Attachment

Report of Member research and monitoring activities related to the Ross Sea Region Marine Protected Area (2022)

Please include information from currently submitted projects in the CMIR, combining projects already submitted (e.g. see CM 91-05 paragraph 16) or newly submitted with the current report.

Member:

United States of America

Year range of projects included:

2016-2021

Number of projects reported (2016 – 2022):

192 (26 active grants and 166 published studies)

Are there activities related to research and monitoring that are relevant to the RSrMPA which have not already been submitted to the CMIR? Please submit data following procedures and formats below.

All activities as of 8 December 2021 have been submitted (see emails to Isaac Forster, David Agnew and Steve Parker, with cc to George Watters, from Cassandra Brooks).

Are there "preliminary results" from the activities you reported in the CMIR that you can describe further?

Yes; please see attached summary of preliminary results from research projects submitted to the CMIR.

Data submission to the CMIR

The CMIR user manual describes how projects may be uploaded directly to the CMIR and can be found on the CMIR website. Note, the template provided here includes a few additional fields to describe the type of project and collaboration among Members. Alternatively, information about multiple projects may be submitted to the Secretariat following the data template below. If projects have been submitted previously to the CMIR as ongoing or proposed, please update these data. Project data already loaded may be downloaded as a csv file from the repository (see user manual) for editing.

Name of data file(s) provided:

Please attach an excel file, csv, or delimited text file with project data in the following format to be added to the CMIR. Note * indicates required fields.

Title	*Title of research project
Description	*Summary or abstract of research project
Research_start_date	*Research start date (known or estimated)
Research_end_date	*Research end date (known or estimated)
Proposing_party	*CCAMLR Member
Collaborators	*List CCAMLR Members collaborating on the project (e.g., USA, ITL, KOR)
Paper_type	*Peer reviewed, CCAMLR, Agency Report
Project_status	*Complete, On-going, or Proposed. Note that ongoing or proposed projects will require being updated.
Objectives	*Conservation objectives for which the research project links to (to see list of objectives visit the CMIR 'Objectives' tab or Table 3 from https://www.ccamlr.org/en/sc-camlr-xxxvi/20)
Themes	Relevant research and monitoring topics the project covers (see CMIR 'Themes' tab or Table 1 in https://www.ccamlr.org/en/sc-camlr-xxxvi/20)
Outcomes	Project objectives or targeted data outcomes
Management_zones	MPA management zones where research is occurring (e.g., SRZ)
Monitoring_areas	Research monitoring areas (e.g., Southwest Ross Sea, Terra Nova Bay, etc.)
Supporting_docs	Links or uploads of supporting documents, such as peer-reviewed papers, etc. These could include DOI numbers or CCAMLR meeting paper references
Primary_contact	*Primary contact name, e-mail
Priority_questions	Hypothesis or priority elements addressed (see Table 4 in https://www.ccamlr.org/en/sc-camlr-xxxvi/20)
Data_location	*Description of how to locate project data - indicate if privately held who/ what to contact, or internet links to data if publicly accessible

Reports may be submitted via CMIR@ccamlr.org

SOME PRELIMINARY RESULTS FROM RESEARCH CONDUCTED IN THE ROSS SEA REGION

Delegation of the USA

INTRODUCTION

The Ross Sea is among the most intensively investigated stretches of the Southern Ocean, including of biota in both the benthos and the water column, with results available from an extensive collection of peer-reviewed literature (summaries in Ainley et al. 2010, Smith et al. 2006, 2014, 2016). This Ross Sea research continues today largely due to the Antarctic programs of CCAMLR Member States, including China, Italy, New Zealand, the Republic of Korea, and the United States. Because of the scientific and conservation values of the Ross Sea region (RSR), the Ross Sea region Marine Protected Area (RSRMPA) was established in 2016.

We reviewed over 150 papers published since the establishment of the MPA. These papers, each of which include at least one U.S. author and incorporate data collected in the RSR by U.S. government-funded research, demonstrate a high level of international scientific collaboration in the RSR with participation of scientists from at least 20 Members of CCAMLR and at least 8 additional non-Member nations. Although most papers do not specifically mention the RSRMPA, many present results that are relevant to the protected area and improve our understanding of climate and ecosystem processes therein, namely the "structure and function" that the RSRMPA was designed to protect. In short, the literature we reviewed characterizes how the ecosystem in the RSR, both its benthic and water-column aspects, has changed and establishes expectations about future change that might continue as a function of climate forcing and human activity, independent of the protections provided by the RSRMPA or the several Antarctic Specially Protected Areas that line its shores. We reviewed literature that characterizes "baselines" that began before establishment of the protected area, identifies habitats that are contained within the various zones and geographical areas of the RSRMPA, and indicates analytical issues that may need to be considered when evaluating whether the specific objectives of the MPA are being achieved.

Our literature review was composed of several steps. First we cataloged all papers published in peer-reviewed journals since 2016 that have at least one U.S. author (note: this catalog has been submitted to the CCAMLR MPA Information Repository, CMIR, and represents the bulk of U.S. projects listed therein). These papers span a range of disciplines, including cryospheric science and physical oceanography, studies of the benthic communities, plankton and predator ecology, and research on indicator species, *i.e.*, emperor and Adélie penguins, Weddell seals, killer whales, and toothfish. We then reviewed the contents of these papers to assess the status of ongoing research within the RSR and RSRMPA. While most of the papers did not specifically mention the RSRMPA and were not presenting results from studies specifically designed to evaluate the protected area, we determined that the research presented in the papers do contain results of relevance to the RSRMPA. We categorized the results of these papers as, for example, "results that characterize baseline conditions," "results that are particularly relevant to the boundaries of the RSRMPA, its zones, and habitat or geographical areas in the RSR," and "results that indicate technical issues to take into consideration during future analyses" and also identified some possible predictions of how the RSR ecosystem might change, consistent with current patterns underway and projections of change.

This review is not exhaustive; for example, we did not include papers that were not authored by at least one U.S. scientist. Colleagues might also have different expectations about how the marine ecosystem in the RSR may change in the future and reach different conclusions regarding how to categorize results from the large volume of literature relevant to the RSRMPA. We do not cite every paper, but a complete bibliography of the papers considered is included in this summary (and has been submitted to the CMIR). We encourage colleagues to use our summary as a springboard for their own reading, careful thought, and, if desired, re-analysis. Where applicable, our entries in the CMIR indicate the location of publicly available data. We believe that extensive work will be needed to review the RSRMPA in 2027, as required by CM 91-05, expect the relevant literature to be even more complex and voluminous by that time, and hope this summary will be useful in the future.

EXPECTATIONS ABOUT FUTURE CHANGE

Evaluating the efficacy of the RSRMPA requires an assessment of the degree to which the RSR ecosystem has changed and is changing, and whether such changes are consistent with our expectations in regard to the relative roles of climate versus fishing. Thus, based on the results of research relevant to the RSRMPA, we attempted to outline changes that may occur. We acknowledge that the cumulative effects of interannual variability among various factors will contribute to long-term change in the biota, with our expectations related to the latter.

We expect several trends in physical conditions driven by mid-latitude ocean warming and the Antarctic ozone hole to continue, though possibly more slowly than in the 1980s-90s. Physical changes should affect biota to varying degrees. These expectations are founded on improved understanding provided by the integration of *in situ* oceanographic and remotely sensed observations (e.g., Bronselear et al. 2018). Warming at mid latitudes, along with atmospheric energetics attributed to the ozone hole, have caused circumpolar winds to intensify over the past few decades (Thompson and Solomon 2002, Turner et al. 2009), and this trend is unlikely to reverse, though it has stabilized. We expect that strong, intensifying winds will have the following effects:

1. maintenance of more expansive sea ice in the RSR than elsewhere in the Southern Ocean (see Stammerjohn et al. 2012, Parkinson 2019). At its maximum, sea ice in the RSR already extends to the Southern Boundary of the Antarctic Circumpolar Current and is unlikely to extend further; thus any interannual variation should be in the negative direction from the maximum (Parkinson 2019);
2. continual increasing or at least high velocity of the Ross Sea Gyre (see Kwok et al. 2017), which contributes to the expanding sea ice;
3. continual increasing of the length of the sea-ice season at a regional scale while decreasing the sea-ice season in coastal, latent heat polynyas (Stammerjohn et al. 2012);

4. latent-heat polynyas opening earlier and developing faster (Ross Sea, McMurdo Sound, Terra Nova Bay) during the transition from winter to spring while also increasing their areal extent (Arrigo et al. 2015);
5. increase in the intrusion of Circumpolar Deep Water (CDW) into outer portions of cross-shelf canyons (Dinniman et al. 2015), in part affecting the development of sensible heat polynyas along the shelf break (Ross Passage, Pennell Bank; Jacobs and Comiso 1989);
6. continual decreasing of the surface salinity in the RSR owing to upstream ice shelf melt, though most recently it has returned to previous levels (Jacobs 2006; Castagno et al. 2019); and
7. increased input of iron into the marine environment, from wind-driven terrigenous input and upstream ice shelf melt, which would stimulate primary production (Arrigo et al. 2015).

Cumulatively, we expect the physical changes noted above will have effects on the overall ecology of the RSR, but the degree to which these changes are having or will have net effects on biota requires continued research. Broadly, we would expect large polynyas that open earlier and have increased iron input to increase primary production in the RSR (Arrigo et al. 2015). Though to-date increased production has had no effect on Adélie penguins (Dugger et al. 2014) and inconclusive effects on Weddell seals (Paterson et al. 2015), such production may most readily affect the filter-feeding benthic communities (Barry et al. 2003; Dayton et al. 2016). Open water in proximity to colonies has been important to these penguins and seals (Ainley et al. 2005; Dugger et al. 2014; LaRue et al. 2019) as their colonies are associated with polynyas (Santora et al. 2020; LaRue et al. 2021). Whether or not Adélie penguin and Weddell seal populations will continue to grow as they have been since around the year 2000 is unknown.

We also expect the toothfish fishery to continue operating in the RSR, and, independent of the RSRMPA, the fishery's access to fish will be determined by CCAMLR conservation measures and trends in sea-ice extent, duration, and thickness. The fishery has been changing the size and/or age structure of the population, and these changes may even be reflected within the General Protection Zone (GPZ), where commercial fishing has been prohibited since 2009 (although toothfish surveys do continue in the GPZ). For example, large fish have decreased in scientific catches taken from McMurdo Sound (Ainley et al. 2013, 2017), and those fish still present in the Sound have retreated from shallow depths (Parker et al. 2016). This spatial shift could also be the result of predation pressure from increasing numbers of Weddell seals in McMurdo Sound, beginning in the early 2000s (Ainley et al. 2015, 2020) and concomitant with increases in the abundance of emperor and Adélie penguins in the southern Ross Sea (Lyver et al. 2014; Kooyman and Ponganis, 2016; Schmidt and Ballard, 2019). One hypothesis is that a reduction in the abundance of large toothfish, which being neutrally buoyant can occur high in the water column, has significantly increased availability of energy-dense silverfish to these other predators (Lyver et al. 2014; Ainley et al. 2017, 2020). Having more silverfish in the diet leads to enhanced breeding success and post-fledging survival of indicator species like Adélie penguins (Ainley et al. 2018).

Expectations regarding the middle of the food web, particularly about Antarctic krill, crystal krill, and silverfish, are not well developed. Although the habitat characteristics of these species have been quantified (Davis et al. 2017), monitoring of these species is inadequate. What has been done suggests minimal change at the regional scale, at least in regard to Antarctic krill and climate during recent decades along the Ross Sea margin (Yang et al. 2021). While it is recognized that penguins and seals can be proxies for prey availability, it is challenging to deduce the direct links between indicator species trends and food web changes without additional experiments or krill and silverfish monitoring.

PRELIMINARY RESULTS

Since the RSRMPA's adoption in 2016, an extensive scientific literature associated with the RSR has been published in peer-reviewed journals. This literature include studies on the physical oceanography and climatology of the Ross Sea, ecological papers on penguins, whales, seals and fishes, and research on Antarctic benthos and pelagic fauna. These papers and their extensive array of results and discoveries across the RSR extend the bountiful, existing RSR literature and provide a scientific baseline for all future studies relevant to how and why the RSR ecosystem is changing. Not only do these studies shape our understanding of "baseline conditions" in the RSR, but they will facilitate future evaluations of the effectiveness of the RSRMPA. As climate change and other anthropogenic effects continue to affect Southern Ocean ecosystems, these papers along with continuing research and monitoring across the RSR will allow for a comprehensive assessment of the MPA over time. Our literature review presents a condensed version of preliminary results relevant to the protected area, and identifies several baselines present in the Ross Sea since 2016.

