within 10 km of Palmer Station than in previous years and showed that most penguins were foraging relatively close (<20 km) to their rookeries where acoustic biomass (primarily antarctic krill) was higher than farther offshore.

Annual servicing of the two Palmer LTER program sediment trap moorings (Hugo Island and Palmer Basin) and replacement of two automatic weather stations (AWS Bonaparte and AWS Hugo) (figure 1) were carried out during cruise *PD*96-12 in December 1996. In early January, however, the R/V *Polar Duke* visited Hugo Island to complete the AWS Hugo service and to survey the island bird population. During the day of exchange with BAS personnel at Rothera, LTER procedures were discussed (Smith et al. 1996) and demonstrated to those involved with the new British nearshore sampling program. In addition, the diets of Adélie penguins on Ginger Island were sampled. The R/V *Polar Duke* also paid the first official visit of the U.S. Antarctic Program to the Ukrainian station, Vernadsky Station.

This research cruise was a result of a productive team composed of Palmer LTER research team members with team leaders: Karen Carney with W.R. Fraser, Wendy Kozlowski with M. Vernet, Dave Menzies with R. Smith, and Luis Tupas with D. Karl. Special thanks go to Charleen Johnson and Janice Jones as well as to Antarctic Support Associates personnel and Captain Karl Sanden and his crew of the R/V *Polar Duke*. Our grateful appreciation is extended to all. This research was supported by National Science Foundation grant OPP 96-32763. This is Palmer LTER contribution number 148.

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Palmer LTER program: Underway semicontinuous measurements of surface ocean carbon dioxide concentrations

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Accurate estimation of carbon dioxide (CO_2) fluxes, coupled with an understanding of the processes that control these fluxes, is necessary to predict future CO_2 concentrations in the southern oceans. The chemical, physical, and biological controls on *in situ* CO_2 concentrations cause habitat variability both temporally and spatially. Open ocean areas presently have high nutrient concentrations but low standing stocks of phytoplankton and low rates of primary production. In sharp contrast to the high-nutrient, low-productivity open ocean areas, coastal regions of Antarctica exposed to the annual advance and retreat of sea ice, sustain seasonal phytoplankton blooms with high rates of primary production (Smith and Nelson 1985; Holm-Hansen et al. 1989). Consequently, coastal and ice-edge regions of Antarctica could potentially remove atmospheric CO_2, but these local sinks may be offset by equally large sources of CO_2 during winter periods of net heterotrophy or as a result of the upwelling of CO_2-enriched waters. The seasonal advance of the ice in the fall and retreat in the spring may also affect the flux of CO_2 in the ice-dominated Arctic Ocean and southern oceans. Quantifying these fluxes will require sampling in the dissimilar ecosystems that make up the southern oceans. The Palmer Long-Term Ecological Research (LTER) Program was established in 1990 to study the physical determinants on the antarctic marine ecosystem. The central tenet of the Palmer LTER program is that the annual advance and retreat of sea ice is a major physical determinant of spatial and temporal changes in the structure and function of the antarctic marine ecosystem, from total annual primary production to breeding successes in seabirds (Smith et al. 1995.

During the 1995–1996 and 1996–1997 austral summer LTER field seasons, an automated underway CO_2 measurement system was deployed on the R/V *Polar Duke*. During each field season, spatial surveys of surface water CO_2 concentrations were conducted in coastal and open ocean ecosystems over a 3-month period from mid-December to mid-February. These surveys included four transects across the Drake Passage, five to eight surveys of Arthur Harbor near the U.S. research base at Palmer Station, and a survey of the LTER grid area located off the Antarctic Peninsula (figure 1). The survey of the LTER grid area included transects into coastal areas of Marguerite Bay and Crystal Sound. Overall, 11,679 surface-

Number of underway analyses made for each underway parameter during the LTER field seasons

Parameter	December 1995 to February 1996	December 1996 to February 1997
CO_2 concentration seawater (microatmospheres)	n = 3,679 range 100 to 400	n = 8,000 range 100 to 400
CO_2 concentration atmosphere (microatmospheres)	n = 3,688 mean = 360±3	n = 4,014 mean = 360±3
pH (millivolts)	n = 0	n = 12,014 range –95.0 to –65.0
Dissolved O_2 (micromoles)	n = 0	n = 12,014 range 315 to 475

