A living laboratory: Antarctica's Ross Sea benthic communities

The Antarctic seafloor and its inhabitants (the benthic ecosystem) are affected by a changing physical environment. These changes include warming and acidifying oceans, sea-ice loss, ice shelf retreat, and extreme weather events. Winners and losers will emerge among ecologically important benthic species, which will alter marine biodiversity and food webs. Studying this 'living laboratory' provides insights on potential impacts of climate change, and informs ecosystem protection and management.

About this document

This summary aims to inform policy makers and scientific peers about benthic research conducted in the Ross Sea region by New Zealand's Antarctic Science Platform (ASP). This research synthesis:

- shares fundamental information about Antarctica's benthic habitats
- highlights the effects of a changing climate on benthic ecosystems in the Ross Sea region
- provides critical baselines and new insights to understand benthic biodiversity and biogeography in a warming world
- provides examples of how the research can be applied by domestic and international collaborators to advance science, environmental management and ecosystem resilience.

Key points

- The Ross Sea region in Antarctica is significant for its near-pristine environment, unbroken food chain, and unique biodiversity. The Victoria Land coast supports diverse benthic habitats and communities, and is recognised as an area of ecological importance in the Ross Sea region Marine Protected Area.
- Environmental change can trigger abrupt community responses in coastal waters. Impacts of a warming climate on Antarctic benthic communities are already being seen.
- Tipping points are likely to be reached over the coming decades. Ecological signposts are needed to signal shifts in system stability and to indicate imminent change.
- A strong link exists between sea ice and ecosystem primary productivity pathways.
- New field samples and data, and the use of remote technologies, are being used to analyse and detect the impact of multiple stressors, and to learn new information on the adaptive capacities of polar species to change.

Research targets signposts of change

Extreme climatic events and rapid glacial retreat can trigger abrupt responses in biological communities living in coastal waters. The direct and indirect consequences of changing sea ice and other environmental parameters (for example, productivity, ocean temperature, salinity, circulation, and biogeochemistry) on benthic ecology is complex and involves multiple processes.

Coastal seafloor communities are directly linked with pelagic (open ocean) ecosystems in the Southern Ocean, the northern part of which is part of New Zealand's Exclusive Economic Zone. Antarctic benthic ecosystems are critical to the Antarctic food web and the integrity of the marine ecosystem.

Research to date shows that important ecosystem components of Antarctica and the Southern Ocean are already experiencing climate change impacts. We have gained insights into which processes, regions, and organisms in the Ross Sea must be observed to understand the future of Antarctica's coastal ecosystems. We know that climate change will create winners and losers among ecologically important species – altering biodiversity and primary production, as well as ecosystem functions. Signposts are needed to signal imminent shifts in system stability.

Benthic ecosystems respond to changing environmental conditions

A continent-wide research review found extensive changes in Antarctic benthic communities, particularly along the West Antarctic Peninsula where environmental change has been the most rapid. These biological changes are driven by warming air and oceans, increased glacial melt and sea-ice loss, and have led to shifts in biomass, species dominance and trophic structures. But comprehensive data is difficult and expensive to obtain. To address these challenges, the ASP has advanced multispecies, long-term monitoring at sentinel sites and is pioneering the use of advanced research tools, including environmental DNA (eDNA), autonomous sampling, and AI to speed up analysis.

Sea-ice decline leads to reduced microbial productivity

Sea ice attached to the Antarctic shoreline ('fast ice') is a major structural habitat feature for the underlying benthic communities. Sea-ice timing (when it forms and retreats), characteristics (like thickness and structure), and extent (area covered) has a greater influence on benthic ecosystems in coastal regions. These ecosystems are at the interface of changes on land and in the sea.

The sea ice microbial community has historically contributed to over 80% of the organic matter that supports benthic macroinvertebrates in the near-shore Antarctic food web, and are important nursery grounds for key taxa including fish and krill. This community has declined in years where the sea-ice extent is reduced, due to the strong link between sea-ice conditions and ecosystem productivity and population processes.

Physiological changes can help to monitor stress levels

Pigment concentrations in Antarctic crustose coralline algae are influenced by local light conditions. This adaptation, where certain pigments have higher concentrations when light levels are low, helps them to maximise photosynthesis in diverse light environments. The pigment level can be detected non-invasively using hyperspectral imaging, and the data used quantitatively to determine the presence, coverage, and health of the algae. This is a promising tool for ecological monitoring of primary productivity, habitat conditions, and understanding how algae adapt to a changing environment.

