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Marine protected areas in the Southern Ocean: status and future

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Abstract Marine protected areas (MPAs) in the Southern Ocean are receiving more and more global attention. The Southern Ocean is one of the world's last regions not yet seriously impacted by human activities, signifying its ecological importance and unique value for scientific research. In response to climate change and growing commercial fishing interests in the Southern Ocean and their impacts on the marine ecosystem, the Commission on the Conservation of Antarctic Marine Living Resources (CCAMLR) is reacting to growing international pressure to establish a system of MPAs in the Southern Ocean to manage fisheries and conserve vital species—such as the keystone resource Antarctic krill and the dominant fish predator Antarctic toothfish—as well as to protect whole ecosystems. This review summarizes progress in the establishment of MPAs in the Southern Ocean by focusing on several major topics: (1) the current status of MPAs in the Southern Ocean; (2) the purpose and objective of MPAs in the Southern Ocean; (3) a short description of the largest high-sea MPA (the Ross Sea MPA); (4) ecological observation and monitoring for the planned MPAs in the Southern Ocean; and (5) the importance of international cooperation in the design, establishment and future management of MPAs in the Southern Ocean.

Keywords **Antarctic krill, CCAMLR, marine protected areas, Southern Ocean**

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1 Introduction

The Southern Ocean is formed by the southern connection of the Pacific, Atlantic and Indian oceans and accounts for about 10% of the world's oceans. As an extraordinary marine ecosystem that plays a large role in various global energy cycles and budgets (Xavier et al., 2016), the Southern Ocean ecosystems with their high species diversity are among the most productive in the world (Smetacek and Nicol, 2005). Antarctic krill are the dominant species in these ecosystems and perform an important trophic link in the Antarctic marine food web, transferring carbon and energy from phytoplankton to species at higher trophic levels (Atkinson et al., 2004). Antarctic species at higher trophic levels, such as migratory and endemic whales, seals and birds, use Antarctic krill as their primary prey (Tynan, 1998). However, relentless change is being chronicled in some regions of the Southern Ocean (Smetacek and Nicol, 2005). Taking the West Antarctic Peninsula as an example, the densities of

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Antarctic krill in the productive southwest Atlantic sector (more than 50% of the Southern Ocean krill stocks) have been declining since the 1970s due to the lessening extent and duration of winter ice (Atkinson et al., 2004). Both Adélie and chinstrap penguins are declining in the Antarctic Peninsula, constituting an example of climate-change 'losers', while Gentoo penguins, as climate-change 'winners', are increasing with an expanding breeding range (Clucas et al., 2014). Owing to obvious climate trends (global warming, ocean acidification, and ice-shelf melting), escalating human activity (fishing, scientific expedition, and tourism), and verified impacts on marine species (changes in abundance and community structure), the Southern Ocean ecosystems are experiencing rapid change, thus the protection of the Antarctic region has achieved global significance (Kawaguchi et al., 2013; Clarke et al, 2007; Harris et al., 2007; Smetacek and Nicol, 2005; Atkinson et al., 2004). In 2005, members of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) committed to establishing a system of Marine Protected Areas (MPAs) to ensure the long-term conservation and sustainable use of the Southern Ocean marine environments and resources. So far, two MPAs have been established: the South Orkney Islands Southern Shelf MPA in 2009 and the Ross Sea region MPA in 2016. Additional MPAs are being negotiated in the context of CCAMLR meetings, such as the Eastern Antarctic MPA (proposed by Australia, France, and the European Union), the Weddell Sea MPA (proposed by the European Union), and the Western Antarctic Peninsula region MPA (proposed by Chile and Argentina), and some other planned MPAs (Lahl, 2015).

This review begins with a rough description of the status of MPAs in the Southern Ocean, followed by a summary of the purpose and objectives of the MPAs; next, we describe the largest high-sea MPA (the Ross Sea MPA), discuss ecosystem monitoring in the Southern Ocean for the planned MPAs, and conclude with an appeal for international cooperation in the course of future work to better protect the Southern Ocean ecosystems.

