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A Long-Term Ecological Research Strategy for Polar Environmental Research

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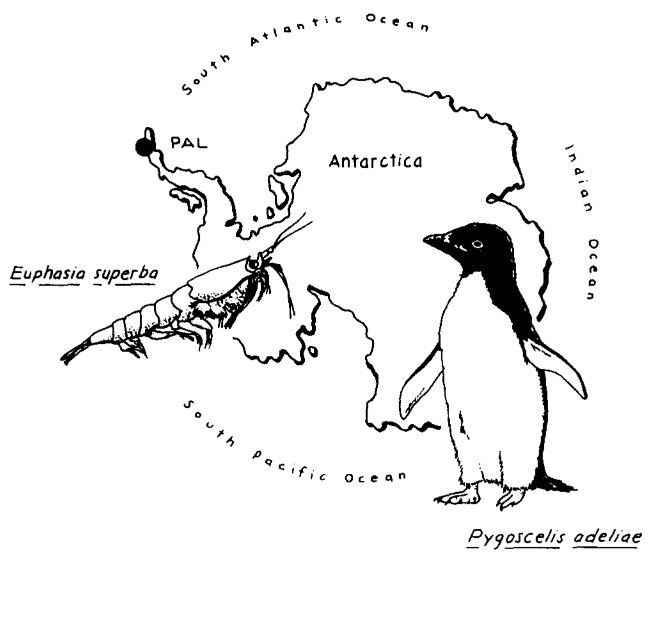
The Palmer Long-Term Ecological Research site was established in the vicinity of Palmer Station, Antarctica in 1990. It is the eighteenth and most recent addition to the LTER Network funded by the National Science Foundation of the United States. The Palmer LTER expands the geographical and habitat coverage of the LTER Network to southern polar regions and offers unique opportunities for ecological synthesis and the study of long-term ecological phenomena in the Antarctic marine ecosystem. The central hypothesis of the Palmer LTER is that many significant biological processes in the Antarctic marine environment are strongly affected by physical processes, particularly interannual variability in the annual extent and dynamics of pack ice and variations in ocean currents. The Palmer LTER Studies Group is multidisciplinary and seeks to understand and model interactions between key species from different trophic levels and the physical environment. It is recognized that anthropogenic impacts in Antarctica cannot be adequately evaluated without understanding the underlying natural variability in Antarctic ecosystems.

Long-term ecological patterns often elude our recognition and understanding. Magnuson *et al.* (1983) and Magnuson (1990) coined the term 'the invisible present'



to refer to the loss of information and tendency to misinterpretation when observations of the present are not placed in appropriate time and space scales. Short-term ecological phenomena that we see every day often have their origins in rare or slow processes or in events occurring on larger scales than normally studied in ecological investigations. For example, seasonal ice cover on Lake Mendota, Wisconsin, has been documented continuously since 1855. Only after many years of study could variation in ice cover be correlated with larger scale processes. Though large interannual variation in the duration of annual ice cover on the lake was seen after 10 years, only after 50 years was it apparent that years of shorter duration of ice cover and El Nino years coincided (Magnuson & Drury, 1991). Also, only after analysis of a data record longer than a century did the warming trend from the end of the 'little ice age' emerge. This correlation of a cyclical seasonal process with a longer, larger scale cyclical process and a long-term trend would never have become apparent without long-term studies.

To better understand larger and longer scale ecological processes, the National Science Foundation of the United States established a network for Long-Term Ecological Research (LTER) in 1981 with the founding of six research sites in the continental United States. Today the LTER Network spans 18 research sites that include a wide range of environments and diversity of research approaches (Fig. 1). From its inception the intent of this programme was to coordinate the research at each site to enhance comparative analyses and to test theoretical constructs between sites (Franklin *et al.*, 1990). One example of a comparative analysis is whether the pattern of primary production between sites is primarily controlled by 'bottom up' variables such as light and nutrients or by a 'top down' variable such as grazing.

