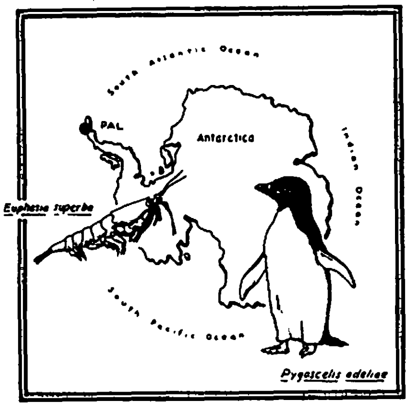


Palmer Station Antarctica (PAL)

RESEARCH SETTING

Research at the Antarctic marine LTER site, Palmer Station and surrounding waters, 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. In polar environments, the annual advance and retreat of the pack ice is an important physical feature covering vast areas of the marine environment. In the Southern Ocean this seasonal cycle of ice formation and melting affects about 50 percent of the open sea.

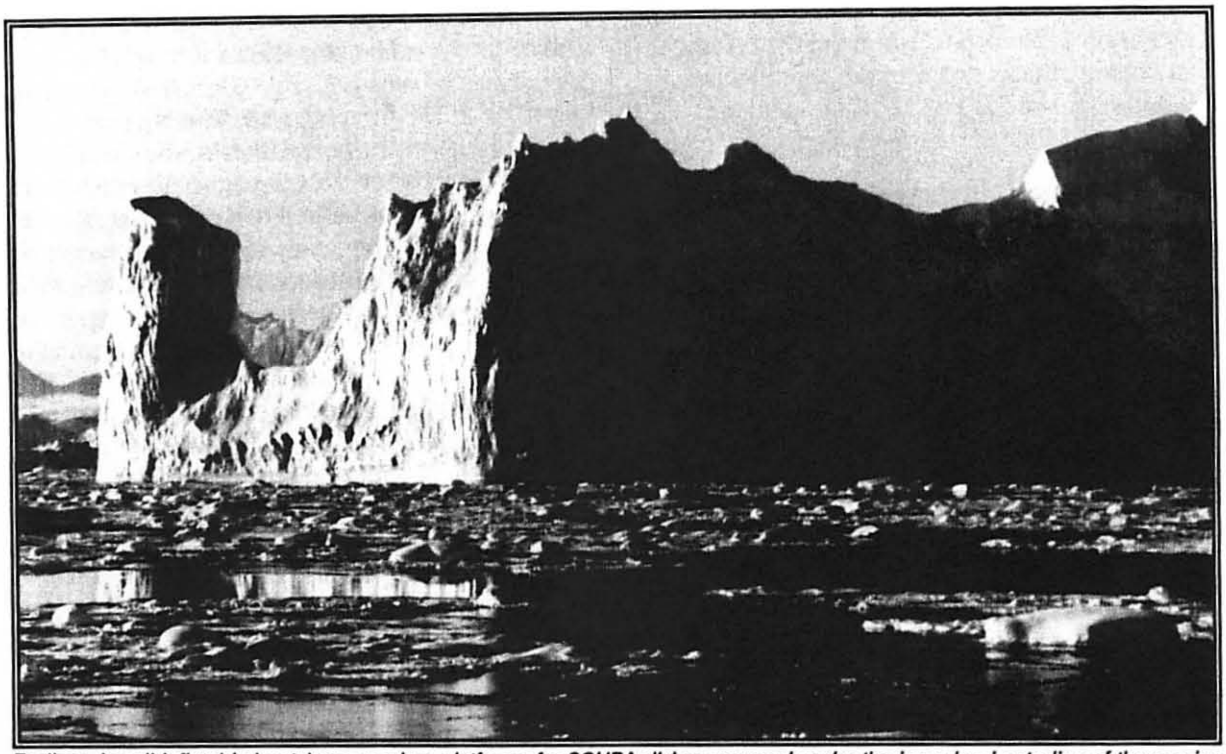
Pack ice not only provides marine habitats distinct from open-water habitats, but also may be the major physical determinant of temporal/spatial changes in the structure and function of polar biota. Thus interannual cycles and/or trends in the annual extent of pack ice are likely to have significant effects on all levels of the food web, from total annual primary production to breeding success in seabirds. 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. In the region around Palmer Station the maximum extent of pack ice varies widely, from near zero to halfway across Drake Passage, and appears to be on a six- to eight-year cycle (Figure 1).