2 The status of MPAs in the Southern Ocean

An MPA is defined by the International Union for Conservation of Nature (IUCN) as "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values". The designation of MPAs in the CAMLR Convention Area is meant to conserve its marine resources (CCAMLR, 2011). The CCAMLR plays a great role in the establishment of these MPAs. Before the Commission was established, there was little protection of the Southern Ocean marine ecosystems. The primary conservation objective of the CCAMLR is the conservation of Antarctic marine living resources, according to Article II. The designation of Southern Ocean MPAs is adopted by members of the CCAMLR as the result of a complex, slow and challenging process (Smith and Jabour, 2018). The Scientific Committee for the Conservation of Antarctic Marine Living Resources (SC-CAMLR) and its working groups are first required to evaluate the scientific basis of a proposed area, and then the value of a proposed MPA is evaluated by the Commission in the context of the science. As part of the general process of the Scientific Committee, the Bioregionalization Workshop typically plays a major role in considering the spatial management options. After detailed consideration and discussions, a drafting group is established to prepare draft conservation measures. Finally, the proposal may be adopted by the CCAMLR after all issues are agreed upon by consensus (Tang, 2017).

The CCAMLR first addressed the topic of a system of MPAs in 2000, when it assessed a proposal for the Balleny Islands Antarctic Specially Protected Area. In 2006, the Bioregionalization Workshop Steering Committee was formed by recommendations from the SC-CAMLR. Then, in 2009, the CCAMLR established the first MPA—the South Orkney Islands Southern Shelf (SOISS) MPA (Figure 1); this is the first high-seas MPA anywhere, and it was established by the CCAMLR partly as a trial (Hawkey et al., 2013). The SOISS MPA, a region that includes submarine shelves and seamounts, including both pelagic and benthic ecosystems (Figure 1), was expressly designated to protect areas of seasonal ice, areas with high primary production, important krill habitat, essential habitat for winter foraging by penguins, and an area central to the formation of frontal systems.

In 2009, the CCAMLR committed to achievement of a representative system of MPAs within the Convention Area by 2012. In 2010, Australia introduced an MPA proposal concerning the East Antarctica, while the United States and New Zealand submitted separate scenarios for a Ross Sea region MPA. However, owing to some Member States' concern for interference with commercial fishing, these two plans were discussed but not adopted. In 2011, CCAMLR adopted Conservation Measure 91-04 'General framework for the establishment of CCAMLR Marine Protected Areas'. A merged Ross Sea proposal by the United States and New Zealand was considered by the CCAMLR in 2012 (CCAMLR, 2011). Meanwhile, Russia suggested sites of special scientific interest as an alternative to establishing MPAs. During 2013, a special meeting of the SC-CAMLR and the Commission was held, in Bremerhaven, Germany, to discuss and revise proposals for the Ross Sea and the East Antarctica regions. German scientists then compiled datasets covering environmental parameters and biological records over 30 years, and they began to be involved in the Weddell Sea MPA proposal. The proposed Weddell Sea MPA was also discussed by the Working Group on Ecosystem Monitoring and Management in 2013. From