Physical Papers

Multiple studies on the oceanography and climatology of the Ross Sea contribute to our understanding of its physical characteristics. Many of these studies include time series that began decades ago (ex: Castagno et al. 2019), beginning with observations made from the USNS *Eltanin* in the 1960s. With the addition of satellites and various sensors, studies on water, air, ice and ocean-current dynamics have improved our understanding of how oceanography influences the biota (initially summarized by Jacobs 2006). Recent research has reported on the effects of local climatology and katabatic winds, enhanced knowledge of sea-ice dynamics, and investigated the physical properties of coastal polynyas and their impact on global ocean currents due to their production of dense, bottom water. Collectively, this research also improves understanding of controls on ecosystem-wide productivity, such as from the input of iron and dissolved trace metals and how these seawater constituents affect phytoplankton and algal blooms (Arrigo et al. 2015). Changing environmental conditions and sea-ice trends impact phytoplankton at the base of the food web, triggering bottom-up trophic responses affecting higher trophic levels (*e.g.*, Li et al. 2016; Kaufman et al. 2017).

One area of particular importance for continued research and monitoring is the Ross Sea Polynya, which has the highest primary production across all Antarctic waters (Gerringa et al. 2019, 2020). The RSR, especially waters overlying the Ross Sea continental shelf, experiences elevated spring and summer phytoplankton blooms as sea ice decreases and availability of light increases. These blooms play an important role in the marine carbon cycle. The seasonal phytoplankton bloom and the phytoplankton species assemblages in the RSR are dependent on nutrient availability. Dissolved nutrients, changes in temperature, and ice coverage could affect these assemblages (Smith et al. 2017; Ryan-Keogh et al. 2017; Smith and Kaufman, 2018; Smith et al. 2021). A better understanding about nutrient availability is required to accurately determine which nutrients limit sea-ice primary productivity and, therefore, affect the structure of the sympagic microbial community (Fripiat et al. 2017). Across the Southern Ocean, primary production is predominantly limited by iron and other dissolved metal availabilities (Alderkamp et al. 2019; Chen et al. 2021; Dinniman et al. 2020; Kaufman et al. 2018; Ryan-Keogh & Smith, 2021; Salomon et al. 2020; Schine et al. 2021; Smith, 2021; Tison et al. 2020). While the Ross Sea is a high productivity region compared to other Antarctic coastal regions, phytoplankton assemblages in the Ross Sea exhibit considerable spatiotemporal variability (Kaufman et al. 2018). The Ross Sea is projected to have reduced sea ice, a main source of dissolved iron, and longer periods of open water by 2100 (Salomon et al. 2020). Primary productivity in the Southern Ocean and the Ross Sea play a vital role in regulating global uptake of atmospheric carbon dioxide, and research on iron availability in the Ross Sea shows iron to be a limiting factor for primary productivity in this region (Arrigo et al. 2015; Tagliabue and Arrigo 2016; Oldham et al. 2021). Availability of dissolved iron therefore influences the impact of this carbon sink. Continued monitoring and research of iron uptake and availability in the Ross Sea is vital for our understanding of the Earth's changing climate and the impacts on the RSR ecosystem.

While extensive research on physical properties across the Ross Sea has been conducted for decades, continued monitoring of physical properties under the effects of climate change will be crucial for evaluating the efficacy of the RSRMPA. Moving forward, the use of climate models that incorporate the relationship between seasonal winds, sea-ice cover and sea-ice extent will improve predictions of sea-ice cover and extent across the Ross Sea region (Holland et al. 2017; Bronselear et al. 2018). Continued studies on sea-ice thickness and extent are recommended (Schlosser et al. 2018). As climate change and anthropogenic activities continue to affect Southern Ocean ecosystems, increased monitoring and scientific research on the physical properties of the RSR are warranted, some of which will continue to be greatly aided by deployed sensors and imagery from satellites. Our literature review on physical studies conducted in the RSR indicates that documenting the physical properties and continuing detailed characterization of baselines is necessary for the successful long-term monitoring of the ecosystem and the RSRMPA.

Ecological Papers

Relatively new research, built on decades-long foundation of older research, has provided insight into both Antarctic marine ecosystems in general and the RSR ecosystem specifically, and have also improved our understanding of the population dynamics, physiologies, and life histories of many Antarctic species. For example, researchers successfully deployed long-term, continuously recording passive-acoustic sensors near the Balleny Islands and in the Terra Nova Bay polynya to assess physical and biological trends in the region (Sukyoung et al. 2021). These sensors successfully detected physical dynamics such as changes in sea ice and katabatic winds, and coupled this information with spatial and temporal trends in the presence and abundance of a variety of marine mammals, confirming a relationship between these trends and sea-ice dynamics. Other studies have relied on innovations in tools and methodologies to test the efficacy of the RSRMPA in respect to fishing and toothfish populations. For example, Ashford et al. (2021) suggested a potential spillover of toothfish from the RSRMPA into areas outside of the MPA. However this effect could be compromised if some of the hypothesized dispersal pathways and areas key to toothfish life cycle remain vulnerable to fishing (e.g., Iselin Bank, as well as the Pacific-Antarctic Ridge and Amundsen Sea, respectively) (Ashford et al. 2021). Remote sensing technology, simultaneous with on-the-ground research, has also played a large role in improving our understanding of population dynamics for Antarctic seal and penguin species. For example, Very High Resolution (VHR) satellites, coupled with crowdsourcing and citizen science, have been used successfully to analyze Weddell seal populations in the RSR. (LaRue et al. 2019a; LaRue et al. 2019b; LaRue et al. 2021). The application of new tools to study species within the boundaries of the RSRMPA facilitates management that may be adaptive and responsive to the combined effects of climate change and fisheries operating within and along the boundary of the RSRMPA.

Fish and Krill

There continues to be debate over the potential ecological and population level effects of the Antarctic toothfish fishery in the Ross Sea, including debate about the presence of large toothfish in McMurdo Sound. Ainley et al. (2013, 2016) detected a decrease in the abundance of large Antarctic toothfish in McMurdo Sound, with the remnant standing stock occupying deeper waters than in previous decades, as a result of both the fishery and recovering populations of Weddell Seals (Ainley et al. 2020). Ainley et al. (2017, also Lyver et al. 2014) further proposed that the dramatic growth in penguin populations in the southern Ross Sea since about the year 2000 could be the result of an increase in Antarctic silverfish and decreased competition among mesopredators, owing fewer competing toothfish in the water column. Indeed, Parker et al. (2016) show that large, old toothfish can now only be reliably caught in McMurdo Sound at depths greater than 500 m, whereas in the 1970-1990s large toothfish could be caught with high catch per unit effort (CPUE) at depths of 300 m or less (Ainley et al. 2020). Parker et al. (2019) contend that large toothfish from McMurdo Sound may mix with the wider Ross Sea toothfish population to only a limited extent. Ashford et al. (2017) built on these arguments, noting that transport pathways may also contribute to the variation observed in toothfish presence; Ainley et al. (2020) point out the depression in toothfish prevalence where predatory seals congregate. All authors agree on the need for continued monitoring using a spatially stratified, standardized approach (Ainley et al. 2016, Parker et al. 2016, Ashford et al. 2017). This is in agreement with others (e.g., Abrams et al. 2016) who also emphasized the need for a comprehensive ecosystem monitoring program to ensure precautionary management for toothfish, including using Weddell seals as an indicator species for ecosystem management (Ainley et al. 2020) and testing the efficacy of the RSRMPA (Parker et al. 2019). Further, while fisheries may drive changes in Ross Sea fish productivity, climate change presents an immense challenge in assessing future changes and compounds risks to Antarctic toothfish (Caccavo et al. 2021).

Several species at middle trophic levels are important to Southern Ocean food webs, with research in the Antarctic Peninsula region showing, at least in some respects, how sea-ice cover and persistence in response to climate change might affect one of these species, Antarctic krill. In the Ross Sea (which is considered to be one of the few sea-ice refugia should climate change continue its current trajectory), Antarctic krill, crystal krill, and Antarctic silverfish are the three key mid-trophic level species connecting primary production to the upper trophic levels. Davis et al. (2017) suggest that these species occupy different habitats determined by environmental conditions, with the habitat of Antarctic krill being distinct from that of crystal krill and silverfish. Antarctic krill concentrate along the shelf break, in a habitat characterized by relatively great bottom depth (>1000 m) and warm temperature (1-1.25°C), owing to upwelling of circumpolar deep water (CDW). The portion of this habitat along the western shelf break was also determined to be particularly important in the results of a particle tracking study (Pinones et al. 2016); the boundary of the RSRMPA's General Protection Zone (GPZ) bisects this important habitat. Crystal krill and Antarctic silverfish occur over the shelf, and are associated with sea ice, with specific spawning areas identified at least in Terra Nova Bay and the Bay of Whales, where efforts were made in search of eggs and larvae, and common characteristics of the habitat are coastal proximity and relatively cold temperature (-1.75 to -2°C). Those are temperatures, along with frazil ice, that emerge from beneath ice shelves. Predicted further warming (post-2050 in the Ross Sea) and other climate change related effects could affect these key species significantly (Davis et al. 2017). Additionally, the contribution of Antarctic krill to Southern Ocean carbon cycling should be considered in future studies and monitoring due to their extraordinarily high biomass in the Southern Ocean (D'Sa et al. 2021). Larval silverfish, which hatched much later in the season, were also found in the eastern Ross Sea (Bay of Whales), with Brooks et al. (2018) suggesting the presence of a geographically separate population or westward connectivity from the Amundsen Sea. Larval silverfish have also been detected in McMurdo Sound.

Recent studies in the Ross Sea provide new insights into Southern Ocean fishes. For example, Eastman et al. (2020) emphasized that the pelagic biotope of Notothenioid fishes is habitat for just a few species, including the Antarctic toothfish and Antarctic silverfish due to their capacity for neutral buoyancy. Their high lipid content and occupation of the water-column biotope make these two fishes disproportionately important to upper trophic level predators. Further, Antarctic toothfish occupation of the water-column biotope may not be constant, but perhaps dependent on the availability of lipid-rich Antarctic silverfish as prey (Eastman et al. 2020). Comprehensive studies on global drivers for change in the Southern Ocean (*e.g.*, Morley et al. 2020) also indicate that changes in temperature, sea ice, and salinity will have direct effects on fish species across the Ross Sea region.

Penguins and Petrels

The RSR is a crucial breeding and foraging habitat for Antarctic seabirds. Known prior to establishment of the RSRMPA, about 30% of the world population of Antarctic petrels foraged along the eastern Ross Sea slope (van Franeker et al. 1999; Ballard et al. 2012). Recent research suggests that there may be a significant number of breeding colonies in Victoria Land, on the western side of the Ross Sea, as well as Marie Byrd Land on the eastern side (Schwaller et al. 2018). Their current population status is unknown. On the other hand, around the year 2000, several penguin populations began to increase, including Adélie penguins breeding at Cape Crozier, Cape Bird, and Beaufort Island (Ainley et al. 2018), and emperor penguins breeding at Cape Crozier and Beaufort Island (Kooyman & Ponganis, 2017; Schmidt & Ballard 2020).

A recent study indicates that emperor penguin colonies exhibit large annual variations in breeding population size, with chick abundance and survivorship being linked to fast ice persistence and local weather conditions (Kooyman and Ponganis, 2017; Schmidt and Ballard, 2019). The GPZ fully contains important foraging habitats for emperor penguins during the chick-rearing season (Kooyman et al. 2018, 2020), including multiple marginal ice zones and polynyas that support thriving biological hotspots and primary production (Saenz et al. 2020) plus two complete and part of a third “Areas of Ecological Significance” (AESs) for air-breathing predators (Hindell et al. 2020). Data indicate that non-breeding (post-moult) emperor penguins forage widely throughout the eastern RSR, with some foraging occurring within the GPZ and Special Research Zone (SRZ) and some foraging occurring outside the RSRMPA, with possible differences in diet among these areas (Goetz et al. 2018).

Results from research published since 2016 indicate that evaluating the efficacy of the RSRMPA will require careful thought. Adélie and emperor penguin abundances should continue to be monitored regularly and throughout the RSR to adequately characterize the frequent and variable colony-specific responses to change (Kooyman and Ponganis, 2017; Santora et al. 2020). Additionally, due to individual- and colony-specific variations in foraging ranges, the tracks from a few individual penguins may not be representative of habitat use by individuals from understudied colonies (Santora et al. 2020), and foraging range continues to be investigated at a number of RSR colonies.