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. Predators tend to concentrate on a core group of species, especially some extremely abundant euphausiids (krill) 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 efficient collectors of their prey items within the foraging area around the rookeries.

Seabirds collect prey samples for us for various physiological and biochemical analyses, and aspects of seabird foraging and reproductive biology will be used as indices of prey abundance and availability. Because these seabirds are easily accessible during the spring and summer breeding season, these indices can be evaluated with greater precision than can the biomass and distribution of their prey by classical oceanographic methods. Although aspects of the biology of dominant consumers may be good indices of prey abundance and availability, we are also examining the mechanisms behind changes in prey levels within the foraging area—such as changes in water mass distribution, variability in reproductive and recruitment success of the prey, and food availability during critical periods of the prey's life history.

Pack Ice / Biological Community Interactions

In the Southern Ocean, pack ice affects primary production in three communities: open water communities, ice-edge blooms, and ice algae. The



Zodiacs (small inflatable boats) are used as platforms for SCUBA diving near and under the ice edge in studies of the sea-ice microbial communities. LANGDON QUETIN

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 and the timing and extent of food availability to the grazers. Although low levels of primary production are detectable in winter, because primary production is limited by light, food availability for herbivores is intensely seasonal and spatially variable. Although macronutrients seldom limit primary production, there may be times during intense ice-edge blooms or within the sea ice when nutrients do limit production.

Growth and reproduction of the dominant herbivore, the antarctic krill (*Euphausia superba*), appear to be food-limited in most areas of the Southern Ocean. The population distributions are suggestive of a close coupling between krill populations, ice dynamics and the associated ice-edge blooms. In addition, unlike adult krill, larvae and juveniles cannot survive long periods of starvation. This inability coupled with a six-month-long winter suggests that food availability in the winter must be critical for survival of larvae and juveniles. Although questions remain about the quantitative importance of ice algae, larvae and juveniles do feed on ice algae both winter and spring; and in winters with heavy pack ice cover, larvae and juveniles are in better physiological condition than in winters with low ice cover. We would predict that better physiological condition should lead to better survival and recruitment of that year class.

Although recruitment and reproductive success vary with environmental conditions, for animals with lifespans of more than several years like krill, total biomass in an undisturbed population can be assumed to be constant. Thus fluctuations in the mesoscale abundance of antarctic krill are usually attributed to their redistribution by physical forces, not to intrinsic features of krill biology. Abundance of adult krill west of the Antarctic Peninsula varies with year, and is greatest after winters of heavy ice cover (Figure 1).

In addition to being the dominant herbivore, antarctic krill is the principal dietary component of both Adélie and chinstrap penguins (*Pygoscelis* *adeliae* and *Pygoscelis antarctica*). Adélies are dependent on pack ice for winter survival (Figure 1) and during critical stages in the reproductive cycle. Although Adélie and chinstrap penguins depend on krill for food during summer, in some years krill are scarce within the foraging area and they must switch to prey such as the antarctic silverfish (*Pleuragramma antarcticum*), with a concomitant decrease in reproductive success.

