions of the Southern Ocean. A comprehensive ecosystem services assessment and mapping of the Southern Ocean urgently needs to be completed, including analyses of social perceptions from stakeholders and all nonmonetary values (1). This should include its support of seasonally present marine mammals and birds, and its role in the Earth system, along with its value as a global wilderness, and its history of peace and science. Further, the Southern Ocean needs to be valued for the suite of services it provides to both current and future generations. Improved management of the Antarctic could boost global climate change mitigation and ensure that Antarctica, as an exceptional global treasure, is not exploited for the benefit of short-term gain for few at the expense of many. Moreover, proximal Indigenous communities have ties to the Antarctic, though these communities have not yet had a voice at Antarctic governance meetings. Worldviews that prioritize conservation for future generations are consistent with the foundations of the Antarctic Treaty System, including the CAMLR Convention, and need to be considered and incorporated into management. CCAMLR could evaluate values, management, and trade-offs in tandem with the wider Antarctic Treaty System, providing unified management for Southern Ocean and Antarctic values.

Moratorium on fishing

Upon coming into force in 1982, CCAMLR soon thereafter closed various regions to fin-fish fishing to allow populations to recover, which is a powerful tool incorporated within its convention. The measure is showing effectiveness, though slowly, in the Antarctic Peninsula region (14). Despite working toward a more ecologically and spatially explicit management framework, CCAMLR has not used this tool under the precautionary principle despite the growing evidence of the external costs from the fishing industry. Given the clear acceleration in climate change, far more rapid now than when CCAMLR was negotiated, we argue that this conservation tool can no longer be neglected. We recommend considering a moratorium (a temporary prohibition) on fishing while a more comprehensive management assessment is undertaken. This assessment should account for all gains and losses, and consider broader climate resilience with the inclusion of regional and global trade-offs in ecosystem services. We acknowledge that among some CCAMLR member states, prohibitions on fishing may seem unreasonable, although such actions are not without historical precedent. Further, given the proven vulnerability of Southern Ocean organisms and ecosystems to climate change and ways in which fishing is known to compromise ecosystem services, a real reassessment of current practices may make an indefinite moratorium appropriate until the climate crisis is better managed.



An emperor penguin stands in front of an icebreaker on the frozen Ross Sea, Antarctica.

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