Seals

Although one of many pinniped species in the region, Weddell seals are the most studied seal species of the RSR as they are year-long residents of the Ross Sea. Similar to the previously mentioned penguins that breed on Ross Island, the abundance of Weddell seals in Erebus Bay, McMurdo Sound, began to increase in about the year 2000 (Ainley et al. 2020), prior to the establishment of the RSRMPA, and continues increasing to this day. Long-term data on Weddell seals in Erebus Bay continue to inform our understanding of this population (Patterson et al. 2018; Macdonald et al. 2020), while new discoveries are still being made. For example, Cziko et al. (2020) reported the first recording of ultrasonic vocalizations in this species. Much of the focus on the Weddell seal is due to the fact that it is an excellent model organism for studying the food web in the RSR ecosystem. Weddell seals have been used to investigate the physiology of large mammals (Kooyman et al. 2020), and to collect oceanographic and atmospheric data that relate to RSR ecology by using satellite tags (Piñones et al. 2019). Weddell seals seem to be noticeably affected by climate change, as environmental changes can affect seal reproductive success (Beltran et al. 2020) and pup survival (Rotella et al. 2016). The potential climate-related effects on seal populations may be compounded by the effects of fisheries if toothfish removals reduce prey availability for seals (Salas et al. 2017) and subsequently reduce seal body mass (Beltran et al. 2017). The seals’ diet includes a significant proportion of both Antarctic toothfish and silverfish, the interaction being a prime example of “intraguild predation” (Ainley et al. 2020).

Whales

Antarctic minke and type-C killer whales (also known as Ross Sea killer whales) occur within the RSR, and are most commonly observed in the southwestern Ross Sea (Ainley et al. 2017; Ainley et al. 2020; Lauriano et al. 2020). There are a few population clusters of type-C killer whales in the southwestern Ross Sea (Pitman et al. 2018; Lauriano et al. 2020), and, although their prevalence (apparent abundance) was decreasing along the outer Ross Island coast, it seems unlikely that their population size had been changing prior to establishment of the RSRMPA (Ainley et al. 2017, Pitman et al. 2018). The RSRMPA GPZ fully encompasses several regionally known coastal feeding areas of type-C killer whales (*e.g.*, Lauriano et al. 2020).

The movements of Antarctic minke whale and type-C killer whale populations are linked to sea-ice cover (Ainley et al. 2017), with coastal observations of whales generally increasing as sea ice retreats in the southern Ross Sea. Minke whales, feeding on krill and to a lesser extent silverfish, move between dense prey patches to forage, remaining in a patch to feed for several days at a time (Ainley et al. 2020), while type-C killer whales feed on various fish species including toothfish and silverfish (Lauriano et al. 2020). Even in small numbers, Antarctic minke whales measurably affect penguin foraging due to competition for prey (Ainley et al. 2017; Ainley et al. 2020), which should be considered when evaluating future population trends.

Antarctic Benthos and Undersea Fauna

With increased research, and aid from technological advancements, Ross Sea scientists have continued to document the population dynamics of benthic fauna (Bowser et al. 2019; Chakrabarty et al. 2021; Dayton et al. 2019; Kim et al. 2021; Lenihan et al. 2018; Palmer et al. 2021; Wing et al. 2018), an avenue of research that began decades ago. This has revealed decadal patterns of community change, led to continued discovery of new species, and resulted in better understanding of the relationship between physical aspects of habitat and benthic communities on the Ross Sea shelf. New population surveys on undersea fauna in the Ross Sea have led to the identification of over 1,000 organisms (Chakrabarty et al. 2021), including corals, fishes, sea stars, spiders, and sponges (Kim et al. 2019; Moran et al. 2018; Szuta et al. 2018). High resolution undersea images from the Ross Ice Shelf show a diverse community of life that was largely unknown and may reveal new ecological insight (Chakrabarty et al. 2021).

Understanding how benthic communities will respond to changes in their physical habitats, i.e. sea ice cover, intrusion of water masses with different temperature signatures, linked with climate change will be useful to inform management decisions relating to the RSRMPA. Indeed, CCAMLR designates some benthic communities, as indicated by the presence of specific species, as vulnerable marine ecosystems (VMEs) and generally prohibits longline fishing at depths shallower than 550 m. Warming temperatures can have lethal effects on benthic species that have low thermal tolerances, and can also increase competition from non-native species (Brasier et al. 2021). Long-term monitoring should continue, as it will be necessary to detect and prepare for changes in benthic populations that are attributed to climate change and yet to be identified (Bowser et al. 2019; Brasier et al. 2021; Dayton et al. 2019; Palmer et al. 2021). The diverse set of studies included in this literature review can provide a useful inventory of benthic fauna that can be monitored to examine any potential changes through the years.

ONGOING RESEARCH

There are currently 18 active, U.S.-funded grants supporting research taking place partially or fully in the RSR: 16 funded by the U.S. National Science Foundation (NSF) and two funded by the U.S. National Aeronautics and Space Administration (NASA). All of these directly or indirectly relate to the RSRMPA. Additionally, there are six recently expired NSF grants that, as of yet, may not have reported or published outcomes. The active grants span three general disciplines: physical science, primary productivity, and animal ecology or biology. The physical science research mainly focuses on changing physical conditions in response to a variable climate. Specifically, the research includes meteorology and atmosphere-ocean general circulation models, variability in sea ice and ice sheets, the Ross Gyre’s exchange with the Antarctic Circumpolar Current (ACC), and processes controlling dissolved iron and carbon sequestration in the Ross Sea. Two active grants are being used to investigate the highly biologically productive Ross Sea polynyas and model the impacts of climate change. The animal ecology and biology studies constitute the majority of active grants. These grants are being used to investigate the following: Adélie and emperor penguin ecology, especially as it relates to changing sea ice and environmental conditions, Adélie and emperor penguin foraging relative to spatial variation in the preyscape, environmental and social factors affecting pup survivorship of Weddell seals, the microbial community in parts of the Ross Sea, and changes in benthic marine invertebrates related to past and present environmental variability. One NASA grant in particular is specifically related to the RSRMPA. This grant, to Principal Investigator Dr. Grant Ballard, is entitled “Opening the Black Box - Integrating Winter Ecology into the Management of the RSR Marine Protected Area”, and the funded research aims to fill in considerable knowledge gaps related to the foraging patterns of RSR Adélie penguins over the winter months.

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New Zealand research and monitoring in the Ross Sea region in support of the Ross Sea region Marine Protected Area: 2022 update

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Abstract

In 2016 the Commission adopted Conservation Measure (CM) 91-05, establishing the Ross Sea region Marine Protected Area (RSrMPA). This paper summarises the research and monitoring activities for New Zealand that are relevant to the Ross Sea region Marine Protected Area, as required by CM 91-05 paragraph 16(i)–(ii).

Over the last 5 years New Zealand has carried out research in the Ross Sea region on subjects directly relevant to the specific objectives of the RSrMPA and in areas including the Ross Sea continental shelf, Ross Sea slope (open areas, General Protection Zone, Special Research Zone), and in the northern region (including seamounts on the Pacific Antarctic fracture zone, Scott Seamount). New Zealand research has included new work on the following topics: (1) Physico-chemical-cryogenic environment; (2) Bio-regions (representative areas); (3) Carrying capacity (phytoplankton, primary production and microbial energy flow); (4) “Keystone” organisms (including krill, silverfish, myctophids, zooplankton, cephalopods); (5) Krill predators (Adélie and emperor penguins, Antarctic minke whales); (6) Toothfish predators (Type-C Weddell seals, killer whales, sperm whales); Toothfish prey (macrourids, icefish, deep-sea cods, morid cods, squid); (8) Antarctic toothfish (biology, ecology, diet, movement, spawning/early life-history); (9) Bycatch species (especially skates, macrourids, icefish); (10) Vulnerable benthic ecosystems (structure-forming benthic invertebrates).

Recent New Zealand research of direct relevance to evaluating the effectiveness and conservation value of the RSrMPA has included: three multidisciplinary research voyages to the Ross Sea region from the research vessel *Tangaroa*; satellite and video tagging of Weddell seals and emperor penguins; annual censusing of Adélie penguins at Ross Island; winter research fishing voyages to study early life-history stages for toothfish; multispecies spatial population of toothfish and prey; bi-annual monitoring of zooplankton communities between New Zealand and the Ross Sea; sea-ice structure and change; evaluation of Earth-system model projections for future change in the Ross Sea region; development of acoustic mark identification approaches; bycatch characterisation; modelling of environmental drivers of benthic habitat forming species. Throughout, this work has been presented to CCAMLR working groups, published in the primary literature or is in the process of being so disseminated. In addition, New Zealand has been developing scientific and strategic plans for research over the next 5 years to contribute to the 10 years RSrMPA review in 2027.

Introduction

In 2016 the Commission adopted Conservation Measure (CM) 91-05, establishing the Ross Sea region Marine Protected Area (RSrMPA), which came into effect in December 2017. CM 91-05 paragraph 15 requires that every five years Members shall submit to the Secretariat, for review by the Scientific Committee, a report on their activities conducted according to, or related to, the MPA Research and Monitoring Plan, including any preliminary results.

In this paper, we summarise recent research and monitoring activities by New Zealand relevant to the RSrMPA. A spreadsheet accompanies this report which details New Zealand research projects to identify specific datasets and Principal Investigators.

RSrMPA specific objectives, categories and research questions

The specific objectives of the RSrMPA are (CM-91-05 paragraph 3):

(i) *to conserve natural ecological structure, dynamics and function throughout the Ross Sea region at all levels of biological organisation, by protecting habitats that are important to native mammals, birds, fishes and invertebrates;*
(ii) *to provide reference areas for monitoring natural variability and long-term change, and in particular a Special Research Zone, in which fishing is limited to better gauge the ecosystem effects of climate change and fishing, to provide other opportunities for better understanding the Antarctic marine ecosystem, to underpin the Antarctic toothfish stock assessment by contributing to a robust tagging program, and to improve understanding of toothfish distribution and movement within the Ross Sea region;*
(iii) *to promote research and other scientific activities (including monitoring) focused on marine living resources;*
(iv) *to conserve biodiversity by protecting representative portions of benthic and pelagic marine environments in areas where fewer data exist to define more specific protection objectives;*
(v) *to protect large-scale ecosystem processes responsible for the productivity and functional integrity of the ecosystem;*
(vi) *to protect core distributions of trophically-dominant pelagic prey species;*
(vii) *to protect core foraging areas for land-based top predators or those that may experience direct trophic competition from fisheries;*
(viii) *to protect coastal locations of particular ecological importance;*
(ix) *to protect areas of importance in the life cycle of Antarctic toothfish;*
(x) *to protect known rare or vulnerable benthic habitats; and*
(xi) *to promote research and scientific understanding of krill, including in the Krill Research Zone in the north-western Ross Sea region*

The specific objectives for the RSrMPA are expanded in 91-05/Annex B, and fall into three main categories: representativeness, threat mitigation and scientific reference areas (CM 91-05, Annex 91-05/C, paragraph 2). We restate these here as context to the reporting of New Zealand research.

Representativeness

Research and monitoring to assess whether the MPA is protecting an adequate proportion of all benthic and pelagic environments in the Ross Sea region. Objective (iv) seeks to protect a representative proportion of each benthic and pelagic bioregion. Bioregions were defined with reference to environmental or physical habitat variables (e.g., depth, sea surface temperature) that are themselves unaffected by fishing activity; for this reason fishing cannot pose a 'threat' to the bioregions themselves; rather the bioregion is a proxy for the underlying biology and ecology that could be affected by fishing but for which particular threat mechanisms may be *unknown. The commitment to protect a minimum representative portion of each bioregion therefore reflects precautionary management in data-poor areas or in habitats for which no specific threat mechanisms are identified (SC-CAMLR-IM-I/09).*

Threat mitigation

Research and monitoring to assess the extent to which threats to the achievement of Article II.3 and the specific objectives of this MPA are being effectively avoided or mitigated by the MPA, in locations where the risk of ecosystem impacts from harvesting activities may otherwise be high.

Objectives (i) and (v)-(x) are to avoid or mitigate potential ecosystem threats from fishing. The level of protection for each feature (i.e., the proportion of the feature included in the MPA) was described in WS-MPA-11/25 (Sharp & Watters, 2011) and SC-CAMLR-IM-I/09, and was set as proportional to its relative ecological importance and to the extent to which existing or potential future fishing activities in the location of the feature may be expected to exert an ecosystem impact. The level of protection was dependent on the particular type and mechanism of plausible threat: where threats are potentially severe, unpredictable and/or irreversible, near 100% protection of the priority area or feature may be required to guarantee accordance with the terms of the CCAMLR Article II(3); for other threats, protecting only a portion of the priority area or feature was considered sufficient (SC-CAMLR-IM-I/09). For the RSrMPA objectives defined to mitigate threats, plausible threats were identified in the design of the MPA (SC-CAMLR-IM-I/09).