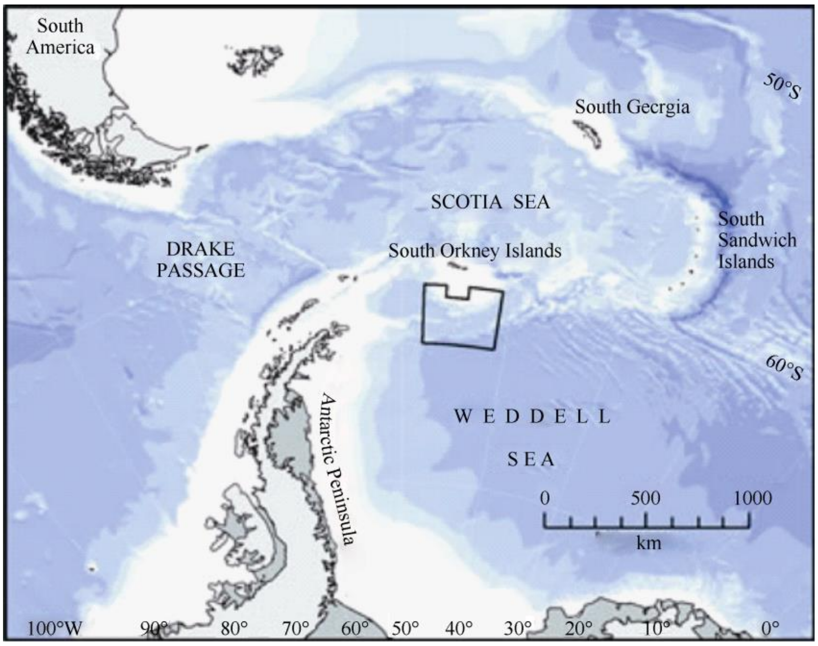

Figure 1 Spatial boundaries of the South Orkney Islands Southern Shelf (SOISS) MPA.

2011 to 2017, the East Antarctic MPA proposal, which was initially compiled by Australia and later joined by France and the European Union, has been negotiated and discussed during multiple CCAMLR meetings; currently, the scale and size of that MPA is much smaller than put forward in the original proposal in 2010 (Figure 2).

