Climate Change and CCAMLR – update on recent research

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1. Summary

This paper presents a brief update on recent climate change-related research that is relevant to discussion and decision making by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and the Scientific Committee (SC-CAMLR). It complements the SCAR Antarctic Climate Change and the Environment (ACCE) Reports, initially published in 2009, and updated annually through submissions to the CEP/ATCM. It is not intended as a synthesis report, but a summary of research that is likely to be of relevance and interest to CCAMLR.

2. Introduction

This paper provides a brief update on recent significant advances in our understanding of climate change across the Antarctic continent and the Southern Ocean, the biological implications of these changes and the potential management considerations associated with key findings of this research.

This paper complements the Antarctic Climate Change and the Environment Reports that are regularly submitted, at the request of ATCM, by SCAR to the CEP/ATCM meetings. The original ACCE report and updated key points are available online at: http://acce.scar.org/wiki/Antarctic_Climate_Change_and_the_Environment. This online wiki version is progressively updated by a number of editors with input from many active scientists. The next major decadal update of the ACCE report will now be published in 2021. The Commission had previously invited SCAR to deliver an overview lecture summarizing this report during plenary at CCAMLR-39 (CCAMLR-38, paragraph 8.5). In light of current circumstances, SCAR requests that this opportunity be postponed to CCAMLR-40 in 2021.

3. Changes in the Antarctic physical environment

i) **The Antarctic Ice Sheet (AIS) is the largest potential source of, and most uncertain contributor to, global sea level rise.** A major review by Noble et al. (2020) summarizes current understanding of the processes and feedbacks that influence the stability of the AIS, integrating atmospheric and oceanic processes acting on short timescales, with ice sheet and solid Earth processes acting on longer timescales. While the AIS has been closely coupled to the climate system during the past, indicating the potential for sustained ice mass loss into the future, modern observations suggest that the AIS has only just started to respond to more recent climate change. Further understanding of how atmosphere and ocean processes act together to induce changes in the AIS are fundamental to understanding the nature and timescales of how the ice sheet responds to a changing climate. The East Antarctic Ice Sheet was previously assumed to have been stable for millions of years, however new analysis by Blackburn et al. (2020) indicates that substantial ice loss from East Antarctica may in fact have contributed 3-4 metres to global sea levels during past interglacial periods. This addresses a major source of uncertainty in estimates of how much sea level will rise as the Earth continues to warm.

ii) **The South Pole has experienced a record rate of warming since 1989.** Over the last three decades, the South Pole has experienced a record warming of 0.61 ± 0.34 °C per decade (Clem et al., 2020), which is more than three times the global average. Strong warming over the Antarctic interior during the last 30 years was chiefly driven by the tropics, especially warm ocean temperatures in the western tropical Pacific Ocean, which have lowered atmospheric pressure over the Weddell Sea (high-latitude South Atlantic) and increased the delivery of warm air to the South Pole. This warming period was mainly driven by natural tropical climate variability, and although it lies within the upper bounds of the simulated range of natural variability, it was likely intensified by increases in greenhouse gases. These atmospheric circulation changes along Antarctica's coast are an important mechanism for driving the flow of relatively warm air inland and causing extreme multi-decadal climate anomalies in its interior.

iii) **Summer sea ice extent in the Weddell Sea decreased to near-record levels in 2016/17.** This recent ice loss was in part caused by the reappearance of the Maud Rise polynya. Turner et al. (2020) used satellite records of ice extent and weather analyses starting in the 1970s to investigate why sea ice in the Weddell Sea has seen an unprecedented decrease since 2013, and to assess the impact on marine life. In December 2016, intense and unseasonal storms developed in the Weddell Sea and drew warm mid-latitude air towards the Antarctic, melting a large amount of sea ice. The ice-free ocean absorbed energy from the Sun, creating a persistent warm ocean temperature anomaly. The winter of 2016 also saw the return of the Maud Rise polynya, a large area of open water within the main sea ice zone, which also contributed to the overall decline in sea ice extent. The polynya developed due to the strong winds associated with the deep storms and unprecedented warm ocean conditions. It is currently not possible to predict whether the summer sea ice extent in the Weddell Sea will return to its pre-2016 values or whether this marks the start of the longer-term decline in Southern Ocean sea ice. However, it has highlighted the large variability in the extent of sea ice in the Weddell Sea and the importance of unusual weather events and the Maud Rise polynya.

iv) **Patterns of ocean warming are driven by ocean heat redistribution.** A recent study by Bronselaer & Zanna (2020) clarified how changes in ocean circulation can influence the storage of heat and carbon by the oceans at global and regional scales, and used these findings to establish the origin of ocean warming patterns. Identifying this coupling between the global ocean uptake of heat and carbon will help to assess the quality of climate models, by comparing the physical response to forcing with observational estimates of ocean heat redistribution. Ocean heat redistribution, although dominant in the past, becomes less important in the future, with ocean warming patterns increasingly influenced by simple uptake of atmospheric warming. More predictable warming patterns will be easier to model, which will improve the accuracy of future projections.