Scientific reference areas

Research and monitoring where the MPA provides opportunities to examine Antarctic marine ecosystems where no or limited fishing has taken or is taking place, to understand, for example, the effects of fishing, environmental variability and climate change on Antarctic marine living resources. Objectives (ii), (iii) and (xi) are to provide for scientific reference areas, allowing opportunities to study marine ecosystems free from human interference (CM 91-04, paragraph 2(iii)), and/or to compare areas in which sustainable harvest is occurring with comparable areas in which no (or greatly reduced) fishing occurs, to better understand and distinguish between the effects of fishing and of other influences, including climate change (SC-CAMLR-IM-I/09). Scientific research and monitoring priorities associated with the RSrMPA are specified in CM 91-05 Annex C. This states that research and monitoring should seek to address the following questions (CM 91-05 Annex C paragraph 1):

- *(i) Do the MPA boundaries continue to adequately encompass the priority populations, features and areas included pursuant of the MPA objectives?*
- *(ii) What are the ecosystem roles of the identified habitats, processes, populations, life-history stages, or other priority features?*
- *(iii) How are the priority features potentially affected by fishing, climate change, environmental variability, or other impacts?*
- *(iv) Does the structure and function of the marine ecosystem differ between areas inside the MPA and areas outside the MPA, or do the populations or subpopulations of marine organisms that occur or forage inside the MPA differ from those that occur or forage outside the MPA?*

New Zealand research and monitoring: 2022 update

The present paper summarises New Zealand research in the Ross Sea region associated with the MPA to June 2021, and updates the earlier summaries submitted to CCAMLR (Pinkerton & Scarrow 2018; Delegations of New Zealand and Italy, 2020; Pinkerton, 2020; Pinkerton, 2021).

The New Zealand research activities were mapped onto the specific objectives of the RSrMPA and are summarised in Figure 1. A brief summary of recent New Zealand research is given next, giving some highlights and initial results.

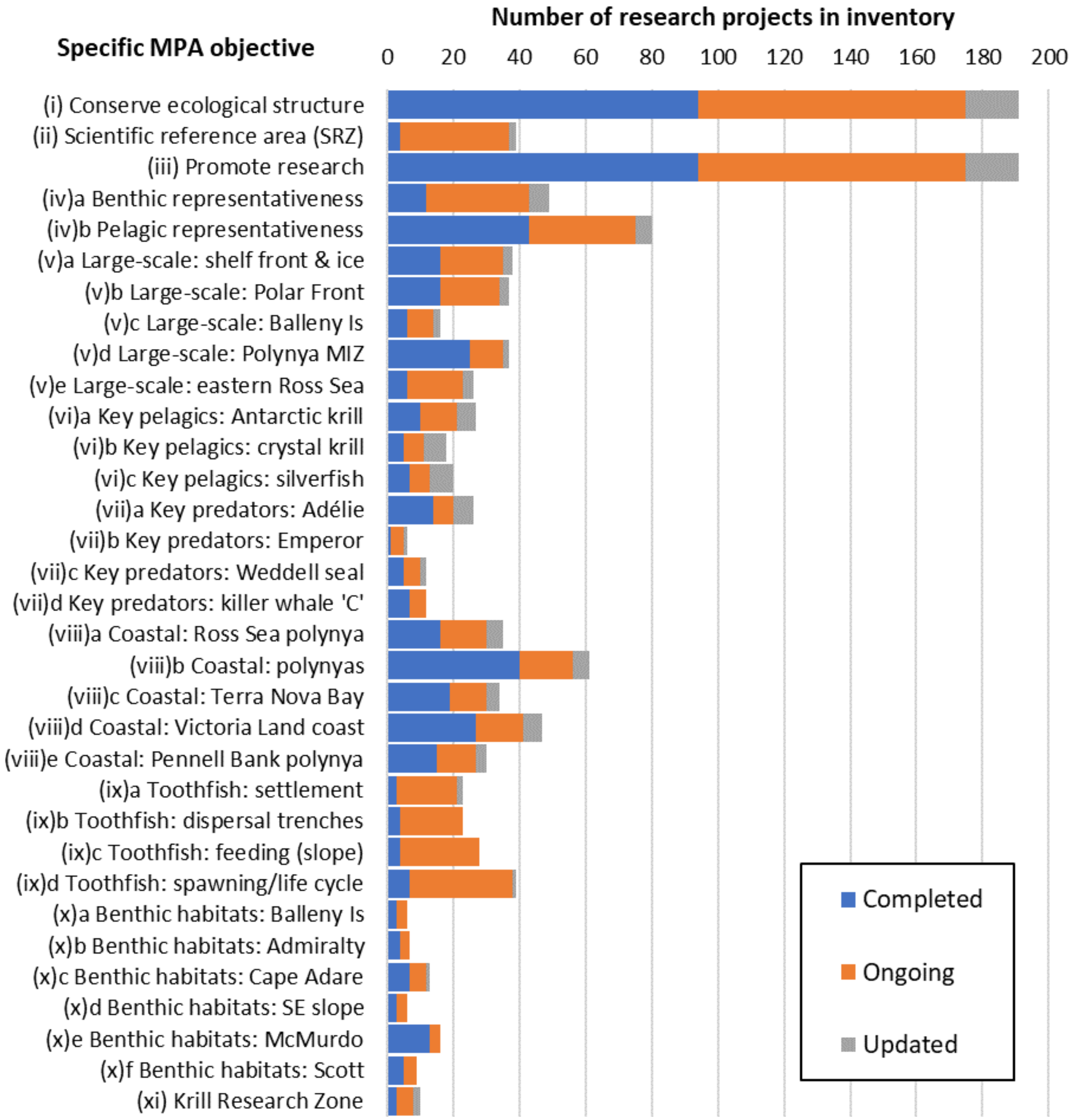

Figure 1. Summary of New Zealand research projects in the Ross Sea region by specific objective of the Ross Sea region MPA (CM 91-05, paragraph 3). 'Completed' projects are those for which no further work is underway or planned at present. 'Ongoing' projects are those which are still active, but for which the summary information included here has not changed since the last report to CCAMLR (Pinkerton, 2021). 'Updated' projects are new projects or those where the information in this report have changed since the last report to CCAMLR.

New Zealand identification codes

In the spreadsheet of New Zealand activities provided to CCAMLR Secretariat, we have provided a column of codes ("NZ identification code"). These New Zealand identification codes should be specified if CCAMLR members are seeking to collaborate with New Zealand researchers, access the available data or find the specific results as they will help to uniquely identify the research activities. These identifications largely follow funding mechanisms; a brief explanation is given here:

- Research voyages: These are identified by the New Zealand research voyage identifier, for example: "**TAN2101**" which indicates TAN=research vessel (RV *Tangaroa* in this case), year "21" (i.e. 2021), voyage number that year "01"
- Field events supported by Antarctica New Zealand, usually from Scott Base, for example "**K850-1920-A**". This code gives the Antarctica NZ event number ("K850" which may be a multi-year project), the season of the fieldwork ("1920" was carried out in the 2019-2020 Antarctic season), and the subevent number ("A") where there are multiple activities under one event.
- Fisheries-specific research funded by the New Zealand Ministry for Primary Industries / Fisheries New Zealand (FNZ), for example, "**ANT_eelcod_antimora**". Here, "ANT" indicates FNZ funding, and the text gives a summary of the focus. These projects may span multiple years, are usually based on fisheries data, and results are typically provided to CCAMLR as a working group papers.
- Other research projects: Several other Antarctic research projects are funded by the Ministry of Business Innovation and Employment (MBIE) through the Endeavour grant scheme (Ross-RAMP), through the Antarctic Platform (ASP), as part of the Strategic Science Investment Fund (SSIF) or the Marsden Research Fund. Additional funding was also provided through the New Zealand Antarctic Research Institute (NZARI) which included philanthropic funding.

New Zealand research results from the first 5 years of the Ross Sea region MPA

Over the first 5 years of the Ross Sea region MPA, New Zealand has carried out research on the following subjects relevant to assessing the performance of the MPA against its specific objectives. We organise this New Zealand research according to the following headings.

1. Physico-chemical and cryogenic environment
2. Bio-regions (representative areas)
3. Carrying capacity (primary production and microbial energy flow)
4. Keystone species (krill, silverfish, myctophids, zooplankton, cephalopods)
5. Krill predators (Adélie and emperor penguins; Antarctic minke whales)
6. Toothfish predators (Weddell seals, Type-C killer whales, sperm whales)
7. Toothfish prey (macrourids, icefish)
8. Antarctic toothfish (the fishery's target-species)
9. Bycatch species (skates)
10. Vulnerable benthic ecosystems (structure-forming benthic invertebrates).

These New Zealand research projects span the MPA objectives as shown in Figure 1 and according to the associated spreadsheet which has been provided to the CCAMLR Secretariat.

1. Physico-chemical environment

New Zealand has studied the physical, cryogenic and biogeochemical oceanography of the Ross Sea region, using moorings, research voyages, autonomous instruments (such as drifters), and field studies from Scott Base (Figure 2). Antarctic sea ice is a key element in the global climate system and provides an essential habitat for Ross Sea species at the micro- (e.g. platelet ice matrix) and macro- (e.g. breeding, moulting habitat for penguins and seals) level. In addition, sea ice provides a spawning habitat for Antarctic silverfish and supports sea ice algae. Sea ice algae have a crucial ecological role as a food source for juvenile Antarctic krill and silverfish (Pinkerton & Hayward, 2021).

The distribution, dynamics, and structure of sea ice are likely to be the single largest determinant of ecosystem productivity in the Ross Sea region. New Zealand has been studying sea-ice at the small and large scales for many years (Stevens et al. 2018). At the smaller scale, there is an active New Zealand research community focussed on understanding the geophysics of sea ice in the Ross Sea. In particular, over the last 5 years, the first Antarctic study of sea ice thickness using electromagnetic measurement techniques from fixed wing aircraft were conducted as part of the New Zealand "Deep South National Science Challenge" (Rack et al. 2021; Haas et al., 2020). At the larger scale, New Zealand research has progressed satellite- and model-based estimates of sea ice concentration and thickness (Brett et al. 2021; Wongpan et al., 2021). The Ross Sea Polynya is the largest polynya in the Southern Ocean, and the focus of ongoing research (e.g. Stewart et al., 2019). There is substantial effort directed at measuring freezing water *in situ*, which poses methodological challenges (Robinson et al. 2020). This point is important because it appears that long-term records can be biased by ice crystals aggregating on sensors. In terms of sampling hydrography and sea ice more widely, animal-borne sensors have also been used to improve estimates of regional sea ice thickness (Frazer et al., 2018) and Argo floats are now regularly being deployed on the Ross Sea continental slope.

Three 40-day research voyages from the New Zealand research vessel Tangaroa in 2018, 2019 and 2021 have measured a suite of physical and biogeochemical properties of the Ross Sea region. These new marine data add to the information from previous New Zealand voyages to the region, in 2008, 2013, and 2015, and are supplemented by a sequence of mooring initiatives (Figure 2**Error! Reference source not found.**). A particular focus has been on deep-bottom water formation and fluxes in the Cape Adare region of the Ross Sea (Bowen et al. 2021), and numerical circulation modelling, especially the Ross Sea Gyre structure and climate evolution (Rickard & Behrens, 2016). The bottom water work is finding a significant effect due to long-term modulation in tides. Collaborative work with other national programs continues with a focus on polynya processes that affect both sea ice and bottom water production (Yoon et al. 2019; Stewart et al. 2019) This is finding variability within polynya and also quantifying the effect of large floating glaciers such as the Drygalski Ice Tongue that influence local circulation and air-ice-ocean mechanics. The data sets, as well as numerical model outputs, are being continually updated in a data synthesis "live-report" (Fernandez, 2021). There is also an on-going New Zealand contribution to international efforts to gauge changes in Ross Sea salinities (Bowen et al. 2021).