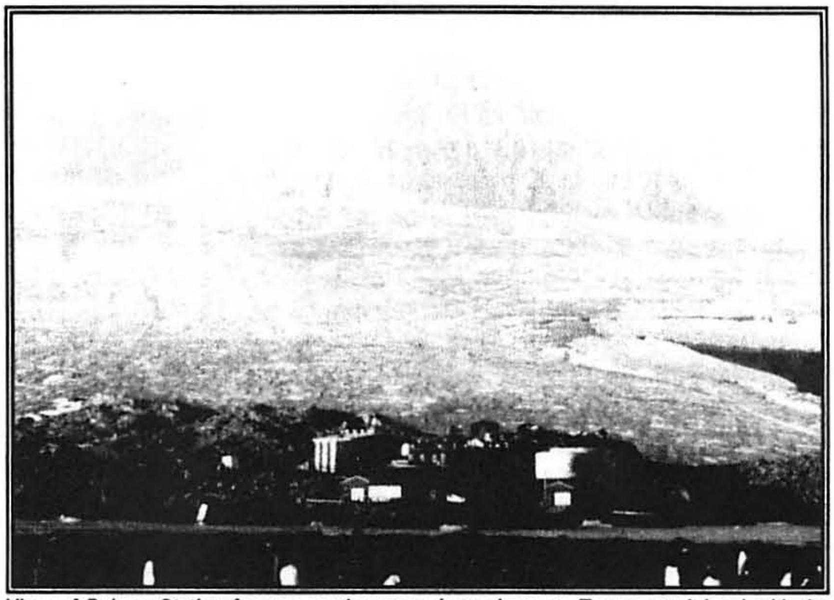
Antarctic silverfish are one of the most abundant fish in high-antarctic marine environments, and serve as an important prey item for many consumers, including south polar skuas (*Catharacta maccormicki*). Spawning adults and the first two age classes of antarctic silverfish occur in cold shelf waters, but older juveniles and subadults move to the warmer East Wind Drift and are often found within krill swarms. Silverfish eat copepods, larval krill and other euphausiids, but rarely adult antarctic krill. Year class strength appears to be higher in years when the ice melts earlier, i.e., warmer years, and thus should be the inverse of that of antarctic krill. Although the mechanisms behind this variation are not yet clear, we believe that the abundance of copepods during the early life history may be critical to survival. The abundance of these copepods may in turn be a function of the timing of the ice-edge blooms, as has been found for shelf-dwelling copepods in the Bering Sea.

Reproductive success of south polar skuas is linked to the extent of pack ice through the abundance of subadult (Age Class 8+) antarctic silverfish in the foraging area. The lag period between high recruitment in antarctic silverfish and reproductive success in the south polar skuas is thus about eight years. Unlike the penguins that arrive at the rookery ready to lay eggs, south polar skuas depend on local food resources within the foraging range of the nesting sites to bring the female into breeding condition. If prey availability is low the female will not lay eggs, and the skuas will not attempt to breed. As a result, reproductive success (number of chicks per pair) is either zero or 1.0 to 1.5 in south polar skuas (Figure 1). In contrast, chicks are fledged per pair of Adélies, 0.67 to 1.17, with no total year class failures.

Predictions suggest that the effects of global change (climate warming, ozone depletion, and increased human pressure on resources) will be more pronounced in Antarctica than in mid-latitudes. Thus detection of these changes above the ever-present background of high natural variability will be easier in Antarctica. Monitoring the ecological effects of changes in sea-ice extent and thickness, and studying the processes underlying these effects, as recommended by the International Geosphere-Biosphere Programme (IGBP), will enable us to predict the impacts of global warming and attendant changes in the

The *Polar Duke*, an ice-strengthened research vessel, is used during time-series and process cruises. LANGDON QUETIN annual cycle of pack ice on antarctic biota. An additional concern is the seasonal thinning of the ozone layer over Antarctica which leads to increases in ultraviolet (UVB) radiation. Although research on the effects of changes in the ozone layer is not within the the core effort, we are closely connected to a separate project examining the effects of UVB on primary production.

One of our principal objectives is to separate long-term (decadal) systematic trends from large interannual variability in populations. This ability is vital if we are to measure the effects of increased human pressure on living resources. In fact, the Antarctic treaty nations signing the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) agreed not to fish any living resource (including krill) to such an extent that either the population itself or consumers depending on that food item were affected. Using the logic that consumers integrate changes over several seasons, CCAMLR is monitoring the consumers of krill rather than the krill themselves in an effort to separate interannual variability in local krill biomass from the effects of commercial fishing. With the Antarctic marine LTER we expect to understand the processes underlying interannual variability, and thus be in an excellent position to separate changes due to natural cycles from those due to commercial fishing pressure.