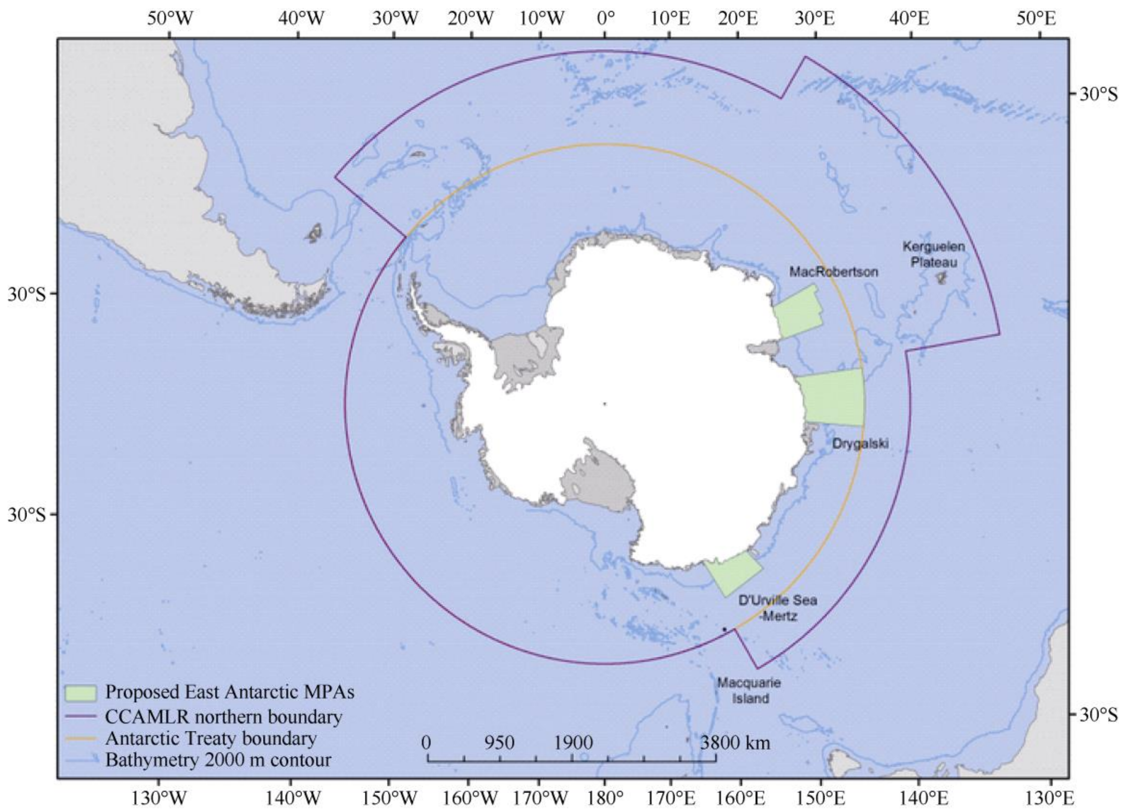

Figure 2 Map of the proposed East Antarctic Marine Protected Area, as projected in 2017 (http://www.antarctica.gov.au/law-and-treaty/ccamlr/marine-protected-areas; last updated 13 October 2017).

Establishment of an MPA in Antarctica is difficult owing to the CCAMLR's consensus requirement: if no consensus is reached, the MPA proposal will not be adopted. Furthermore, conservation value and a sound scientific basis are two vital components of an MPA proposal. An important step towards successfully establishing an MPA is to ensure understanding of the science and conservation potential underlying the proposal. With the objective latitude of some fishing states like Russia, China and other countries on the establishment of MPAs, the process of MPA establishment has been deadlocked in the CCAMLR meetings since 2012 (Tang, 2017). Overall, the main opposing attitudes to Southern Ocean MPAs have been related to political agendas and fishing interests (Smith and Jabour, 2018). For instance, Russia's main concern about the East Antarctic MPA proposal related to the boundaries and catch limits for toothfish, while China disputed what are the most appropriate ways to achieve conservation goals while also including the rational use of marine resources in areas beyond national jurisdiction (CCAMLR, 2015). Moreover, Ukraine and Japan have questioned the scientific evidence needed to support designation of an MPA (Smith and Jabour, 2018).

In 2016, the second MPA in the Southern Ocean and also the world's largest high-seas MPA—the Ross Sea region MPA, was agreed on. Final consensus for the joint proposal by the United States and New Zealand during the 2016 CCAMLR meeting is considered a major step towards the establishment of MPAs in the Southern Ocean, although the proposals for the East Antarctic MPA and the Weddell Sea MPA are still under debate.

3 The purpose and objective of Southern Ocean MPAs

Regional warming, ice decrease, and ocean acidification are the most immediate conservation threats to the Southern Ocean ecosystems (Kawaguchi et al., 2013; Ducklow et al., 2007). These impacts could be exacerbated by frequent and ongoing human activities like fishing and tourism. The proposal and establishment of MPAs is theoretically an effective way to conserve the biodiversity and ecosystems of the Southern Ocean. Objectives to establishment often involve issues around biodiversity protection, fisheries management, and human utilization (Hockey and Branch, 1997). The challenges can be divided into two categories: (1) preventing the degradation of ecosystems; and (2) counteracting the overfishing of commercial species such as fish, krill and other invertebrates (Lahl, 2015). Regardless, several key functions are performed by MPAs: the first is the conservation of marine ecosystems through protecting critical species, habitats and processes; the second is the sustainable management of fish resources. Other lesser functions are enhancing ecotourism, preserving historical value, and providing a framework for scientific research (Hawkey et al., 2013).

An MPA is a region demarcated to provide protection for all or part of the natural resources it contains. The CCAMLR's aim is to contribute to sustaining Antarctic marine ecosystems from the scope of structure and function, maintain the ability to adapt to climate change, and reduce the invasion potential of alien species as a result of human activity (CCAMLR, 2011). To meet the specific objectives of habitat conservation, ecosystem monitoring or fisheries management, certain human activities are limited or prohibited entirely. However, suspicions linger that the Southern Ocean MPAs are being used as a tool to support Antarctic territories (Smith and Jabour, 2018), whereas some countries such as Russia claim that the Convention Area should be considered a global commons and not under any one country's authority.