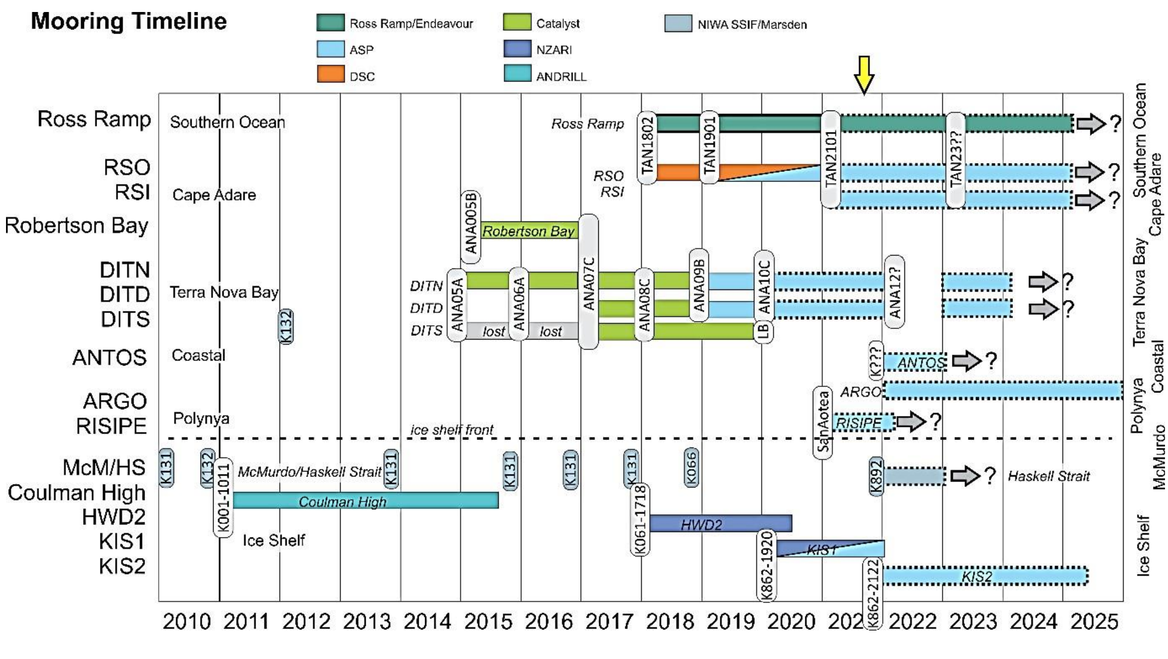

Figure 2. Summary of New Zealand hydrographic and instrumented mooring in the Ross Sea region. Acronyms[1]

[1] ASP=Antarctic Science Platform; DSC=Deep South National Science Challenge; NZARI=New Zealand Antarctic Research Institute; ANDRILL=Antarctic Drilling Project; SSIF=New Zealand Strategic Science Investment Fund; Marsden=Marsden Fund of the Royal Society of New Zealand. TAN1802, TAN1901 and TAN2101 are research voyages on the New Zealand research vessel *Tangaroa*. Fieldwork from

2. Bio-regions (representative areas, connectivity)

New Zealand has advanced research on bio-regionalisation as a way of investigating the extent to which MPAs deliver adequate, representative and comprehensive protection. The research has had three main parts: (1) analysis of data from satellites and hydrodynamic (hindcast) models to assess regions of environmental change (Pinkerton, 2019); (2) evaluating and selecting an "inner" set of Earth-system models to forecast changes in the Ross Sea region due to climate change (Behrens & Rickard & Behrens, 2016; Rickard et al., 2022); and (3) advancing end-to-end ecosystem models to explore changes in food-web structure and dynamics across the Southern Ocean (Hill et al., 2021).

Satellite data and the data-assimilating numerical models reveal complex and heterogenous patterns of oceanographic change in the Southern Ocean since 1981 (Pinkerton, 2019). Knowledge of large-scale, climate-driven variation is needed in the context of evaluating the role of the RSrMPA because climate change and fishing effects may act synergistically. Key results are: (1) warming of the ocean surface north of the southern limit of the Antarctic Circumpolar Current (ACC) and slight cooling nearer to the Antarctic continent; (2) evidence of small movement north of the Subantarctic Front; (3) increasing concentration of chlorophyll-a (chl-a) and modelled net primary production (NPP) in the Subantarctic Front and around the southern limit of the ACC except in the Ross Sea region; (4) decreasing chl-a and NPP in the Ross Sea sector and on parts of the Antarctic continental shelf over the last 20 years; (5) gradual loss of sea-ice in the Amundsen Sea and increasing sea-ice in the Weddell, Bellingshausen and Ross Seas; (6) deepening of the mixed-layer near the Polar Front, contrasting with shallowing of the mixed layer in the Ross Sea region (Porter et al. 2019), and both increases and decreases in mixed layer depth in the Weddell Sea; (7) small increasing trends in incident light intensity in Subantarctic waters and generally decreasing trends near the Antarctic continent.

New Zealand has been active in using information from multiple Earth-system models to understand future trajectories of change. A knowledge of climate-driven change is required to understand the conservation value of the Ross Sea region MPA. Building on research for the CMIP-5 set of models (Rickard & Behrens, 2016), New Zealand researchers are exploring the CMIP-6 Earth-system models of the Southern Ocean. By evaluating the performance of different Earth-system models again in situ and satellite measurements of physical, biogeochemical and biological data, New Zealand researchers have identified consistencies and differences between modelling approaches and, on that basis, can recommend the most reliable set of models to project future change (Rickard & Behrens, 2016; Rickard et al., 2022). New Zealand has also significantly contributed to international efforts reviewing the effects of climate variability and change on Southern Ocean ecosystems (e.g. Gutt et al. 2021; McCormack et al., 2021) including acidification (e.g. Figuerola et al., 2021) and connectivity (e.g. Murphy et al., 2021).

Ecosystem models in general are highly under-constrained, meaning that there is substantial ambiguity and uncertainty in food-web structure. This limits our ability to anticipate the ecosystem effects of climate change and fishing, and to assess the conservation value of large MPAs. In an international study including researchers from New Zealand, UK, France, Canada and Portugal, methods were developed to address the challenge of distinguishing between actual differences in food-web properties and apparent differences due to imperfect data and the vagaries of the particular modelling approach chosen (Hill et al., 2021). We found that differences in food-web structure between regions persisted when model "personality" was removed, implying real regional differences in ecosystem structure which underpin differences in function. Our work concludes that existing regional models are therefore a useful resource for comparing ecosystem structure, function and response to change if comparative studies assess and report the influence of model personality (Hill et al., 2021). Ongoing work in New Zealand will reduce ambiguity in food-web models further by using stable isotope data as an additional constraint on model balancing.

Scott Base is indicated by the event number, "Kxxx-yyyy" where xxx is a number and yytt is the Antarctic season (year). RSO=Ross Sea Outflow mooring line; RSI=Ross Sea Inflow mooring line; DITN=Drygalski North mooring location; DITS=Drygalski South mooring location; DITD=Drygalski Deep mooring location; ANTOS=Antarctic Near-Shore and Terrestrial Observation System; RISIPE=Ross Ice Shelf Integrated Polynya Experiment; HWD2=HotWater Drill Site 2 ; KIS1/2=Kamb Ice Stream; McM/HS= McMurdo/Haskell Strait.

3. Carrying capacity (primary production in the Southern Ocean)

Measurements of microbial communities were made on the 2018, 2019 and 2021 voyages to the Ross Sea, including bio-optical characterisation, size-based metrics, phytoplankton pigments, productivity rates, and loss terms (grazing rates). Analyses of these data have been published (e.g. Llopis Monferrer et al., 2021) or are in progress. Modelling of upper ocean microbial processes in the Ross Sea region is also an active area of research in New Zealand.

Patterns of change in primary producers in the Southern Ocean over the period of satellite observation (last 20 years) have been summarised under the framework of the Marine Ecosystem Assessment for the Southern Ocean (MEASO). Pinkerton et al. (2021) brought together analyses of recent trends in phytoplankton biomass, primary production and irradiance at the base of the mixed layer in the Southern Ocean and summarises future projections. Satellite observations suggest that phytoplankton biomass in the mixed-layer has increased over the last 20 years in most (but not all) parts of the Southern Ocean, whereas primary production at the base of the mixed-layer has likely decreased over the same period. Different satellite models of primary production (chl-a versus carbon-based) give different patterns and directions of recent change in net primary production (NPP). At present, the satellite record is not long enough to distinguish between trends and climate-related cycles in primary production. Over the next 100 years, Earth system models project increasing NPP in the water column in the MEASO northern and Antarctic zones but decreases in the Subantarctic zone. Low confidence in these projections arises from: (1) the difficulty in mapping supply mechanisms for key nutrients (silicate, iron); and (2) understanding the effects of multiple stressors (including irradiance, nutrients, temperature, pCO_2, pH, grazing) on different species of Antarctic phytoplankton. There are likely to be changes to the seasonal patterns of production and the microbial community present over the next 50–100 years (Pinkerton et al., 2021). These changes will have ecological consequences across Southern Ocean food-webs, especially on species such as Antarctic krill and silverfish (McCormack et al., 2021). Another important unknown is the magnitude of the feedback loop between baleen whales and marine productivity.

In addition to primary production in the water column, Pinkerton & Hayward (2021) developed an index of primary production by sea ice algae in the Southern Ocean and used this to track change in ice algal production. Sea ice algae in the Southern Ocean have strong ecological and biogeochemical significance; they provide a lipid-rich food-resource to keystone species such as Antarctic krill and are hence a key link between sea ice dynamics and large-scale ecosystem productivity. This means that being able to estimate seasonal and interannual changes in ice algal production at the Antarctic circumpolar scale is an important step forward. Application of the new method suggests that between 1987–2017, Antarctic ice algal production has generally increased with the largest increases seen off East Antarctica, the Weddell Sea, and the western Ross Sea.

4. Keystone species and groups

Middle-trophic level organisms are a crucial, diverse and typically poorly-known component of Southern Ocean food webs. New Zealand has focussed on those components of the food-web that link the microbial system with higher-level predators (such as seabirds, marine mammals and demersal fish) and which typically have higher trophic importance than would be expected from their biomass alone. In the Ross Sea region (as elsewhere in the Southern Ocean), these "keystone" organisms include krill, Antarctic silverfish, myctophids and mesozooplankton (Pinkerton et al., 2010; Pinkerton & Bradford-Grieve, 2014; McCormack et al., 2021).

On all recent New Zealand voyages to the Ross Sea region New Zealand has used multifrequency (fishery) acoustic sensors (18, 38, 70, 120, 200 kHz) to measure patterns of occurrence of mesopelagic species including Antarctic and crystal krill, silverfish and myctophids (Escobar-Flores et al. 2018a,b; 2019). In addition, we have deployed and recovered acoustic sensors on mooring on the Victoria Land coast to study the seasonal cycle of mesopelagic organisms, including silverfish (O'Driscoll et al., 2021). Comparative eco-physiological analysis allowed us insights into the potential resilience of Antarctic silverfish in a changing climate (Carlig et al., 2021).

Zooplankton in the Southern Ocean consume microbes, primary and secondary producers and, in turn, are prey for fish, cephalopods, birds, and marine mammals. In providing the link between primary production and higher trophic levels, zooplankton influence energy flows, biological production and biomass, biogeochemical cycles, carbon flux and food web interactions and thereby modulate the structure and functioning of ecosystems. New Zealand is a strong supporter of the Southern Ocean Continuous Plankton Recorder (SO-CPR) survey, being the third-largest contributor of data in recent years. A twice-yearly zooplankton transect between New Zealand and the Ross Sea has now been carried out for 13 years by the New Zealand fishing vessel FV *San Aotea II*. Analysis of the SO-CPR dataset revealed seasonal and spatial patterns of key zooplankton groups across the Southern Ocean between 1997–2018 (Pinkerton et al., 2020). Statistical models were used to determine relationships between key taxonomic groups of zooplankton, zooplankton communities, and environmental conditions. Analyses were presented on the abundances of broad zooplankton groups including copepods, krill, foraminifera, pteropods and gelatinous zooplankton. These zooplankton taxonomic groups are notable because of their biomass and abundance and their roles in maintaining ecosystem structure and function. Trend analysis suggests that the overall abundances of copepods, foraminifera, and appendicularians (including pelagic sea-squirts) are increasing at between 0.5–0.6% per year overall and at up to 6% per year in some areas (Polar frontal regions). In contrast, the modelled environmental suitability for pteropods over the Ross Sea shelf has significantly worsened over the last 20 years, with predicted decreases in abundance of up to ~8% per year. Eight characteristic zooplankton communities in the Southern Ocean were identified based on multivariate cluster analysis of SO-CPR data from the Ross Sea region. The analysis suggests that the amount of ocean covered by the northern (Subantarctic) communities did not change significantly between 1998–2018, whereas the main Polar Frontal communities have expanded (at ~2% per year) and sea-ice communities have decreased (at up to 6% per year). Drawing on this modelling work, Johnston et al. (2022, with New Zealand co-authors) considered the status, change and futures of zooplankton in the Southern Ocean. The analysis focussed on Antarctic krill and other key zooplankton species, and provided an overview of observed and potential future responses of these taxa to a changing Southern Ocean and the functional relationships by which drivers may impact them. New Zealand is also investigating genetic- and image-based approaches to zooplankton identification and measurement to complement taxonomic identification by microscopy.