Macroalgae may play a larger role in carbon sequestration

Antarctic macroalgae (seaweed) may account for up to 2.8% of global macroalgal carbon fixation and could play a larger role in carbon sequestration than previously thought. Recent research has challenged the assumption that Antarctica has little suitable habitat for macroalgae. Surveys of the seafloor revealed diverse and abundant macroalgal communities in un-navigated coastal habitats of the Ross Sea, including extensive groups living at depths >70 m, and crustose coralline algae as deep as 125 m. These discoveries and the associated carbon sequestration potential provide important evidence for the continued preservation and protection of Antarctic coastal benthic areas.

Non-Antarctic kelps can cross the Southern Ocean

Long-distance dispersal by kelp across the Southern Ocean is more common than previously thought. Using genomic and oceanographic data, researchers documented instances of kelp rafts drifting for thousands of kilometres, including from surrounding continents, to Antarctic shores. This movement is despite the presumed ocean circulation barriers. Invasive species that can hitch a ride on these rafts are a genuine threat to Antarctica's ecosystems.

Scientists have identified research priorities

ASP researchers joined other Antarctic experts, under the umbrella of one of the Scientific Committee for Antarctic Research's scientific research programmes, 'Antarctic Thresholds-Ecosystem Resilience and Adaptation'. The team synthesised knowledge on the impacts and risks of climate and other environmental change on biological processes and ecosystem functions in the Antarctic.

This review showed that life in the Southern Ocean and Antarctica is highly sensitive to environmental changes, and that the responses of Antarctic ecology to environmental changes vary considerably across regions, habitats, ecosystems, communities, and organisms.

Priorities for future research include:

- the impacts of accelerating biogeochemical cycles – the movement and transformation of chemical elements and compounds between living organisms, the atmosphere, and the Earth
- ocean acidification
- biodiversity shifts
- changing sea-ice conditions
- pollution.

Field observations improve understanding and future projections

The responses of organisms, ecosystem functions, and ecosystem services to environmental change are complex and varied. Determining ecosystem resilience to change requires knowledge of the interactions of key species and ecological functions under present and future scenarios.

Improved projections on how life in the Antarctic will respond to climate change requires a combination of:

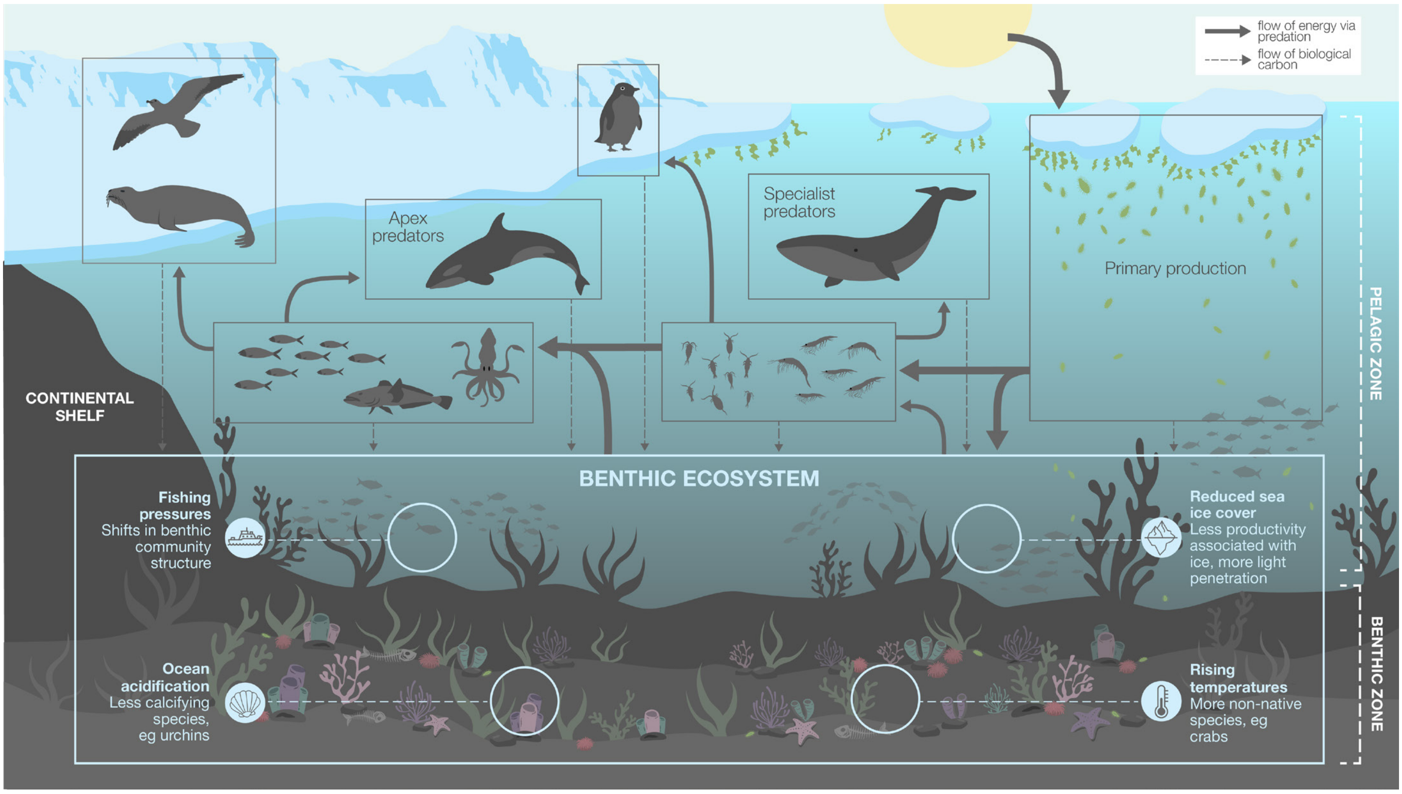
- baseline information on long-term natural variability in patterns and processes
- long-term observations (time series) of environmental conditions
- understanding the capacity of Antarctic species to adapt to change
- time series of ecosystem functioning and sensitivities
- identification of the key ecosystem health indicators that are sentinels of change
- observations in areas beyond those already surveyed.