4. Changes in the Antarctic biological environment

i) **Circumpolar projections of Antarctic krill growth potential suggest seasonal and temporal shifts in habitat quality.** Krill relative growth potential is a measure of habitat quality, and may be affected by changes in ocean temperature and primary production. A circumpolar assessment of the robustness of krill growth habitat to climate change by Veytia et al. (2020) suggested both seasonal and temporal shifts in habitat quality, with implications for krill reproduction and consequently population size. Krill are most sensitive to changes in temperature at the upper limits of their thermotolerance, i.e. at the northern limit of their distribution. 90% of CCAMLR subareas will experience a change in growth potential of +/-15%, with 40% of areas showing projected increases, mostly because of higher sea surface temperatures in spring, becoming more favorable for krill growth. Krill habitat quality around the northern Antarctic Peninsula (in key fishing areas) is predicted to improve in spring but decline in summer. Southward shifts in krill habitat will also likely affect dependent predators, especially those breeding on sub-Antarctic islands. Regions likely to experience habitat quality decline or retreat are concentrated near the northern limits of krill distribution and in the East Pacific during autumn, meaning habitat will likely shift to higher latitudes in these areas. There is still uncertainty surrounding these estimates, due to model biases as well as gaps in knowledge of krill physiology, habitat use and population dynamics.

ii) **Increases in iron supply and light availability to phytoplankton are very likely to increase primary production and carbon export around Antarctica.** Phytoplankton, zooplankton, higher trophic level organisms and microbial communities are strongly influenced by Southern Ocean biogeochemistry, in particular through nutrient supply and ocean acidification. Henley et al. (2020) describe the changing biogeochemistry of the Southern Ocean, driven by changes in the environment, including iron supply, surface mixed layer depth and its effect on underwater light climate, declining sea ice, and poleward shifts and increasing strength of westerly wind belts. Biological carbon uptake is likely to increase for the Southern Ocean as a whole, but there is greater uncertainty around projections of primary production in the sub-Antarctic. Climate-mediated changes in Southern Ocean biogeochemistry over the coming decades are very likely to impact primary production, sea-air CO_2 exchange and ecosystem functioning. CMIP5 model simulations project, on average, increases in carbon export in the sub-Antarctic north of 50°S, particularly in the Atlantic sector, and south of ~60°S in the Antarctic Zone, particularly in the Indian sector, whilst decreases are projected between 50° and ~60°S in the open Southern Ocean.

iii) **Under 'business-as-usual' emission scenarios, 80% of emperor penguin colonies are projected to be quasi-extinct by 2100.** Jenouvrier et al. (2020) projected the dynamics of all known emperor penguin colonies under different climate change scenarios, using models that incorporate dispersal behaviour and the potential selection of new habitat. With 'business-as-usual' greenhouse gas emissions, large sea-ice declines are projected, and some colonies are likely to experience complete loss of sea ice during non-breeding, incubation and laying stages by the end of the century. Under this scenario, the total abundance of emperor penguins is projected to decline by at least 81% relative to its initial size, regardless of dispersal abilities, with 80% of colonies likely to have a conservation status of 'quasi-extinct' (defined as a population decline of more than 90%). In contrast, if the Paris Agreement objectives are met, viable emperor penguin refuges will exist in Antarctica, and only 19% and 31% of colonies are projected to be quasi-extinct by 2100 under the Paris 1.5°C and 2°C climate scenarios respectively.

5. Research on integrating considerations of climate change into management

i) **Incorporating climate change adaptation into marine protected area planning**. Climate change adaptation strategies are rarely incorporated into MPA design and management plans. Wilson et al. (2020) synthesized best practices for marine conservation planning to respond to environmental change. These authors highlighted the value of setting clear conservation goals, based on both species-based and higher level conservation features in the early stages of MPA planning. They also showed that vulnerability assessments for all conservation features and multiple climate change impacts can provide important insights into how species and communities may be impacted, and which specific climate change adaptation strategies should be incorporated into MPA design. The study suggests that MPAs should be closely monitored with relevant indicators and managed adaptively in response to monitoring results. Incorporating climate change adaptation strategies across every stage of the planning process maximizes the likelihood that MPAs will effectively protect marine biodiversity in a changing climate.

ii) **Best practices for an ecosystem approach to fisheries management, including under environmental change.** Link et al. (2020) provide an innovative operational framework of implementing ecosystem based management, including managing for changes in physiology, ecosystem shifts and climate change. In the context of potential impacts from climate change that can negatively influence fish populations (e.g., shifting populations, physiological changes, and changes to habitat quality or quantity), a number of potential management interventions are identified, including seasonal closures, adjusting biological reference points, changing spatial fishery allocations, adjusting parameters in stock assessments, considering prey availability or competition, considering temperature parameters, and undertaking habitat monitoring.

iii) **Successful ecosystem-based management of Antarctic krill should address uncertainties in krill recruitment, behavior and ecological adaptation.** In recent times, there has been relatively little discussion of the risks posed by the fishery to the krill population itself. This lack of attention reflects a view that catches up to the trigger level could not have a measurable impact on the krill population because they represent only a small fraction of overall biomass (ca. 1%). However, this view is challenged by the high levels of variability observed in available indices of krill abundance (which typically span two to three orders of magnitude), and in the increasing spatial focus of the fishery which could result in substantial local impacts. In a recent output from the SCAR Krill Action Group (SKAG), Meyer et al. (2020) highlight how management benefits could be achieved by incorporating uncertainty surrounding key aspects of krill ecology into management decisions, and how knowledge in these key areas can be improved. This improved information could be supplied, in part, by the fishery itself. The full paper is provided in SC-CAMLR-39/BG/XX.

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