Cephalopods (squid and octopods) are an important part of Ross Sea region trophic structure but information on their abundance and ecology is very limited. In collaboration with researchers from Portugal and USA (Queirós et al., 2021) we used stable isotope analyses of $\delta^{13}C$ (a proxy for foraging habitat) and $\delta^{15}N$ (a proxy for trophic position) to investigate the habitat use and trophic ecology of ten squid species, collected from two species of albatrosses. Isotopes were analysed in two sections of the squid to represent different stages of the life cycle. Our results suggest that Southern Ocean squids tend to move southwards as they grow (different feeding strategies between life stages), with oceanic fronts being an important habitat for these species. The implication is that adults may move southwards with a warming oceanographic climate.

5. Krill predators (Adélie and emperor penguins, Antarctic minke whales)

New Zealand has long collaborated in research on Adélie penguins with scientists from the USA around Ross Island. More recently, New Zealand has carried out research on Adélie penguins at Cape Adare and contributed (through Professor Craig Cary) to Adélie research led by South Korea (KOPRI) at Cape Hallett. Over the last 5 years, New Zealand has carried out research: (1) to monitor and understand Adélie penguin foraging, reproduction and survival at the Cape Adare colony (fieldwork in 2018/19, 2019/20, and 2021/22); (2) to use DNA from guano, ornithogenic sediments, ancient bones and eggshell to produce new detailed reconstructions of the population size and diet of Adélie penguins in the Ross Sea over the past 50,000 years in order to establish long-term demographic and dietary baselines for Adélie penguins in the Ross Sea region (Wood et al., 2019); (3) to advance aerial census methods to provide long-term, wide-area tracking of changes in numbers of Adélie penguins at the southwest colonies and along the Victoria Land coast. Many of the results of this work have been published in collaboration with research collaborators from the USA (e.g., Massaro et al., 2020; Lescroël et al., 2020; Kappes et al., 2021); (4) to model indirect trophic interactions between Adélie penguins and Antarctic toothfish (Pinkerton et al., 2016). We found that Adélie penguins from the smaller colony studied in the south-western Ross Sea were consistently consuming more (potentially energy-rich) silverfish compared to birds at the larger nearby colony which ate more krill. At the smaller colony, middle-aged penguins have a higher proportion of fish in their diet compared to older and younger (less-experienced) penguins.

Emperor penguins are likely to be an important part of the Ross Sea ecosystem and, in collaboration with USA researchers, New Zealand led fieldwork in 2019/20 at Cape Crozier to tag birds and better understand their feeding preferences and habitat usage. In addition, nearly a third of the Ross Sea region MPA is located in the eastern part of the region (east of 170°W). More information is needed on the movement and distribution of these eastern Ross Sea emperor penguin colonies to quantify and monitor how much their foraging habitat is included in the MPA and understand the potential consequences of changes to sea-ice. Research on predators in this eastern Ross Sea region is scarce because of logistic challenges but a New Zealand co-authored paper described for the first time the habitat preference and dive behaviour of non-breeding emperor penguins from Cape Colbeck (Goetz et al., 2018). New Zealand has also contributed to research to understand patterns of mercury and other trace metal concentrations in Adélie and emperor penguins in the Ross Sea region (Pilcher et al., 2020).

While baleen whales are not explicitly listed in the CM 91-05, the consumption of krill and potentially silverfish by Antarctic minke whales (*Balaenoptera bonaerensis*) in the Ross Sea region is likely to exceed that of both Adélie and emperor penguins, based on their respective abundance and distribution. New Zealand scientists have initiated a research programme on minke whales in McMurdo Sound to collect photo-ID, dart biopsies and behavioural observations. In this area, minke whales act as a *pioneer species* with regard to accessing marine habitat newly uncovered by retreating sea ice. Minke whales have consistently been observed to be the first cetacean to appear in fresh leads, and may traverse considerable distances under closed ice to reach openings in the sea ice. Preliminary results indicate that individual minke whales may show site fidelity. Migration to the polar regions is central to the life history of the majority of large whales. New Zealand is involved in international research projects (such as the Southern Ocean Research Partnership, IWC-SORP) focussing on additional baleen whale species migrating to the Southern Ocean, including humpback (*Megaptera novaeangliae*), blue (*Balaenoptera musculus*) and fin (*Balaenoptera physalus*) whales (e.g. Riekkola et al., 2018; Derville et al., 2019).

6. Toothfish predators (Weddell seals, Type-C killer whales, sperm whales)

Three species are known to commonly eat Antarctic toothfish in the Ross Sea region: Weddell seals (*Leptonychotes weddellii*), the Type-C ecotype killer whale (*Orcinus orca*), and sperm whale (*Physeter macrocephalus*). New Zealand has been active over the last 5 years in research to understand the basic ecology (abundance, seasonal and spatial occurrence, diet) of these toothfish predators in the Ross Sea region and to develop methods for monitoring change in these populations.

Weddell seals have been a focus for New Zealand research associated with the RSrMPA because of the known predation by these seals on toothfish and uncertainty as to how important toothfish are to these predators (Pinkerton et al., 2008; Eisert at al. 2013; Eisert et al. 2019). Four approaches have been taken by New Zealand to improve knowledge of the potential risk to Weddell seals from the toothfish fishery and climate change, and to assess the role of the RSrMPA. These approaches are: (1) from 2013 onwards, fieldwork on local seal aggregations to improve the accuracy of remote sensing methods; (2) fieldwork carried out from Scott Base in 2019 and 2020 attached video and time-depth loggers to lactating female seals to improve understanding of foraging, prey selection and habitat use during this critical life stage, building on previous work on energetics of reproduction (Eisert et al. 2013); (3) in collaboration with IMOS (Australia), satellite CTD tags were attached to female seals in the southwestern Ross Sea after moult to understand overwinter movement patterns (Hindell et al., 2020;

Harcourt et al., 2021); (4) tracer experiments to verify Weddell seal diet estimates based on stable isotope analysis (whiskers, hair; Eisert & Horton, 2015); (5) camera traps and behavioural observations have revealed new insights into predation behaviour by Weddell seals on Antarctic toothfish, including consumption of toothfish out of the water; (6) passive acoustic sensors ("listening posts") were installed short-term in McMurdo Sound (in 2017/18, 2018/19 and 2019/20) and long-term for nearly 5 years from three sites in the Ross Sea region (Pacific Antarctic ridge; Scott seamount; Iselin Bank). Preliminary analysis suggests the presence of Weddell seals on the Ross Sea shelf slope during winter; (7) while fieldwork on Weddell seals in the eastern Ross Sea region has not been possible, New Zealand-led research has developed remote (satellite-based) methods to census Weddell seals around the whole Antarctic, including those areas that are hard to access on the ground (Grayson & Eisert, 2018; LaRue et al. 2020).

A draft paper (Harcourt et al., 2021) analysed over-winter tracking data from Weddell seals in the Ross Sea region to quantify the relative importance of intrinsic (individual variability) and extrinsic (habitat structure) factors in their winter foraging behaviour. The study compared Weddell seals tagged with biologgers at three geographically and hydrographically distinct locations: Prydz Bay, Terre Adélie and the Ross Sea. The study found that most Weddell seals that were tagged remained in relatively small areas close to the coast throughout the winter, but some dispersed widely. The type of foraging behaviour (benthic vs pelagic) varied from 57% benthic dives in Prydz Bay through 42% Terre Adélie to only 25% in the Ross Sea. The probability of benthic diving was lower the deeper the ocean. Sea ice concentration had little influence on the time seals spent in shallow coastal waters, but in deeper offshore water they used areas of higher ice concentration. In this study and considering only the seals tagged from the south-western Ross Sea, the RSrMPA General Protection Area encompassed all the observed Weddell seal habitat.

Type-C killer whales (TCKW) are a known predator of Antarctic toothfish and the most commonly observed type of killer whale in the Ross Sea region, in particular in coastal regions of McMurdo Sound and Terra Nova Bay (Eisert et al. 2015, Lauriano et al. 2011). In 2013, New Zealand researchers initiated an ongoing research programme to determine the dependence of TCKW on Antarctic toothfish and their vulnerability to a potential reduction in their prey base. Preliminary results indicate that TCKW show site fidelity and return annually to McMurdo Sound which may be specifically to access toothfish (Eisert et al. 2015). Predation on toothfish is observed consistently in McMurdo Sound, as well as consumption of cryopelagic fish (*Pagothenia borchgrevinki*) in newly-broken sea ice; TCKW do not appear to target non-fish vertebrates such as penguins or seals, although possible harassment of crabeater seals has been observed on two occasions. After several years of study, TCKW have started to direct prey-sharing behaviour towards human researchers, allowing unequivocal determination of prey species.

Although there is direct evidence of predation of sperm whales on toothfish (i.e. toothfish found in stomachs of sperm whales taken by Russian whaling vessels in the 1960s), and circumstantial evidence (high habitat overlap), depredation of toothfish by sperm whales in the Ross Sea region has not been reported to date. Although sightings of sperm whales from New Zealand research voyages in the Ross Sea region are sparse (Bowden et al., 2018b; O'Driscoll et al., 2019, 2021), our analysis of the first year of underwater acoustic data demonstrate that sperm whales forage in the Ross Sea year-round (Giorli & Pinkerton, 2021). The acoustic data provides evidence of spatial and seasonal overlap between sperm whales and Antarctic toothfish on the Iselin Bank and parts of the Pacific-Antarctic ridge, consistent with acoustic measurements from the joint New Zealand-Australia Ross Sea research voyage which showed that underwater sounds from sperm whales could be detected through most of the northern Ross Sea region in 2015 (Miller & Miller, 2018). In the northern area, near the Pacific-Antarctic Ridge, the number of sperm whale records detected was almost one order of magnitude higher than in the southern areas (Iselin Bank) where near year-round sea-ice seems to prevent sperm whales finding breathing holes (Giorli & Pinkerton, 2021). The highly migratory nature of sperm whales mean that research on the role of the RSrMPA regarding this species needs to maintain a global and international perspective and New Zealand has established collaborations with Italian, British, Australian and US whale researchers.

There are other potential predators of toothfish in the Ross Sea region, including Arnoux beaked whales (*Berardius arnuxii*) and potentially other species of beaked whales. Arnoux beaked whales are known to occur in the Ross Sea, are capable of diving to depths where toothfish occur on the Ross Sea slope and are predominantly fish and squid eaters (Brownell & Ainley, 2009). New Zealand is in the process of using the acoustic data recorded to see if vocalizations of beaked whales are present in this extended record from three locations (Pacific Antarctic ridge; Scott seamount; Iselin Bank).

7. Toothfish prey (macrourids, icefish, deep-sea cod, eel cod)

New Zealand continues to carry out research to understand and monitor changes to the trophic connections between Antarctic toothfish and its prey (e.g. Parker et al., 2020b). Three of the main bycatch species in the Ross Sea region toothfish fishery (*Macrourus whitsoni*, *M. caml*, *Chionobathyscus dewitti*) are also important prey items for toothfish, especially on the Ross Sea continental slope (Moore & Parker, 2021). Preliminary assessment suggests that predation-release (less consumption by toothfish) is likely to be more important than increased mortality due to fishing for macrourids and icefish, which means some of these prey species are likely to increase in abundance over time (Mormede et al., 2014). Over the last 5 years, New Zealand research on this topic has included: (1) three stratified trawl surveys on the Ross Sea shelf and slope with a focus on macrourids to date (2008, 2015, and 2019; Bowden et al., 2018a,b; O'Driscoll et al., 2019); (2) biomass estimates of macrourids on the Ross Sea slope (Devine et al., 2020); (3) species-specific improved estimates biological productivity for key bycatch species (growth rates, mortality, spawning; Moore et al., 2022a); (4) distribution and niche analysis for bycatch species, based on information concerning interactions with the fishery (for example, estimating proportions of different species in the catch) (Moore & Parker, 2021); (5) identification tools for bycatch species based on otolith morphology (Pinkerton et al., 2015; Moore et al., 2022b, which showed that observer species identification on New Zealand vessels was >90% accurate); (6) investigation of potential acoustic methods for assessing macrourid abundance (O'Driscoll et al., 2019); (7) annual (since 2012) stratified surveys of sub-adult toothfish in the southern Ross Sea with sampling for stomach contents and stable isotopes of toothfish (Devine et al., 2021 and references therein).

