# At-a-glance: Key findings of MEASO

i. The Antarctic Treaty system (beginning in 1959 with the Antarctic Treaty) and its emphasis on conservation and protection, exemplified in the Convention on the Conservation of Antarctic Marine Living Resources (1980) and its Protocol on Environmental Protection to the Antarctic Treaty (1991), provide the most recent articulation of the global interest in Antarctica and the Southern Ocean and the need for their protection.

ii. The Southern Ocean and its ecosystems play critical roles in the climate system. Ecosystem functions are at risk because of anthropogenic climate change.

iii. Global policies and actions are urgently required to safeguard Southern Ocean ecosystems from the effects of climate change, ocean warming and acidification caused by greenhouse gas emissions.

iv. Regional human pressures on Southern Ocean species and ecosystems have been dominated by fisheries, with human presence (science and tourism) and pollution having localised, but increasing, impacts.

v. The Marine Ecosystem Assessment for the Southern Ocean (MEASO) has demonstrated the array of existing knowledge, data, tools and approaches available for informing decisions on conserving and sustaining the marine ecosystems in the region and the services they provide, and how implementation of those processes could be improved.

## Policy-relevant findings and recommended research priorities

### *Managing for change*

vi. Effective regional and local protection is critical to safeguard ecosystems against the effects of climate change that are already underway. However, long-term maintenance of Southern Ocean ecosystems, particularly polar-adapted Antarctic species and coastal systems, can only be achieved, with high confidence, in the long term by significant and urgent global action to curb climate change and ocean acidification.

vii. Strategies for conserving Southern Ocean marine biodiversity, including management of fisheries, need to be further developed, based on current knowledge of the implications of climate change, to ensure resilience of Southern Ocean ecosystems into the future, accounting for not only long-term change but the potential for increased near-term variability and extreme events.

viii. Managing human activities in the Southern Ocean will benefit from assessing risks associated with different scenarios of climate change and future socio-economic demands; improved socio-ecological modelling and stakeholder engagement will enable better consideration of risks to environments, societies and economies.

### *Measuring change*

ix. Directly measuring the state of Southern Ocean ecosystems is central to ecosystem assessments; new approaches, and greater and more sustained investment than at present is required for covering the complexity of food webs, diverse communities, and the large extent and remoteness of the region.

x. A greater geographic spread of ongoing, comprehensive, long-term ecosystem studies is needed to assess spatial and seasonal variability and for establishing trends in the structure and function of Southern Ocean ecosystems, and the relative importance of different ecological processes in different areas.

xi. Systematic and sustained long-term measurements of habitats and biota are needed to underpin assessments of ecosystem change in the Southern Ocean, and for projecting future changes.

xii. Assessments of change will be facilitated by archiving, curating and openly sharing data, algorithms, and tools, based on FAIR principles (Findable, Accessible, Interoperable, and Reusable).

### *Projecting change to support risk assessments*

xiii. Projecting future changes in the survival and/or dynamics of species and communities needs improved models of the impacts from change in habitats, food webs, and human activity.

xiv. Projecting change in ecosystems at appropriate spatial scales needs dynamic ecological models driven by outputs of global ice-ocean-atmosphere (physio-chemical) models down-scaled to spatial scales relevant to ecological processes.

## State, variability and change in Southern Ocean ecosystems

### *Value and importance of Southern Ocean ecosystems in the Earth System*

xv. Southern Ocean ecosystems are an integral part of the Earth System; changes in Southern Ocean ecosystems will have impacts throughout the world's oceans and climate system, and vice versa.

xvi. The Southern Ocean exchanges water with all oceans to the north through surface eddies driven by wind as well as through deep water convection driven by temperature and salinity. Such connectivity enables movement of pelagic organisms (plankton and fish) and biological material into and out of the Southern Ocean.

xvii. The Southern Ocean provides important feeding and breeding grounds for migratory birds and marine mammals; migratory species transport important nutrients to and from the Southern Ocean each year and can contribute to the transport of invasive species.

xviii. In many parts of the world, people have a deep, often unacknowledged, connection with the Southern Ocean and value it greatly, despite not living there.

xix. Human activities in the region (science operations, fisheries, tourism) involve a large-scale transfer of people and material north and south each year, linking communities and social systems elsewhere to the Southern Ocean and also potentially contributing to unexpected impacts in the region through transport of non-native species/diseases, direct disturbance, and pollution.

xx. The demand for, and global importance of, ecosystem services from the Southern Ocean, are expected to increase during the 21st century, and climate change is expected to impact on these services.