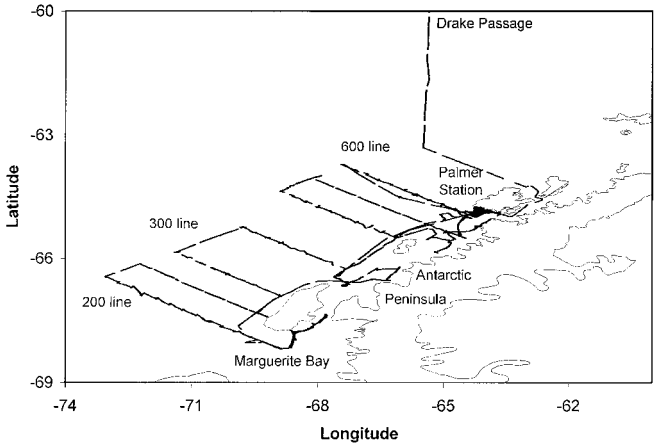

Figure 1. Ship track of the R/V *Polar Duke* during the 1996–1997 LTER field season showing underway measurement locations. The LTER grid is located off the Antarctic Peninsula and the grid lines extend perpendicular to the peninsula to a distance of approximately 200 kilometers from the coast.

water and 7,702 atmospheric CO_2 concentrations were measured over the 2-year period (table).

The underway CO_2 system analyzes surface seawater from the ship's bow intake located approximately 5 meters below the surface and atmospheric air obtained from a line at the top of the bridge. Surface seawater concentrations are determined by continuously pumping water through a counter-flow rotating-disk equilibrator (Schink et al. 1970). A fixed volume of recirculated air is equilibrated with water flowing through the equilibrator by the motion of rotating disks. Equilibrated air is then analyzed for CO_2 concentration with a LICOR 6262 infared CO_2 analyzer. The LICOR is calibrated every 3 hours with a set of standard gases. The system is automated using a PC computer and LabVIEW® software. Equilibrator temperature is measured with an Omega RTD, and system pressure is measured with a Setra pressure transducer. Between calibrations, equilibrator and atmospheric samples are measured every 5 minutes. During the 1996 field season, an Orion pH electrode and an Endeco pulsed oxygen electrode were added to the system. Other underway measurements include salinity, temperature, fluorescence, light, and meteorological parameters.

Initial analysis of three LTER grid lines from the 1995–1996 and 1996–1997 field seasons shows surface seawater CO_2 concentrations range from 100 microatmospheres to 380 microatmospheres compared to a mean atmospheric CO_2 concentration of 360±3 microatmospheres. Typically, areas of surface ocean supersaturation (surface-water CO_2 concentration is greater than atmospheric CO_2 concentration) were found at the oceanic edge of the outer shelf, implying upwelling as a potential source for these CO_2-enriched waters. Areas of undersaturation (surface-water CO_2 concentration is less than atmospheric CO_2 concentration) were encountered in coastal waters and were associated with increases in chlorophyll and oxygen concentrations implying a biological source. For example, undersaturations of 260 and 160 microatmospheres are found approximately 50 kilometers from shore on

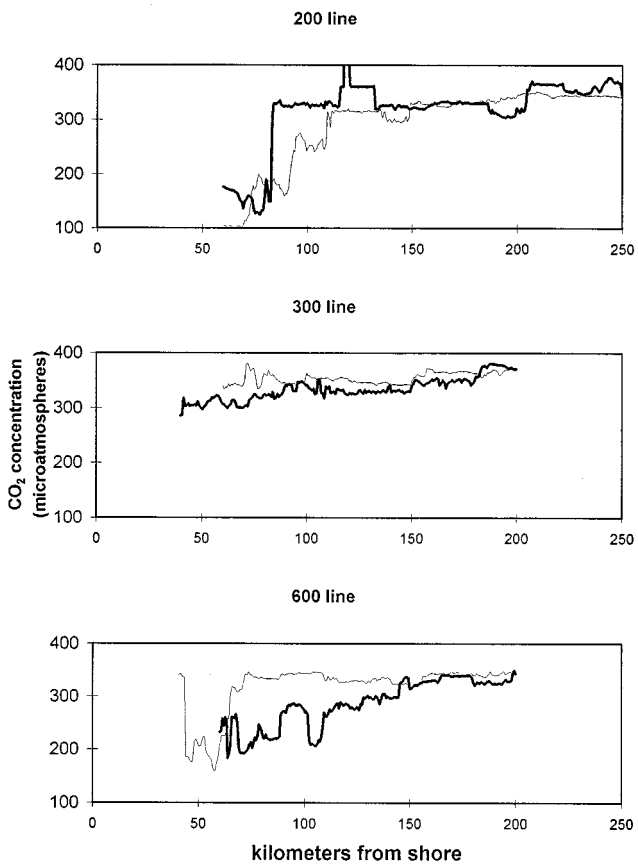

Figure 2. Surface water CO_2 concentrations in microatmospheres, for samples collected on the 200, 300, and 600 lines of the LTER grid. Thick dark lines represent data from the 1995–1996 LTER field season and the thin dark lines represent data from the 1996–1997 LTER field season.