Forming a strategic approach, Parker et al. (2020b) describes New Zealand research planning where the new field measurements, data analysis and modelling in New Zealand will develop a better understanding of the ecological consequences of the predation release and bycatch mortality on the prey community as a whole. New Zealand has begun development of a new multispecies model for toothfish and its prey, and continues to work on methods for monitoring changes in macrourids and icefish towards improving our understanding of how the RSrMPA can help conserve these bycatch species (Grüss et al., 2022).

8. Antarctic toothfish

New Zealand has carried out research on many key aspects of the life cycle and ecological connections of Antarctic toothfish in the Ross Sea region. For example, in the last year, eleven New Zealand papers were submitted to WG-FSA-21 [Devine et al. (2021); Grüss et al. (2021a,b,c,d,e); Parker et al., 2021a; Delegation of New Zealand (2021a); Moore & Parker (2021); Moore et al. (2021); Dunn & Rasmussen (2021)] and four to WG-SAM-21 [Grüss et al. (2021f,g,h); Delegation of New Zealand (2021b)]. These papers covered topics relevant to the RSrMPA including the results from the 2021 shelf survey of Antarctic toothfish, toothfish assessment modelling, and research progress on macrourids and other bycatch species (including tagging of skates). With Italian colleagues, New Zealand has led work on methods to measure toothfish through fast ice in McMurdo Sound (Di Blasi et al., 2021). New Zealand also contributed to Zhu et al. (2021) and signalled its intension to continue the sub-adult survey of toothfish in the Ross Sea region in 2022 (Delegation of New Zealand, 2021b). New Zealand has also proposed approaches to monitoring and manage the effects of climate change on toothfish assessments

(Pinkerton et al., 2018) and advances spatial modelling of toothfish populations (e.g. Mormede et al. 2020; Grüss et al., 2022).

Based on two New Zealand winter research voyages (Parker & DiBlasi, 2020), New Zealand has published work on the first observations of spawning in Antarctic toothfish (Parker et al., 2019), and subsequently on buoyancy measurements of fertilised eggs of Antarctic toothfish (Parker et al., 2021b). Using this new information, New Zealand developed the use of a high-resolution hydrodynamic model to investigate the impact of ocean circulation and sea-ice drift on the dispersal of eggs, larvae, and juvenile Antarctic toothfish (Behrens et al., 2021). In this modelling study, virtual toothfish eggs were released on seamounts of the Pacific-Antarctic ridge in the northern Ross Sea and Southeast Pacific Basin and advected using hydrodynamical model data. Particles were seeded annually and tracked for three years after release. Recruitment success was evaluated based on the number of modelled juveniles that reached known coastal recruitment areas, between the eastern Ross and Amundsen Seas, within three years. Sensitivities to certain juvenile behaviours were explored. Spawning recruitment success increased during the second winter season if juveniles were entrained in the Ross Gyre circulation or if they actively swam towards the shelf. These modelling results suggest that the ecological advantage of sea-ice association in the early life cycle of toothfish diminishes as they grow, promoting a behaviour change during their second winter. The next step of this work is to simulate the effects of climate variability on toothfish larval success and correlated this with the time series of measured year-class strengths based on the sub-adult survey series which has been conducted annually since 2012 (Devine et al., 2021 and references therein). If we can successfully reproduce patterns in measured year-class strengths in Antarctic toothfish between 2012 and 2021 based on measured variation in oceanographic conditions (like currents, wind and sea-ice), this link between climate, fishing and toothfish recruitment, could have advantages in improving the management of the toothfish fishery, reducing risk and better assessing the role of spatial protection.

9. Bycatch species (skates, macrourids, icefish)

In a characterization of bycatch in the Ross Sea region toothfish fishery, New Zealand research found that five fish families, including macrourids (Macrouridae), skates (Rajidae), icefish (Channichthyidae), eel cods (Muraenolepididae) and morid cods (Moridae), comprised 97.7% of the total bycatch by numbers, and 99.5% of the total bycatch by weight. Macrourids (primarily *Macrourus whitsoni* and *M. caml*) were the major bycatch component of the Ross Sea region toothfish fishery, accounting for 74.7% of the total bycatch in number (Moore & Parker 2021). As discussed in Section 7 (Toothfish prey), because they are prey of toothfish in the Ross Sea region, macrourids, icefish, eel cods and morid cods will be affects both by predation release and bycatch mortality. In contrast, the impact of the toothfish fishery on skates is likely to be entirely negative (increased mortality of skates due to being caught as bycatch). New Zealand has helped set up protocols and cut-off rules to help quantify and reduce skate bycatch mortality and initiated the CCAMLR skate tagging programme (Parker & Francis, 2018; Francis & Parker, 2019; Parker et al., 2020a; Moore et al., 2021).

The impact of the toothfish fishery on skates in the Ross Sea region, the effectiveness of the cut-off rule and the effects of the MPA in helping mitigate skate bycatch mortality remain uncertain. It is known that a proportion of skates which are cut-off from long-lines in the Ross Sea region survive the event, but this proportion, the reduction in fitness of affected skates, and the overall population size of skates are not well known. New Zealand has carried out analysis of trends in skate tag-recapture data over time in an attempt to estimate trends in their relative abundance (Parker & Francis, 2018), and this work continues (Moore et al., 2021). The 2-year programme was implemented in the 2019/20 and 2020/21 fishing seasons in the Ross Sea region to tag and release skates for population size estimation and to validate the thorn ageing method for Antarctic starry skate (*Amblyraja georgiana*). The program has been largely successful to date, with a total of 8,506 skates tagged and released over the past two seasons in the Ross Sea region, with a further 484 individual skates voluntarily tagged in the Amundsen Sea Region. Recaptures from these releases will be used to monitor trends in population size through time with additional tagging occurring periodically. In addition, 2,117 skates that were tagged and released in the 2019/20 season on Australian, Spanish, New Zealand, and United Kingdom vessels were also injected with either oxytetracycline hydrochloride or strontium chloride in order to incorporate chemical marks into the caudal thorns for age validation. A total of 44 skates tagged during the programme have been recaptured to date. Results from the age validation experiments, as well as those of biological and movement analysis, will be provided to future CCAMLR meetings.

10. Vulnerable marine ecosystems (VMEs: structure-forming benthic invertebrates)

New measurements of the benthic ecosystems of the Ross Sea region have been made on the 2018, 2019 and 2021 research voyages to the Ross Sea, with a focus on vulnerable marine ecosystems (VMEs). The 2018 New Zealand voyage made the first scientific study of benthic habitats at Long Ridge, a key fishing area on the Pacific Antarctic Ridge in 88.1. On the 2019 voyage, we surveyed VME areas along the Ross Sea shelf and in particular in the MPA Special Research Zone.

Alongside the new field measurements, we have developed methods to assess and understand the environmental and oceanographic drivers of patterns of occurrence of benthic structure-forming species including VMEs (Bowden et al., 2021; Cummings et al., 2021). Cummings et al. (2021) presented research on two components of the Ross Sea benthic fauna: mega-epifauna, and macro-infauna, sampled using video and multicore, respectively, on the continental shelf and in previously unsampled habitats on the northern continental slope and abyssal plain. Clear differences in seafloor characteristics and communities were noted between environments. Seafloor substrates were more diverse on the Slope and Abyss, while taxa were generally more diverse on the Shelf. Mega-epifauna were predominantly suspension feeders across the Shelf and Slope, with deposit feeder grazers found in higher or equal abundances in the abyssal region. In contrast, suspension feeders were the least common macro-infaunal feeding type on the Shelf and Slope. Concordance between the mega-epifauna and macro-infauna data suggests that non-destructive video sampling of mega-epifauna can be used to indicate likely composition of macro-infauna, at larger spatial scales, at least. Primary productivity, seabed organic flux, and sea ice concentrations, and their variability over time, were important structuring factors for both community types. This illustrates the importance of better understanding bentho-pelagic coupling and incorporating this in biogeographic and process-distribution models, to enable meaningful predictions of how these ecosystems may be impacted by projected environmental changes. This study enhanced our understanding of the large-scale distributions and functions of seabed habitats and fauna inside and outside the Ross Sea MPA boundaries, expanding the baseline dataset against which the success of the MPA, as well as variability and change in benthic communities can be evaluated longer term.

New Zealand has also long carried out research on terrestrial and coastal ecosystems in the Ross Sea region, especially in McMurdo Sound and sites along the southern Victoria Land coast (e.g. Cummings et al., 2018, 2019; Piazza et al., 2019; Howard-Williams et al., 2021; Hawes et al., 2021).

Future research

New Zealand continues to carry out research in the Ross Sea region pursuant to CM 91-05 and the Ross Sea region MPA research and monitoring plan (Dunn et al., 2017). Funding for this research continues under Ross-RAMP, the New Zealand Antarctic Science Platform and Fisheries New Zealand Antarctic and Biodiversity research funding.

Ross-RAMP

The New Zealand Ross Sea region Research and Monitoring Programme (Ross-RAMP[2]) is a 6-year research programme funded by the New Zealand government to improve monitoring and understanding of the conservation value of the Ross Sea region MPA. The Ross-RAMP research has delivered or co-delivered much of the research presented here, and includes analysis of satellite data, physical and

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2 https://niwa.co.nz/our-science/antarctica/ross-sea-region-research-and-monitoring-programme

biogeochemical modelling, research voyages, fisheries research (on toothfish and bycatch), Continuous Plankton Recorder (zooplankton) surveys, fisheries data analysis, ecosystem and climate modelling, and fieldwork from Scott Base on Adélie penguins, emperor penguins and Weddell seals.

Top Predator Alliance NZ (TPA)

The TPA programme (initiated in 2013) primarily focusses on long-term process studies on type-C killer whales, Weddell seals, and other marine mammals in the Ross Sea region. Priority topics are trophic ecology, energetics, habitat use, abundance, and refinement of remote sensing methodology.

New Zealand Antarctic Science Platform

The New Zealand Antarctic Science Platform (ASP[3]) is a New Zealand government research programme that commenced in 2019 to provide 7 years of funding for Antarctic science through until mid-2025. The primary purpose of the ASP is to conduct science to understand Antarctica's impact on the global earth system, and how this might change in a +2° C (Paris agreement) world. As such, ASP research is focussed around understanding and anticipating the effect of climate change on the Ross Sea region, including feedbacks between critical physical-biological elements. To meet its purpose, the ASP has four projects: (1) Antarctic ice dynamics; (2) Antarctic ocean mechanics; (3) Projecting Ross Sea region ecosystem changes in a warming world; (4) Sea-ice and carbon cycle feedbacks. The project most relevant to the RSrMPA is Project 3, which aims to anticipate changes to ecosystems of the Ross Sea region, from terrestrial, coastal and open-ocean processes. There is also support for MPA-relevant work in the production (Project 1) and fate (Project 2) of meltwater as well as sea-ice distributions (Project 4). There is collaborative work between Project 3 and Project 4 on sampling of sea-ice platelet structure with a successful trial of a novel sampling method for platelet ice in November 2021 (Robinson & Parker, 2021). In addition, ASP is supporting the development of eDNA approaches to ecosystem monitoring including in conjunction with autonomous instrumentation for long-term (year-round) measurements, and has deployed Argo floats and moorings in the Ross Sea Polynya (Stewart et al. 2019). Finally, the Platform supports four modelling research fellows, including one focused on biogeochemical processes in the Ross Sea region, and has part-supported purchases of capital equipment for monitoring and for "process-focused" data collection.

RV Tangaroa voyage in January-February 2023

Planning is underway for the New Zealand research voyage to the Ross Sea region in 2023, to be carried out in January - February 2023. This voyage will be funded by the New Zealand MBIE, including through ASP, Ross-RAMP, Strategic Science Investment Fund, and Italian collaboration (BioRoss). The voyage follows on from recent New Zealand research in the Ross Sea from the RV Tangaroa in 2008, 2013, 2015[4], 2018[5], 2019[6] and 2021[7]. These voyages have substantially benefited from collaborations with scientists from US, South Korea, China, Australia, Spain, France, Italy, and UK.