### *Changing habitats in the Southern Ocean*

xxi. The Southern Ocean is warming, with some areas warming faster than others.

xxii. Sea ice, a key habitat and defining feature of the Southern Ocean, has been declining in some areas but increasing in others; prognoses for sea ice are amongst the greatest uncertainties about the future of marine ecosystems in the region.

xxiii. The Southern Ocean is freshening, becoming windier, and has a changing light environment, all of which are affecting blooms of phytoplankton.

xxiv. Nutrients (iron, silicon, phosphorus, nitrogen) that are required for primary production are changing regionally but supply is dependent on local conditions.

xxv. Absorption of large amounts of atmospheric $CO_2$ by the Southern Ocean is causing ocean acidification.

xxvi. The melting and retreat of glaciers and the collapse of ice shelves from increased oceanic and atmospheric temperatures are affecting coastal ecosystems.

xxvii. Globally-generated pollutants, including micro-plastics, are increasingly detected in the environment and in biota of the Southern Ocean, and local effects of pollution are altering environments adjacent to stations.

### *Biological changes and vulnerabilities*

xxviii. Sea ice supports year-round productivity, and habitat for feeding, breeding and refuge for many species.

xxix. Coastal and shelf systems of the Southern Ocean in waters shallower than 2000 m are among the most productive ecosystems in the global ocean and drive production locally and downstream.

xxx. Primary production by phytoplankton and carbon export to deeper water around Antarctica are changing, but the drivers are complex and trajectories of change are uncertain.

xxxi. Warming will alter seasonal patterns (phenology) in production and the relative abundances of different types of phytoplankton (particularly diatom vs. non-diatom) with consequent effects to food webs and to climate.

xxxii. Individual sensitivities of benthic and pelagic species to individual drivers of change in habitat conditions are determined by their shape and size, ability to regulate their physiology, and ability to move away from inhospitable conditions.

xxxiii. Reduced dominance of Antarctic krill may arise in the Atlantic sector of the Southern Ocean due to sea ice and diatom loss, and warming, thereby impacting higher trophic levels and the energetic efficiency of the ecosystem.

xxxiv. Regional reductions in sea ice and increasing ocean temperatures are causing the Antarctic (polar) ecosystem to contract towards Antarctica, increasing the potential for more northern species to move southward; the interacting effects on polar species of changes in multiple environmental drivers make the consequences for lower trophic levels difficult to predict.

xxxv. Birds and marine mammals dependent on sea ice for breeding and resting will be negatively impacted by declining sea ice cover. Conversely, those that do not depend on sea ice may benefit from reduced sea ice, although this will depend on whether or not their prey are also affected by sea ice loss.

xxxvi. Species in shore-based colonies will be impacted by shifting prey distributions, particularly for subantarctic species, and by changing on-shore environmental conditions at their colonies.

xxxvii. Foraging success of migratory birds and marine mammals may be disrupted should there be a change in timing of productivity in the ocean-ice systems.

xxxviii. Pollution and pathogens are emerging as factors impacting species in the Southern Ocean, including zooplankton, fish, marine mammals and birds.

xxxix. Benthic systems will be negatively impacted by warming, freshening and acidification of their habitats and additionally by increased iceberg scour on the Antarctic continental shelf.

xl. Changes in Southern Ocean food webs are dependent on the energy pathways prevalent in any given area and the sensitivity of species (either as predators or as prey) to changes in other species impacted by environmental change.