Research at each site is structured around five core areas, one of which is to evaluate the pattern and frequency of disturbance at each site (Callahan, 1984). Pollution is clearly one type of disturbance that may have effects on a site, whether it be on the scale of global warming or on the smaller scale of an oil spill. As is common to all ecosystem studies, variations in natural ecological processes need to be understood within the context of human disturbance; and possible

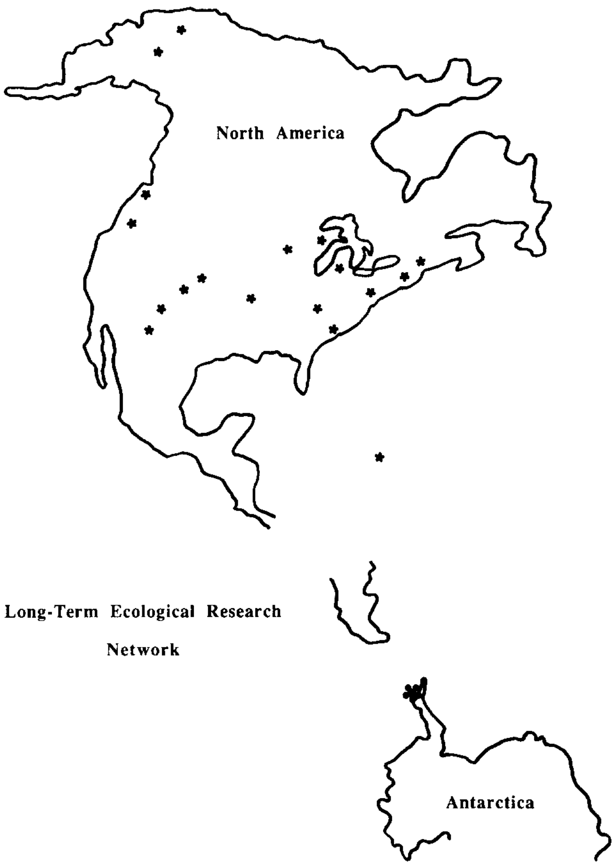


Fig. 1 Geographical distribution of the 18 sites within the Long-Term Ecological Research (LTER) Network. The Palmer LTER is located in the region around Palmer Station on the west side of the Antarctic Peninsula, Antarctica.

pollution effects need to be evaluated against the pattern of natural variability in the environment, and in the plant and animal populations inhabiting the ecosystem. Polar regions are no exception.

The Palmer LTER, established at Palmer Station, Antarctica in 1990, is the newest LTER site. Predictions suggest that the effects of global change (climate warming, ozone depletion, and increased human pressure on resources) will be more pronounced and thus detectable earlier in Antarctica than in mid-latitudes (Manabe & Stouffer, 1979). Our earlier detection and understanding of the cause and effect of these changes in Antarctica may serve as a model for more temperate areas. The Palmer LTER will monitor the ecological effects of changes in sea-ice extent and thickness, study the processes underlying these effects, as recommended by the International Geosphere–Biosphere Programme (IGBP) (Anon., 1989), and will build interactive models in an effort to predict the impacts of global warming and attendant changes in the annual cycle of pack ice on Antarctic biota.

A comprehensive strategy for any environmental research programme should include long-term data bases complimented by shorter, more intensive studies of processes. For example, in the polar environment one concern is the seasonal thinning of the ozone layer over Antarctica which leads to increases in ultraviolet (UVB) radiation, and decreases in total primary production (Smith *et al.*, 1992). Complimentary research on the effects of UVB on Antarctic communities, when coupled with long-term observations, will enable us to better predict future impacts.

LTER Study Region

The LTER study region is adjacent to and surrounds Palmer Station, located in a protected harbour on the southwest side of Anvers Island midway down the Antarctic Peninsula (64°40′S, 64°W) (Fig. 2). Within a 9 km radius of Palmer Station are two exposed, prominent points, and groups of islands that extend to the edge of the Bismarck Strait to the southeast. Palmer Basin, 22 km southwest of Palmer Station, is the only deep basin in the area. The maximum depth is 1280 m, and the basin is connected to the open ocean on the west side of Anvers Island, and to the southern end of the strait between Anvers Island and the Antarctic Peninsula to the northeast.