The ASP has been collecting field data to analyse and detect the impact of multiple stressors, and to learn new information on the adaptive capacities of polar species to change.

Technology advances research

Using non-intrusive and remote technologies to study benthic habitats has been one of the great successes from the Antarctic Science Platform. Researchers are using techniques that have helped to accelerate data gathering and understanding of the Ross Sea benthic ecosystem. These methods can help develop spatially explicit projections for the future and identify key ecological functions.

Figure 1 (below): Arrows show the flow of energy to and from the benthic ecosystem, which is connected throughout the entire food web. Circles indicate the drivers of change facing the ecosystem.



Specific techniques include:

- an increased use of autonomous sampling platforms, including unmanned underwater vehicles, towed and remotely piloted, to capture images at depth, combined with AI tools to speed up analysis of video sampling
- analyses of environmental DNA (an example uses minute traces of DNA trapped by filter-feeding sponges to reveal a snapshot of what is present in an ecosystem)
- use of underwater hyperspectral survey methods with AI-based image analysis to non-invasively detect the presence and coverage of marine algae
- use of satellite-derived information to quantify sea-ice conditions, water temperature, and phytoplankton biomass
- deployment of coastal seafloor monitoring stations to understand the environment surrounding benthic communities.

Our research is an important part of global understanding and action

Current knowledge on the human footprint is essential to inform Antarctic Treaty policy and national legislation to ensure healthy Antarctic ecosystems. This knowledge justifies an extended protection of Antarctic species from the risks of climate change, pollution, and other disturbances.

Over the course of the ASP, we have developed new techniques to enhance coverage and understanding of benthic communities, through increased use of ROVs and towed cameras. This advancement allows larger areas to be surveyed and to greater depths.

Integrating eDNA into analyses allows rapid, semi-automated assessment of species presence, combined with the physical observations to validate eDNA inferences. Collaborations with international scientists bring new insights and technologies to our research. By combining sea ice- and vessel-based research, we have spread our understanding from the McMurdo Sound to the full length of the Victoria Land coast in never-before surveyed locations. This represents a major north-south transect that spans environmental gradients and several biogeographic regions. We have sampled multiple sites on more than one occasion, building a valuable time series. Such an extensive sample set is rare and provides an important legacy – a critical set of baseline research material taken at the beginning of a changing regime within the Ross Sea.

Definitions

Benthic: living in, on, or near the seafloor and its sediments.

Pelagic: inhabiting or relating to the open ocean or high seas.

Ecosystem resilience: the capacity of an ecosystem to absorb disturbances and stresses while keeping its basic function.

Biogeochemical cycles: pathways by which essential elements and compounds (like carbon, nitrogen, and water) are cycled between living organisms and their non-living environment.

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