Climate change and the Antarctic marine ecosystem

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The Antarctic climate has changed throughout time and on a wide range of temporal scales. Southern Ocean bottom temperatures have changed dramatically over the past 60 Ma, as has been demonstrated by palaeotemperature studies of benthic foraminifera isolated from deep-sea sediment cores. Glaciation of the Antarctic continent probably began 36–40 Ma BP, and throughout its existence the continental ice-cap has varied in volume and the extent to which it has covered the continental shelves. A key driver of this variability has been Milankovitch cyclicity, long-term variations in the Earth's orbit which affect received solar radiation on timescales ranging from <20,000 to >100,000 years. These variations affect the timing and duration of seasons, and the extent of the tropical and polar regions. For the last 15 Ma there has been consistent cooling of the Southern Ocean, and this is the period that has driven the evolution of the Antarctic climate and biota we observe today.

Climatic and tectonic changes on geological and Milankovitch scales have produced a generally rich and diverse Antarctic marine fauna adapted to cope with this variability, by slow growth, longevity and intermittent recruitment. The marine fauna of Antarctica is generally rich and diverse, though some taxa are more speciose than others (notably species-rich groups include amphipod and isopod crustaceans, echinoderms and pycnogonids). In contrast, the Southern Ocean has very few decapod crustaceans, and is dominated by only one group of teleost fish. Climate change is likely to influence this biodiversity through three processes, namely direct temperature effects on organisms, oceanographic shifts and changes in the dynamics of sea-ice. In some cases, any effects may be exacerbated by changes in UV flux as a result of changes in the seasonal development of the ozone hole. At present, there is evidence for small temperature changes in both shallow and deep waters around Antarctica, and for some associated oceanographic changes. There is also some evidence for changes in sea-ice distribution and dynamics, though here it is difficult to distinguish a climate-change signal from natural long-period variability in the system. The clearest evidence for long-term changes in sea-ice dynamics comes from the Amundsen and Bellingshausen Seas, where there has been a decrease in winter sea-ice cover of about 10% since satellite records began. The atmospheric climate of the Antarctic Peninsula is warming faster than almost anywhere else on the planet, with warming being most evident in winter, and this may be related to the changes in sea-ice dynamics observed in the Amundsen and Bellingshausen Seas. In contrast, the climate of the Antarctic continent shows no consistent pattern, and some places have even displayed a slight cooling.

Data for biological responses to climate change in Antarctica are few, although there are strong indications of changes in population dynamics of some seabirds in relation to sea-ice. Climate change has already affected the breeding distribution of pygoscelid penguins, but no change has yet been observed for plankton or benthos. Some marine invertebrates have been shown to live near their maximum temperature limits (a situation analogous to that of some tropical corals) and would therefore seem liable to extinction should seawater temperatures rise significantly in the near future. How the fate of individual sensitive species relates to the response of whole ecological assemblages is, however, far from clear.

The dynamics of sea-ice are complex, and can influence the population dynamics of many zooplankton which depend on sea-ice at stages in their life-cycle. An excellent example of this is the Antarctic krill, *Euphausia superba*, which is widely regarded as a keystone species in the food web at lower latitudes in the Southern Ocean. Young krill hatch along the western Antarctic Peninsula and are carried in the strong Antarctic Circumpolar Current to South Georgia, where they form a major part of the diet of many higher predators (fish, squid, seabirds and marine mammals). This means that variations in krill supply driven by changes in sea-ice dynamics thus influence the breeding success of dependent predators at South Georgia.

Demonstrating long-term changes in the biodiversity of marine systems is hindered by the paucity of data and the overwhelming effects of man's activities, even in Antarctica. Important insights into the potential effects of future climate change come from examining historical changes in the fauna, and from comparison of the two polar regions. To understand the impact of climate change on the Antarctic ecosystem as a whole, one needs to understand the structure of the food web. Although often portrayed as a simple, two-step linear food chain (diatoms to krill to whales, the classic Antarctic food chain of many textbooks), the Southern Ocean food web is similar to other marine food webs in that it is non-linear, incorporates a microbial loop and has a significant flux to benthos. The major difference from non-polar food webs is the role of sea-ice. The food web structure and its non-linear dynamics make prediction of future responses very difficult. The removal of great whales might have resulted in a regime shift to a system dominated by fur seals and squid. Currently, we cannot predict the biological consequences of climate change on the Antarctic. Rather than focusing on individual taxa, the impact of climate change on assemblages needs to be investigated.

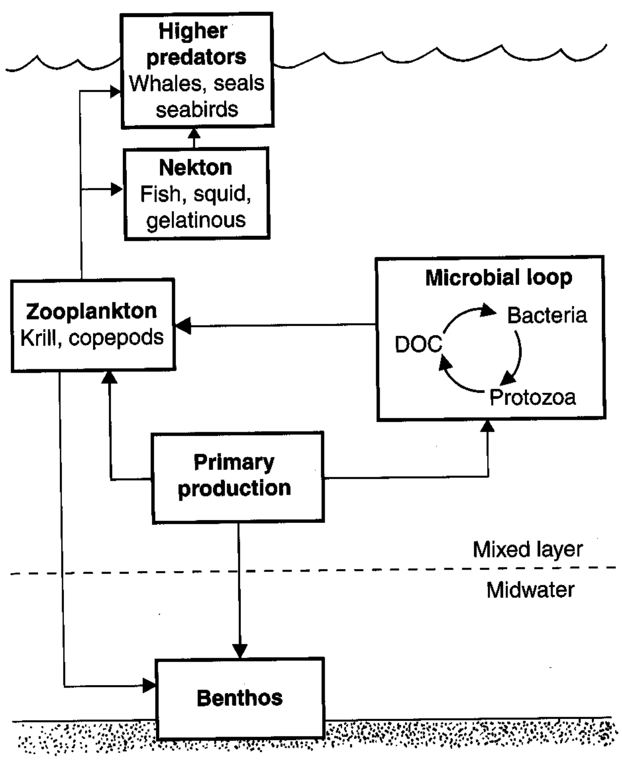

Figure 1. *Schematic diagram of the Southern Ocean food web.*