View of Palmer Station from a nearby penguin rookery on Torgersen Island with the glacier and Mt. Williams in the background. ROBIN ROSS

Site Characteristics

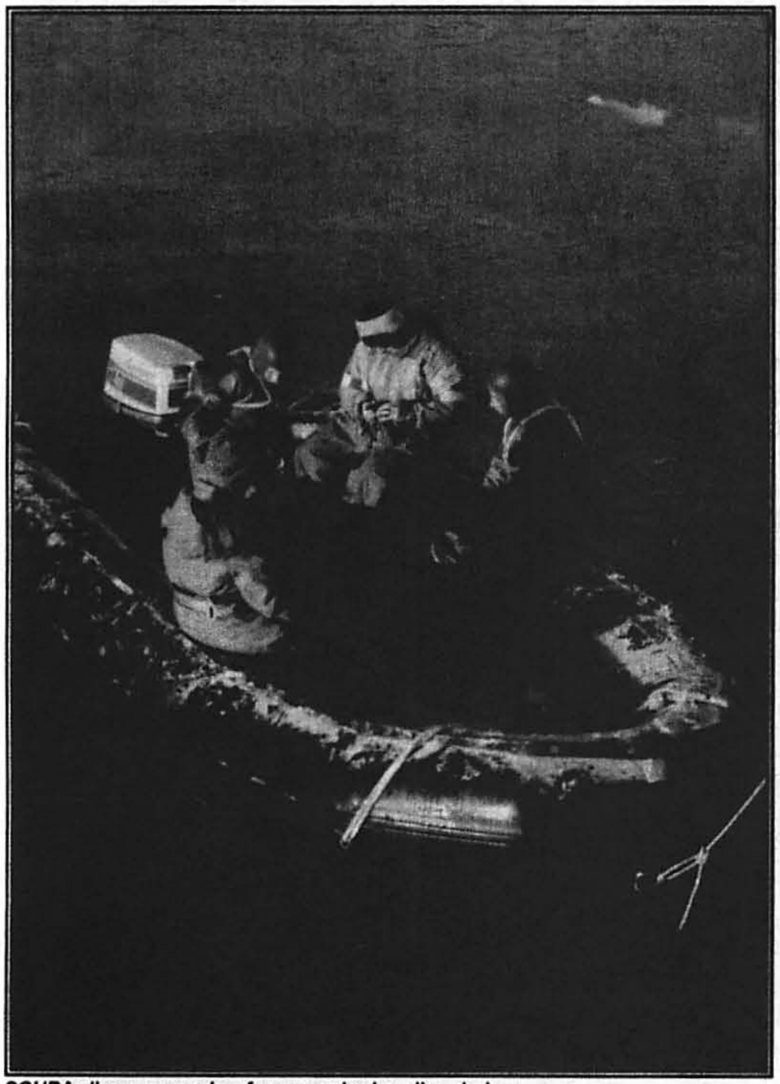
The LTER site region surrounds Palmer Station, located in a protected harbor on the southwest side of Anvers Island midway down the Antarctic Peninsula (64°40'S, 64°W). Within a 9-km radius of Palmer Station are two exposed, prominent points, and groups of islands that extend to the edge of the Bismarck Strait to the southeast. These islands have a diverse topography which extends into the intertidal and subtidal zones surrounding and linking the islands. Palmer Basin, 22 km southwest of Palmer Station, is the only deep basin in the area. The maximum depth is 1,280 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. Both channels are about 450 m deep.

The climate is typically maritime Antarctic, with snow and rain common any time of the year. The temperature at Palmer 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 20 inches and snowfall about 14 inches.