4 The Ross Sea region MPA

The Ross Sea has been scientifically investigated since the initiation of Antarctic exploration in the early 1900s. The Ross Sea is considered one of the last remaining marine ecosystems with minor anthropogenic influence, despite relatively high commercial fishing activity (Halpern et al., 2008). This region is also seen as a key environment to protect owing to its exceptional ecological value and scientific research potential (Ballard et al., 2012).

In contrast to the Atlantic sector of Antarctic, the ice concentration in the Ross Sea sector has been shown to be significantly increasing (Stammerjohn et al., 2012). Substantial variations in physical forcing, ice coverage, and biological processes on a variety of time and spatial scales are exhibited in the continental shelf of the Ross Sea (Smith et al., 2014). The Ross Sea is one of the most productive areas of the Southern Ocean; specifically, high primary productivity and substantial concentrations of Antarctic krill and the Antarctic toothfish (*Dissostichus mawsoni*) are found in this region (Davis et al., 2017; Arrigo et al., 1999). For now, the Ross Sea is one of the few places in the world that still has a full community of upper-trophic-level predators, such as fishes, penguins, seals and whales (Ballard et al., 2012). Notably, the Ross Sea is a chief site for penguin foraging, and the world's largest colonies of Adélie and emperor penguins are found in this region (Smith et al., 2014). However, substantial uncertainties exist in our knowledge of the Ross Sea food web in regard to energy and carbon transfer between different trophic levels, as well as the spatio-temporal variations of important species in response to environmental change (Smith et al., 2014).

As mentioned, the Ross Sea MPA proposal was put forward separately by the United States and New Zealand in 2010. The United States' proposal for the MPA covered 1.8 million km^2, of which about 0.8 million km^2 would be closed to fishing and used only for scientific study of the effects of climate change; New Zealand's proposal covered 2.5 million km^2 and would allow for fishing in some areas

(Cressey, 2012). A joint proposal was formed after compromise by the two countries about the protection objectives and the MPA boundaries. The Ross Sea MPA proposal that was finally adopted, in 2016, designates about 2.27 million km^2 which is divided into three zones: the General Protection Zone, the Special Research Zone, and the Krill Research Zone (Figure 3; CCAMLR, 2016b). The General Protection Zone includes three areas and is designed to provide representative protection of different habitats and bioregions, to mitigate or eliminate a number of specifically identified potential ecosystem threats from fishing, and to support existing and future scientific research and monitoring. The Special Research Zone includes an important fishing area on the continental slope and is designed to serve as a scientific reference area to advance research to increase scientific understanding about the ecosystem effects of external forces like fishing and climate change and to continue to inform the science-based management of the Ross Sea toothfish fishery. The Krill Research Zone is intended to investigate life-history hypotheses, biological parameters, ecological relationships, and variations in biomass and production of Antarctic krill (CCAMLR, 2016b).

More than 70% of the Ross Sea region MPA is closed to fishing (CCAMLR, 2016a). The General Protected Zone is considered a 'no-take' area prohibiting all commercial fishing. Toothfish fishing is limited within the Special Research Zone, while krill fishing is allowed in the Special Research Zone and the Krill Research Zone.

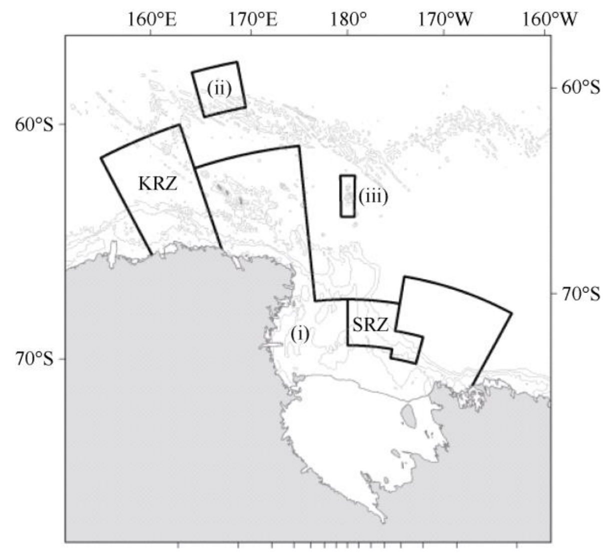

Figure 3 The Ross Sea region Marine Protected Area, including the boundaries of the General Protection Zone which is composed of areas (i), (ii) and (iii), the Special Research Zone (SRZ), and the Krill Research Zone (KRZ) (CCAMLR, 2016b).