The climate is typically maritime Antarctic, with snow and rain common any time of the year. The temperature at Palmer Station is relatively mild, averaging about −10°C in July and 2°C in January, with temperature extremes recorded at −31°C and 9°C. Annual rainfall averages about 10 inches and snowfall about 14 inches. Two large scale physical processes impact the Southern Ocean ecosystem: the seasonal advance and retreat of pack ice, and oceanic circulation patterns.

The central hypothesis of the Palmer LTER states that many significant biological processes in the Antarctic marine environment are strongly affected by physical factors, particularly the annual advance and retreat of pack ice and variations in ocean currents. In polar environments, the annual advance and retreat of the pack ice is an important physical feature covering vast areas of the marine environment (Garrison & Siniff, 1986). In the Southern Ocean this seasonal cycle of ice formation and melting affects about 50% of the open sea. The amplitude and phase of interannual variability in the regional extent of pack ice is not the same in all sectors of the Southern Ocean (Zwally *et al.*, 1983). In the region around Palmer Station the maximum extent of pack ice varies widely, from near zero to halfway across Drake Passage (Quetin & Ross, 1991), and in recent years has been on a 6 to 8 year cycle (pers. comm.). The timing of the onset of ice formation also varies systematically from late May to August. Pack ice not only provides marine habitats distinct from open-water habitats, but also may be the major physical determinant of temporal/spatial changes in the structure and function of polar biota (Fraser & Ainley, 1986). Thus interannual cycles and/or trends in the annual extent of pack ice are likely to have significant effects on all levels of the food web, from total annual primary production to breeding success in seabirds.

Mesoscale oceanic circulation patterns are reasonably well-known (Hofmann *et al.*, in press). A southwest setting flow (East Wind Drift, EWD), beginning around Anvers Island, feeds into a cyclonic eddy about 300 km south and seaward of the EWD. The Antarctic Circumpolar Current (ACC) flows northeast on the outside of