the 200 and 600 grid lines (figure 2). CO_2 concentrations typically increased with increasing distance from shore. In comparison, CO_2 concentrations remained relatively constant along the 300 line (located between the 200 and 600 line) from 50 to 200 kilometers from shore. The coastal areas on the 200 and 600 line are near the mouths of large submarine canyons that may sustain large phytoplankton blooms by an enhanced macro- and micronutrient supply. Further analysis is needed to test the numerous ecological predictions of this hypothesis.

We thank Capt. Karl Sanden, the crew of the R/V *Polar Duke*, and the staff of Antarctic Support Associates for assistance. This work was supported by National Science Foundation grant OPP 96-32763 to R.C. Smith through a subcontract to D.M. Karl.

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A cross-site study of microbial ectoenzyme activities and regulation: Preliminary results from the Palmer Long-Term Ecological Research component

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The microbial loop is ubiquitous in marine and freshwater ecosystems (Hobbie 1994), but dissimilar biotic and abiotic factors regulate its components' activities in different habitats. We have commenced a cross-site project to investigate regulation of microbial ectoenzyme expression and bacterial processes in polar and subtropical marine habitats, sites represented, respectively, by the Palmer Long-Term Ecological Research (LTER) grid (Waters and Smith 1992), and the Hawaii Ocean Time-series (HOT) station ALOHA (A Long-Term Oligotrophic Habitat Assessment) (Karl and Lukas 1996).

Working from R/V *Polar Duke* in the Palmer LTER region, Marguerite Bay, and Tickle Channel from 11 January to 7 February 1997, we first described potential activities of the ectoenzymes α-glucosidase (AGase), ß-glucosidase (BGase), and leucine aminopeptidase (LAPase) in seawater from various depths at *in situ* temperatures. Fluorogenic substrate analogs were applied after Hoppe (1983), Somville and Billen (1983), and Christian and Karl (1995a), and fluorescence was determined in a Perkin-Elmer LS-5B spectrofluorometer. Activities are potential because substrate analogs were applied at saturating rather than trace concentrations.

Within a region of the LTER grid bounded by stations 200.000 to 600.200, surface AGase activities (figure 1*A*) were lowest at the center and seaward of a line approximately 75 kilometers (km) off the peninsula (mean 0.190 nanomoles per liter per day, SD=0.189, n=46). Higher activities at each end of the grid may reflect topographically steered upwelling. Enzyme activity peaked in Marguerite Bay where a phytoplankton bloom (diatoms and *Phaeocystis*) and highest oxygen (O_2) and lowest carbon dioxide (CO_2) levels were encountered (Carrillo and Karl, *Antarctic Journal*, in this issue). The pattern of BGase activities (figure 1*B*) across the grid was similar to that of BGase, except BGase activities were undetectable (<0.1 nanomoles per liter per day) in 29 of 53 surface samples. Across the grid, surface water BGase activities averaged 0.097 nanomoles per liter per day (SD=0.181, n=46). These data support the view that activities in the Antarctic Peninsula coastal zone may represent global minima (Christian and Karl 1995b). Christian and Karl (1994) also noted high BGase activities near sea ice in Marguerite Bay in 1991–1992. During the LTER *PD*97-01 cruise, activities were highest in Marguerite Bay and Tickle Channel; the latter was blocked by sea-ice.

Proteolytic activity is common in polar marine bacteria (Kriss 1963), and Christian and Karl (1995b) described high LAPase activities in the LTER grid. In the southern oceans, this may reflect a bacterial requirement for more dissolved organic matter (DOM) for growth at low temperatures (*sensu* Wiebe, Sheldon, and Pomeroy 1993). Activities peaked (>2,000 nanomoles per liter per day) along the 600 line (figure 2) and decreased with increasing latitude; elevated levels accompanied the bloom in Marguerite Bay and Tickle Passage (approximately 600 to approx-imately 1,800 nanomoles per liter per day, respectively). LAPase activity generally peaked at the sur-