The specific objectives of the Ross Sea MPA are mainly to protect the habitats, core distribution region, and core foraging region of all levels of species (e.g., invertebrates, krill, fishes, birds, and mammals) so as to conserve the natural ecological structures, dynamics and function of the Ross Sea region (CCAMLR, 2016b). With regard to the research and monitoring undertaken in the Ross Sea MPA, data that are collected shall be standardized and focus on the following questions: (1) Do the MPA's boundaries continue to sufficiently encompass the priority populations, features, and areas according to the MPA objectives? (2) What are the roles of the identified habitats, processes, populations, life-history stages, or other priority features in the scope of the Southern Ocean ecosystem? (3) How are the ecosystem's priority features potentially affected by fishing, climate change, environmental variability, or other factors? (4) Are there differences in the structure and function of the marine ecosystem between regions inside the MPA and regions outside the MPA, or differences in the populations or subpopulations of marine organisms between those that occur or forage inside the MPA and those that occur or forage outside the MPA (CCAMLR, 2016b)?

5 Ecosystem observation and research for the planned MPAs in the Southern Ocean

A major issue facing decision-makers regarding MPA establishment is the paucity and patchiness of marine ecology data (Harris et al., 2007). Studies of biodiversity, the bioregionalization of various trophic-level species, and spatial processes in the ecosystems provide important scientific background in support of the development of a CCAMLR MPA. In polar investigations, sampling coverage in terms of species composition, abundance, and diversity is usually small and unrepresentative, restricted by the harsh field conditions and challenges to traditional sampling methods. Most research and observations are deployed on ice-free regions in austral summer, while basic biological information on specific parts of the environment—such as ice-covered regions and the deep ocean—remains scarce (Xavier et al., 2016).

Some international initiatives, such as the Southern Ocean Observing System (SOOS) and the Deep Ocean Observing System (DOOS), are aimed at developing an effective observation system and collecting scientific data in the Southern Ocean. Long-term monitoring programs in the Southern Ocean, like oceanographic moorings that can collect data in wintertime, should be conducted to help us better understand the structure and function of the ecosystems. Long-term monitoring is also necessary to determine the effectiveness of MPAs in protecting the overall Southern Ocean ecosystem. Meanwhile, the development and use of innovative technology to monitor the Southern Ocean ecosystems are required in the future (Xavier et al., 2016). Examples of new technology or advanced methods include autonomous underwater vehicles (AUV) and remotely operated vehicles (ROV), which can be used in places that traditional equipment might not be able to access, like the benthic zone and ice-covered settings (Marsh et al., 2013); gliders with newly developed sensors for measuring biogeochemical variables, which may be operated over extensive areas and for extended periods (Thomalla et al., 2017); and float technology, such as the Argo array, including Bio-Argo, Deep-Argo and surface drifters, which can collect continuous data (Riser et al., 2016). The use of new technologies for future observation efforts could effectively improve the spatial and temporal extent of ecological sampling and exploration of the Southern Ocean (Riser et al., 2016; Xavier et al., 2016).