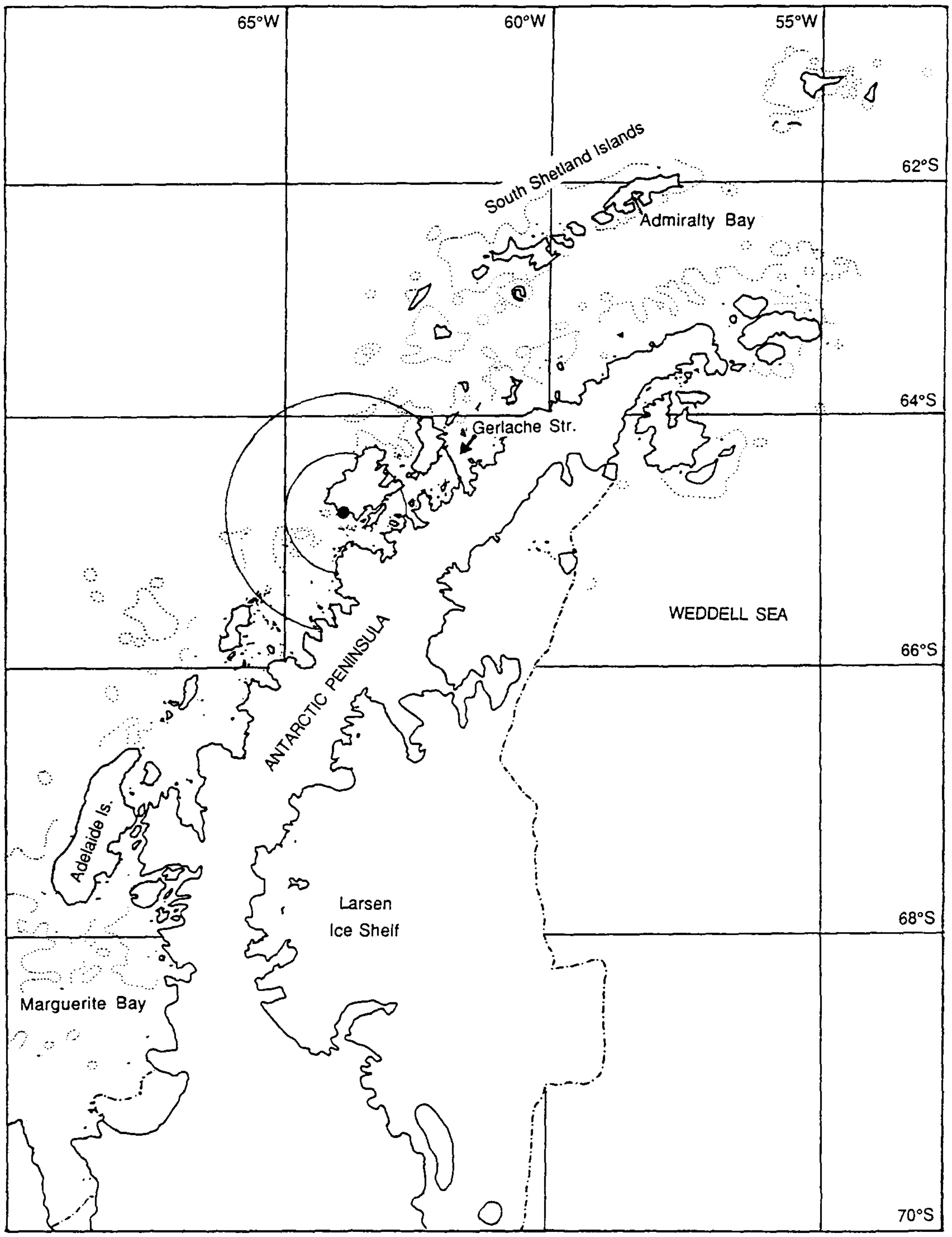


Fig. 2 The west side of the Antarctic Peninsula. The region of interest for the Palmer LTER is from Marguerite Bay to the northern edge of Gerlache Strait and seaward for 200 km. The foraging range of the seabirds during the reproductive season is indicated by two concentric circles at 50 and 100 km from Palmer Station (black dot).

this gyre. However, the geographic position of the ACC varies (Gordon, 1988) over many kilometres. The ACC also generates eddies that may persist for a month or so and extend tens of kilometres (Nowlin & Klinck, 1986). Changes in the timing of the seasonal change in wind direction and thus Ekman stress (Capella, 1989) may also affect the strength of the EWD. Shifts in water masses and changes in local current regimes may impact distributions and food availability to many marine communities.

Palmer LTER Research Objectives

The overall objectives of the Palmer LTER are: *1.* to document interannual variability in the development and extent of annual pack ice, in the seasonal cycle of large groups of primary producers (diatoms, prymnesiophytes), and in populations of key species from different trophic levels (Table 1); *2.* to quantify the processes that underlie natural variation in these representative populations; *3.* to construct models that

TABLE 1

Spatial and temporal scales of the Palmer LTER.

Spatial scale	km^2
Southern Ocean ice cover	10^7
Bellingshausen/Amundsen Sea	10^6
Large gyres	10^6
Antarctic Peninsula Region	10^5
Palmer Basin (near field, 100 × 100 km)	10^4
Seabirds (Adélie penguins, south polar skuas)	
Summer foraging (50 × 50 km)	10^3
Winter range	10^5
Eddies	10^2
Silverfish population (*Pleuragramma antarcticum*)	$\sim 10^5$
Krill (*Euphausia superba*) population	10^6
aggregations	$< 10^0$
Temporal scale	**Min**
Climate	
Seasonal cycle, year	0.5×10^5
Episodic weather, hours to days	10^1–10^4
Ice movements, hours to weeks	10^1–10^5
Optical variability, min to hours	10^{-1}
Phytoplankton	
Diel cycles, hours	10^1–10^3
Blooms (turnover times), days	10^4
Secondary Producers (life span)	
Krill, 5–7 years	3×10^5
Antarctic silverfish, ~25 years	10^6
Seabirds (life span)	
Adélie penguin, ~12 years	5×10^5
South polar skua, 40 years (70 max)	10^6

link ecosystem processes to physical environmental variables and their natural scales, and to simulate the spatial/temporal relationships between representative populations; and *4.* to employ such models to predict and validate the impacts of altered periodicities in the annual extent of pack ice on ecosystem dynamics. One of our challenges is to link the different spatial and temporal scales characteristic of the different components of the ecosystem (Table 1). The inherent interannual variability in the extent of pack ice generates natural experiments on the effects of pack ice on the various trophic levels. The results of these experiments are the parameters and processes monitored during and after seasons of different pack ice cover.