The 2023 New Zealand Ross Sea voyage will have a multi-disciplinary complement of scientists and technicians. An initial set of objectives to be included is: (1) Ocean heat transport and melt water in the Ross Sea (e.g. Bowen et al., 2021); (2) Retrieval and redeployment of moored passive acoustic recorders ("listening posts"); (3) Fisheries acoustic data collection, midwater netting, and acoustic-optical system; (4) Coastal marine biogeography and ecosystem processes along the Northern Victoria Land coast, including benthic invertebrate sampling; (5) Microbial community structure and function, biogeochemistry, and bio-optics; (6) Zooplankton monitoring in the Southern Ocean; (7) Developing Environmental DNA technologies for population monitoring of Southern Ocean indicator species; (8) Ocean-derived aerosol-cloud-climate interactions in the Ross Sea region; (9) Measuring microplastics

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[3] https://www.antarcticscienceplatform.org.nz/

[4] https://niwa.co.nz/our-science/voyages/new-zealand-australia-antarctic-ecosystems-voyage

[5] https://niwa.co.nz/our-science/voyages/antarctica-2018

[6] https://niwa.co.nz/our-science/voyages/Ross-Sea-MPA-2019

[7] https://niwa.co.nz/our-science/voyages/2021_Antarctica

over the Southern Ocean; (10) Identifying and characterising submarine groundwater discharge in the Ross Sea; (11) Subsurface characterisation of active seeps.

These objectives, and the proposed voyage plan (Figure 3) are preliminary (draft) and are subject to change during the planning process. New Zealand remains active in pursuing collaborative work in the Ross Sea region with other members of CCAMLR. The next-but-one New Zealand research voyage to the Ross Sea region is scheduled for early 2025.

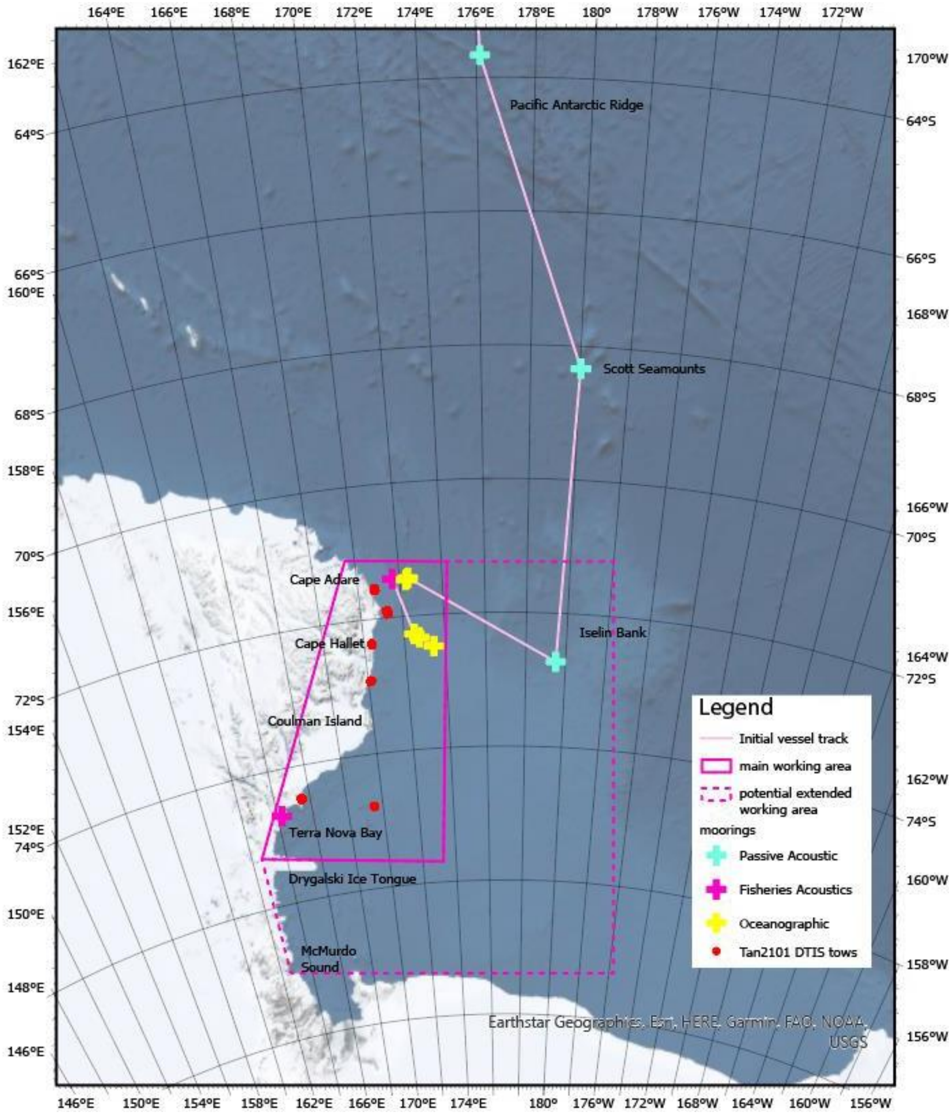

Figure 3. Draft location map for the planned New Zealand research voyage in January-February 2023.

Discussion

As noted in CM 91-05 paragraph 4, when possible, members are to participate in, and cooperate to conduct research and monitoring consistent with the activities outlined in the RMP. The research activities of New Zealand have benefited substantially from the collaboration and coordination of research efforts with international colleagues. We encourage continued collaboration and continued reporting of current and planned research relevant to delivering research associated with the RSrMPA Research and Monitoring Plan.

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Attachment

Report of Member research and monitoring activities related to the Ross Sea Region Marine Protected Area (2022)

Please include information from currently submitted projects in the CMIR, combining projects already submitted (e.g. see CM 91-05 paragraph 16) or newly submitted with the current report.

Member:

Korea, Republic of

Year range of projects included:

2017-2022

Number of projects reported (2016 – 2022):

1

Are there activities related to research and monitoring that are relevant to the RSrMPA which have not already been submitted to the CMIR? Please submit data following procedures and formats below.

N/A

Are there "preliminary results" from the activities you reported in the CMIR that you can describe further?

N/A

Data submission to the CMIR

The CMIR user manual describes how projects may be uploaded directly to the CMIR and can be found on the CMIR website. Note, the template provided here includes a few additional fields to describe the type of project and collaboration among Members. Alternatively, information about multiple projects may be submitted to the Secretariat following the data template below. If projects have been submitted previously to the CMIR as ongoing or proposed, please update these data. Project data already loaded may be downloaded as a csv file from the repository (see user manual) for editing.

Name of data file(s) provided:

1. Data for CCAMLR Ecosystem Monitoring Program (CEMP-data, 2018)
2. Data for CCAMLR Ecosystem Monitoring Program (CEMP-data, 2019)
3. Data for CCAMLR Ecosystem Monitoring Program (CEMP-data, 2020)
4. Census data of Emperor Penguin (Victoria Land, Ross Sea)
5. GPS tracking data of Adelie penguin (Cape Hallett, 2017)
6. GPS tracking data of Adelie penguin (Cape Hallett, 2018)

7. GPS tracking data of Adelie penguin (Cape Hallett, 2019) 8. GPS tracking data of Adelie penguin (Terra Nova Bay, 2018) 9. GPS tracking data of Adelie penguin (Inexpressible Island, 2018) 10. ANA11A EK60 data in the Ross Sea 11. ANA10C EK60 data in the Ross Sea 12. ANA09B EK60 data in the Ross Sea 13. ANA08C EK60 raw data in the Ross Sea 14. Reconstructed Chlorophyll-a Concentration off the Cape Hallett 15. Stable isotope ratios of carbon and nitrogen from penguin and its diets in the Ross Sea region, 2018-2019

Please attach an excel file, csv, or delimited text file with project data in the following format to be added to the CMIR. Note * indicates required fields.

Title	*Title of research project
Description	*Summary or abstract of research project
Research_start_date	*Research start date (known or estimated)
Research_end_date	*Research end date (known or estimated)
Proposing_party	*CCAMLR Member
Collaborators	*List CCAMLR Members collaborating on the project (e.g., USA, ITL, KOR)
Paper_type	*Peer reviewed, CCAMLR, Agency Report
Project_status	*Complete, On-going, or Proposed. Note that ongoing or proposed projects will require being updated.
Objectives	*Conservation objectives for which the research project links to (to see list of objectives visit the CMIR 'Objectives' tab or Table 3 from https://www.ccamlr.org/en/sc-camlr-xxxvi/20)
Themes	Relevant research and monitoring topics the project covers (see CMIR 'Themes' tab or Table 1 in https://www.ccamlr.org/en/sc-camlr-xxxvi/20)
Outcomes	Project objectives or targeted data outcomes
Management_zones	MPA management zones where research is occurring (e.g., SRZ)
Monitoring_areas	Research monitoring areas (e.g., Southwest Ross Sea, Terra Nova Bay, etc.)
Supporting_docs	Links or uploads of supporting documents, such as peer-reviewed papers, etc. These could include DOI numbers or CCAMLR meeting paper references
Primary_contact	*Primary contact name, e-mail
Priority_questions	Hypothesis or priority elements addressed (see Table 4 in https://www.ccamlr.org/en/sc-camlr-xxxvi/20)
Data_location	*Description of how to locate project data - indicate if privately held who/ what to contact, or internet links to data if publicly accessible

Reports may be submitted via CMIR@ccamlr.org

Attachment

Report of Member research and monitoring activities related to the Ross Sea Region Marine Protected Area (2022)

Please include information from currently submitted projects in the CMIR, combining projects already submitted (e.g. see CM 91-05 paragraph 16) or newly submitted with the current report.

Member:

Italy

Year range of projects included:

2011 – 2019

Number of projects reported (2016 – 2022):

49

Are there activities related to research and monitoring that are relevant to the RSrMPA which have not already been submitted to the CMIR? Please submit data following procedures and formats below.

Yes, information concerning 21 new activities are being submitted to the CMIR following the instruction and format below.

Are there "preliminary results" from the activities you reported in the CMIR that you can describe further?

The activities carried out by Italy in the Ross Sea Region MPA during 2017-2022 mainly addressed biological and ecological questions related to species demography and life history on the Ross Sea continental shelf and to oceanographic research. The main results are reported in 107 scientific papers published in peer reviewed international journals. It is worth noting that part of the Italian activities conducted in the RSR MPA addresses environmental pollution, an aspect that has potential considerable implications for the management of the MPA.

Data submission to the CMIR

The CMIR user manual describes how projects may be uploaded directly to the CMIR and can be found on the CMIR website. Note, the template provided here includes a few additional fields to describe the type of project and collaboration among Members. Alternatively, information about multiple projects may be submitted to the Secretariat following the data template below. If projects have been submitted previously to the CMIR as ongoing or proposed, please update these data. Project data already loaded may be downloaded as a csv file from the repository (see user manual) for editing.

Name of data file(s) provided:

2022_listo of italian PNRA activities in the RSR MPA

Please attach an excel file, csv, or delimited text file with project data in the following format to be added to the CMIR. Note * indicates required fields.

Title	*Title of research project
Description	*Summary or abstract of research project
Research_start_date	*Research start date (known or estimated)
Research_end_date	*Research end date (known or estimated)
Proposing_party	*CCAMLR Member
Collaborators	*List CCAMLR Members collaborating on the project (e.g., USA, ITL, KOR)
Paper_type	*Peer reviewed, CCAMLR, Agency Report
Project_status	*Complete, On-going, or Proposed. Note that ongoing or proposed projects will require being updated.
Objectives	*Conservation objectives for which the research project links to (to see list of objectives visit the CMIR 'Objectives' tab or Table 3 from https://www.ccamlr.org/en/sc-camlr-xxxvi/20)
Themes	Relevant research and monitoring topics the project covers (see CMIR 'Themes' tab or Table 1 in https://www.ccamlr.org/en/sc-camlr-xxxvi/20)
Outcomes	Project objectives or targeted data outcomes
Management_zones	MPA management zones where research is occurring (e.g., SRZ)
Monitoring_areas	Research monitoring areas (e.g., Southwest Ross Sea, Terra Nova Bay, etc.)
Supporting_docs	Links or uploads of supporting documents, such as peer-reviewed papers, etc. These could include DOI numbers or CCAMLR meeting paper references
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Priority_questions	Hypothesis or priority elements addressed (see Table 4 in https://www.ccamlr.org/en/sc-camlr-xxxvi/20)
Data_location	*Description of how to locate project data - indicate if privately held who/ what to contact, or internet links to data if publicly accessible

Reports may be submitted via CMIR@ccamlr.org