Two important issues relevant to Southern Ocean ecology observation and research are identifying major ecosystem processes and investigating food web structures and ocean functioning (Xavier et al., 2016). Although the understanding of Southern Ocean biological structure (e.g., composition, abundance, community) and processes (e.g., distribution, feeding ecology) has been improved in recent years, the adaptability or acclimation of different organisms to various predicted physical changes like decreasing sea ice, ocean acidification and other environmental dynamics remain poorly understood (Xavier et al., 2016). Some international research programs organized by the Scientific Committee on Antarctic Research (SCAR), particularly Antarctic Thresholds—Ecosystem Resilience and Adaptation (AnT-ERA) and State of the Antarctic Ecosystem (AntEco), will help to examine ecological processes in the Southern Ocean, from the molecular to the ecosystem level.

To pinpoint current and planned observations in the Ross Sea MPA and other nearby areas that are scientifically important for understanding all environments across the sea (including polynyas, boundary regions, the under-sampled eastern part, and the Ross Gyre), the first workshop of Ross Sea SOOS Working Group was held in September 2017, in Shanghai, China. This workgroup recommend systematic observations at all spatio-temporal scales of the Ross Sea, to study linkages among physical processes, biogeochemical cycles, and biological processes, and to forecast future states of the Ross Sea (SOOS, 2017).

6 The importance of international cooperation in the design, establishment and future management of MPAs in the Southern Ocean

Because of the exceptional ecological value and urgent pressure to protect the Southern Ocean, MPAs are considered a relatively new management approach to conserve the Southern Ocean at the ecosystem level. Nevertheless, the establishment of Antarctic MPAs has been debated in CCAMLR meetings (Yang et al., 2014). There are different agendas for conservation and exploitation among the 25 CCAMLR members, and the relationship between conservation and rational use is a crucial consideration for the establishment of MPAs in the Southern Ocean. There are also reoccurring conflicts about the concept of ecosystem protection and scientific research freedom, although the freedom of scientific research is in fact protected by the Antarctic Treaty.

The size and location of proposed MPAs need to incorporate numerous factors, such as the ranges of the species being protected, the amount of habitat needing protection, and the extent of fisheries activities in the given area. Deciding on which parts of an ecosystem or which habitats or species should be protected is extremely difficult. The best solution to such disputes is sound, unbiased science. From an ecosystem perspective, single, large MPAs will be more effective in protecting marine species which are relatively mobile (Walter, 2000).

Considering the existing debates and challenges for creating MPAs in the Antarctic, it is exceptionally important to have international cooperation in the design, establishment and future management of MPAs in the Southern Ocean. To coordinate various interests among the different member states and to achieve integration and consensus in MPA proposals, common international cooperation is merited; this could include specific workshops about MPAs, multilateral policy discussions, and joint cruises that are based on hypothesis-driven research (Harris, 2007).

As a major and growing industrial power and one of the newest member of the CCAMLR, China should become more active in ongoing MPA proposals (Liu and Brooks, 2018; Tang, 2017; Ling et al., 2008). China became a CCAMLR member in 2007, but subsequently engaged little and expressed few specific opinions in MPA discussions (Tang, 2017). Bilateral interaction between the United States and China, and China's specific support, greatly influenced the multilateral debates and final adoption of the Ross Sea MPA proposal. Meanwhile, China's scientific capacity in Antarctic regions has improved rapidly and this could help Chinese scientists to better participate in Southern Ocean studies and thus help China to play a greater role in future Antarctic governance (Liu and Brooks, 2018).

Since the establishment of the first Southern Ocean MPA (the South Orkney Islands Southern Shelf MPA) in 2009, and the largest high-sea MPA (the Ross Sea MPA) in 2016, we have now reached a turning point for MPA establishment in the Southern Ocean. We do not yet have the data to prove the success of MPAs on the high seas, but there is plenty of evidence showing the success of more traditional inshore MPAs (Lam, 1998). If high-seas MPAs are planned and implemented to the same high standard, there is reason to expect that such MPAs will provide similar benefits. Though the newly developed Southern Ocean MPAs are in a relatively early stage of maturity, substantial work on the management and monitoring of the MPAs is necessary to protect and conserve Antarctic marine resources in the future.

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