Research at the Palmer LTER site will focus on the pelagic marine ecosystem and the ecological processes which link the extent of annual pack ice to the biological dynamics of different trophic levels. Although the Antarctic marine food web is as complex as any other marine food web, the links between primary producers, grazers and apex predators (seabirds, seals and whales) are often short and may involve fewer than three or four species (Fig. 3). Predators tend to concentrate on a core group of species, especially some extremely abundant euphausiids and fish close to the base of the food web. Our general approach capitalizes on this close coupling between trophic levels, the limited number of species involved, and the fact that the dominant predators are seabirds that nest on land and are easily accessible during the spring and summer breeding season. Thus aspects of seabird foraging and reproductive biology can be used as indices of local and short-term prey abundance and availability, i.e. within the foraging range during the breeding period. These indices can be evaluated with greater precision than can the biomass and distribution of their prey by classical oceanographic methods. However, although aspects of the biology of dominant consumers may be good indices of local prey abundance and availability, they may not be reliable indices of the regional population dynamics of the prey species.

Adélie penguins dominate the seabird assemblage, but the islands and points of land in the area also support chinstrap penguins and south polar skuas. Adélies from Palmer Station are believed to winter in the pack ice of the Bellingshausen Sea near to Palmer. About 600 pairs of south polar skuas also reside on about a dozen islands in the vicinity. During the summer breeding season, these seabirds depend on resources in the adjacent deep-water foraging area: 50 km radius for the Adélies, 100 to 160 km for the south polar skuas. Their major prey items, Antarctic krill and silverfish respectively, are found within Palmer Basin, within the EWD and on the eastern edge of the ACC.

Initial studies will examine the mechanisms behind changes in prey levels within the summer foraging area—such as changes in water mass distribution, variability in reproductive and recruitment success of the prey, and changes in food availability during critical periods of the prey's life history. Extreme interannual mesoscale variation in the distribution patterns of krill, which greatly impacts the predators, is likely not due to recruitment failure (Priddle *et al.*, 1988). Recruitment failure for 1 year would not change the abundance of krill enough to be detectable by current sampling regimes. Poor recruitment would need to occur over a number of seasons for decreases in krill abundance to be detectable. The model of Priddle *et al.* (1988) predicts that krill abundance would take 3 years to return to initial levels after two consecutive years of recruitment failure. However, the extreme changes in krill abundance observed in a region are often seasonal or recovery occurs in a year. This timing in the change of the abundance of krill indicates that changes in current patterns and eddy distribution may influence the distribution of Antarctic krill and thus the prey available to seabirds.

The impact of the extent of ice on the prey and predators may be direct or mediated by the effect of ice on lower trophic levels. In the Southern Ocean, pack ice affects primary production in three communities: open water communities, ice-edge blooms, and ice algae. The stable layer created by melting pack ice and increasing incident radiation in the spring promotes ice-edge blooms that precede blooms in open water in the surrounding seas. Ice-edge blooms are a significant component of total productivity in the Southern Ocean, and variation in the timing and amount of ice-edge bloom production from variation in the extent of pack ice will affect both total primary production (Smith *et al.*, 1988) and the timing and extent of food availability to the grazers.