Mesoscale oceanic circulation patterns are reasonably well-known. 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 this gyre. The extent of sea ice is highly variable in the area, with particularly severe ice conditions occurring roughly every seven to 10 years and lasting two to three years.

Palmer is especially well-situated for studies of birds, seals, and other components of the marine ecosystem, and it is equipped with a large, well-outfitted laboratory and seawater aquaria. The station consists of two major and several smaller buildings. Peak population is 43, including support personnel. Many Palmer-based research projects are undertaken in conjunction with the research ship *Polar Duke*. Small boats support research near the station.

Adélie penguins dominate the seabird assemblage, but the islands and points of land in the area also support chinstrap penguins and south polar skuas. About 12,000 pairs of Adélie penguins are distributed among five main island rookeries within two miles of the station. The Adélies from Palmer Station are believed to winter in the pack ice of the Bellingshausen Sea near Palmer. About 600 pairs of south polar skuas reside on about a dozen islands in the vicinity. During the summer breeding season, the seabirds depend on resources in the adjacent deep-water foraging area: 50-km radius for the Adélies, 160 km for the south polar skuas. Both antarctic krill and silverfish are found within Palmer Basin, within the EWD and on the eastern edge of the ACC.



SCUBA divers preparing for an under-ice dive during the austral winter. LANGDON QUETIN

RESEARCH PROGRAM STATUS

Our central hypothesis 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. The overall objectives of the Antarctic marine LTER are:

- to document interannual variability in the development and extent of annual pack ice, and in life-history parameters of primary producers and populations of key species from different trophic levels;
- to quantify the processes that underlie natural variation in these representative populations;
- to construct models that link ecosystem processes to physical environmental variables, and that simulate the spatial/temporal relationships between representative populations; and
- to employ such models to predict and validate the impacts of altered periodicities in the annual extent of pack ice on ecosystem dynamics.

Each component (seabirds, prey, phytoplankton) has a series of testable working hypotheses. Our general approach capitalizes on populations of seabirds that are easily accessible near Palmer Station during a prolonged breeding season, and that sample the marine environment. We are monitoring a suite of critical biological and environmental variables continuously on a small spatial scale (Palmer Station and environs) representing the seabird summer foraging area, but on a long and recurrent temporal scale (every year, the entire breeding season). We will use satellite imagery to continuously monitor certain environmental parameters such as sea ice extent and thickness, sea surface temperature, and potentially color (fluorescence) on larger spatial scales and throughout the year. In addition, automatic weather stations at several selected positions in the regions will continuously monitor atmospheric pressure, wind speed and direction, and air temperature.

Research at Palmer Station and in the surrounding nearshore marine environment focuses on the seabirds, the prey of the seabirds, primary production and hydrographic characteristics of the water column throughout the austral spring/summer. Aspects of the foraging behavior of the penguins and south polar skuas serve as indices of the abundance of the two prey items (krill and silverfish). We are monitoring processes (reproduction, recruitment) and parameters (food availability) that are sensitive to environmental change and are important in the structure and function of the communities.

To verify that this area is representative of the entire region we are extending the spatial scale of sampling of prey distribution, abundance, and physiological condition, water column properties, primary production estimates, and hydrographic measurements during two types of research cruise. (1) Time-series cruises (two weeks) are scheduled for the same timeframe every year (late spring) to survey the foraging area of the seabirds and determine how well the continuous measurements of the nearshore marine environment represent the basin as a whole. (2) Process-oriented cruises (six to eight weeks) at critical times in biological cycles will confirm that local monitoring of critical environmental parameters will allow modeling of regional processes, particularly of primary production and oceanic circulation.

The first of these pairs of cruises is planned for the fall and spring of years representing the extremes of pack ice cover. The inherent interannual variability in the extent of pack ice allows us to "conduct" natural experiments of the effect of pack ice on the various trophic levels by monitoring parameters and processes during and after seasons of different pack ice cover.