One of our principal objectives is to separate long-term (decadal) systematic trends from large interannual

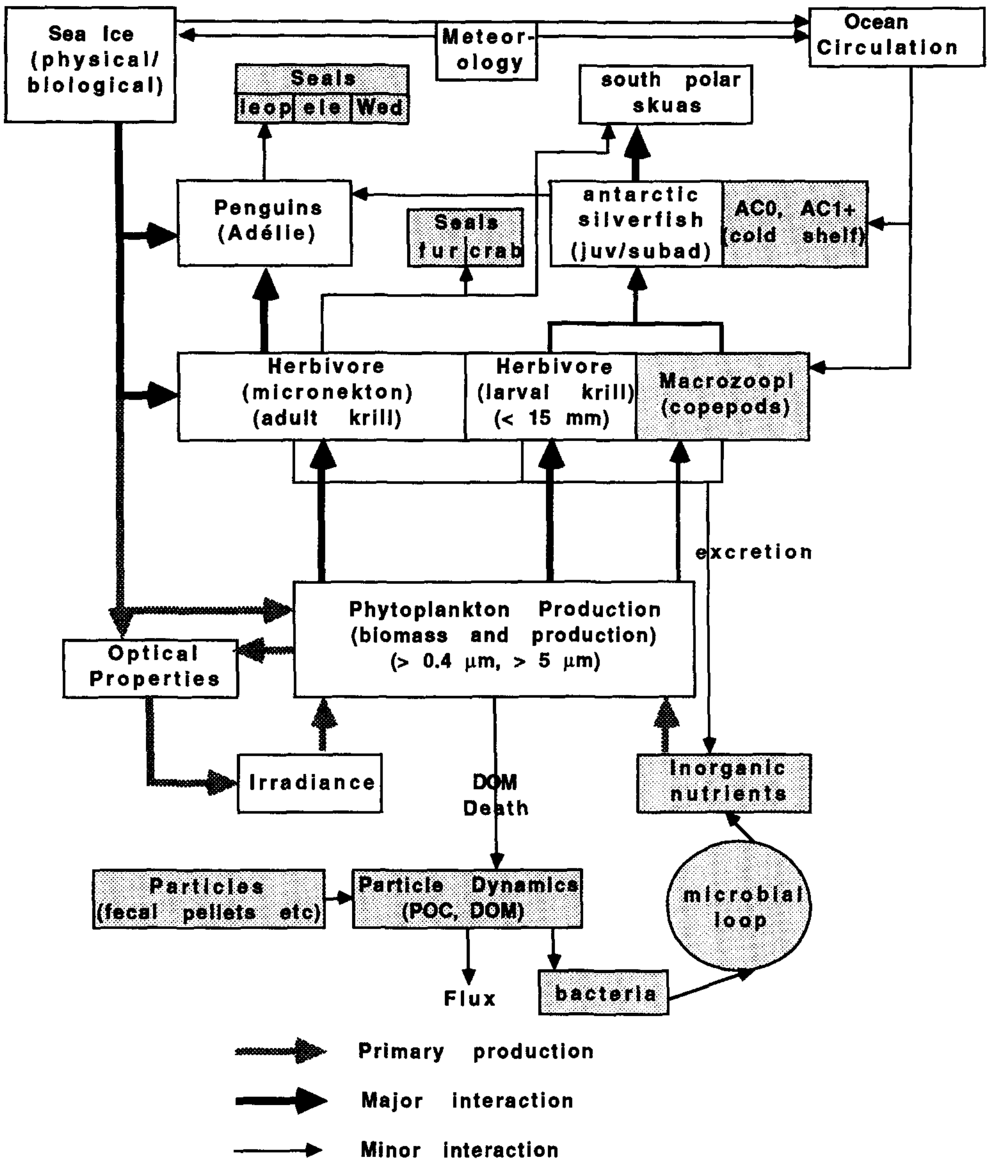


Fig. 3 Conceptual diagram of the ecosystem (food web and environmental factors) investigated by the Palmer LTER. Open boxes indicate components with both processes and parameters measured. Shaded boxes indicate components with parameters only measured.

variability in populations. This ability is vital if we are to measure the effects of increased human pressure on living resources and uphold the agreement of the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) not to fish any living resource (including krill) to such an extent that either the population itself or consumers depending on that food item are affected. With the Palmer LTER we expect to understand the processes underlying interannual variability, and thus be in a position to separate changes due to natural cycles from those due to systematic trends. Understanding natural variability within the Antarctic marine environment is fundamental to our understanding of the more subtle impacts of humankind.

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