FUTURE DIRECTIONS

We anticipate that the core program will serve as a nucleus for satellite or collaborative proposals intended to address questions of interest not presently perceived as intrinsic to the testing of our hypotheses. For example, the initial research plan does not encompass either the antarctic terrestrial or the marine benthic ecosystems because exchanges of organic matter/nutrients appear to flow one way—from the marine to the terrestrial, and from the pelagic to the benthic realm. However, research on terrestrial and benthic ecosystems could easily be conducted from Palmer Station. Thus, this LTER site may be useful for such studies in the future.

We expect that cross-site comparisons of control mechanisms of different populations (biological versus physical) and patterns of interannual spatial and/or temporal variability in populations or parameters like nutrients or dissolved organic carbon (DOC) will prove enlightening. For example, primary production in the Southern Ocean is generally believed to be light-limited, although some nutrient limitation may occur in ice algae and at the end of ice-edge blooms. Cross-site comparisons of the pattern and control of primary production and the resulting community structure and function of nutrient-limited and light-limited ecosystems would be valuable. ■

* PAL Temperature Record 1974 - 1990

(precipitation and evapotranspiration data not available)

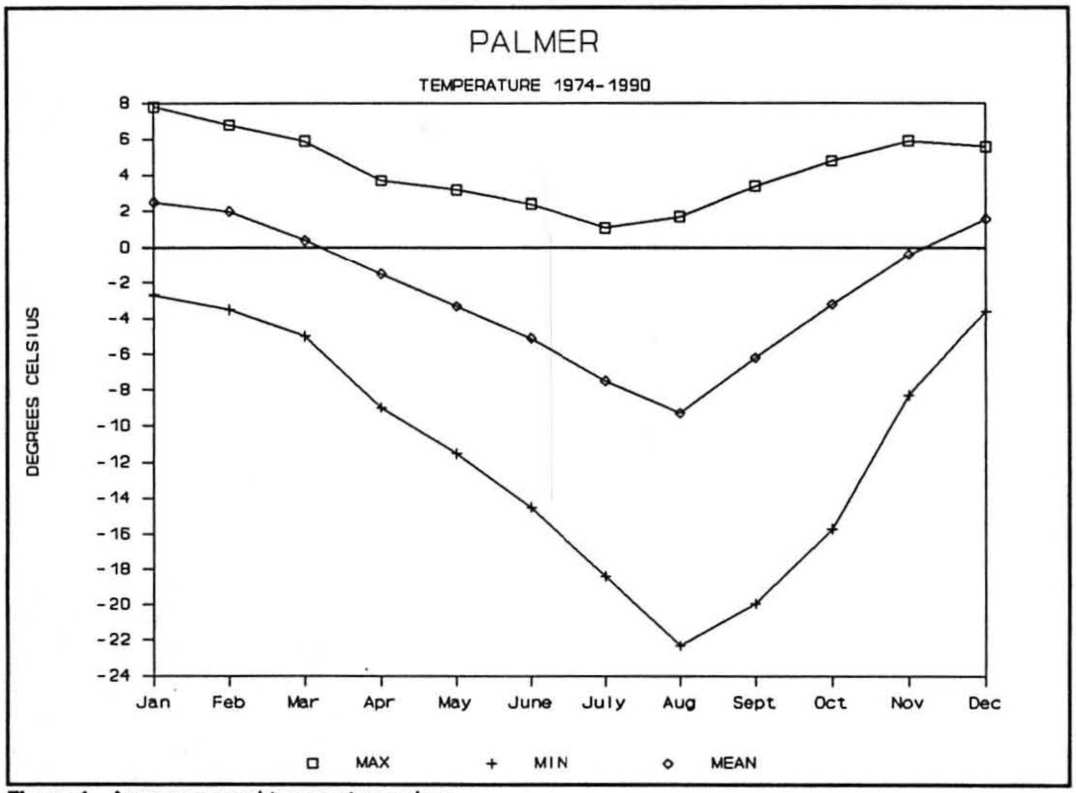


Figure 1. Average annual temperature values.

* Data from on-site or nearest weather station.

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