Palmer Long-Term Ecological Research

Palmer LTER: Annual season October 1996 to March 1997

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The Palmer Long-Term Ecological Research (LTER) Program (Smith et al. 1995) completed a sixth season of sampling at Palmer Station. The Palmer LTER sampling strategy combines seasonal time series data from the nearshore Palmer grid and seabird observations from nesting sites near Palmer Station with annual cruises that cover a regional grid along the western Antarctic Peninsula. The LTER January cruise (*PD*97-1) visited the Palmer Basin inshore stations four times to provide continuity in the seasonal record (Ross and Baker, *Antarctic Journal*, in this issue).

A summary of events for the 1996–1997 Palmer field season is given in tables 1 and 2; table 1 gives the weekly standard sampling plan, which varied somewhat, and table 2 gives the season's sampling overview. An additional activity late in the season was excavation of penguin rookery sediments for local paleo studies (S. Emslie). Significant dates include

- arrival of research teams at Palmer (11 November 1996),
- first bird observations (13 October 1996),
- first chlorophyll sample (20 November 1996),
- first zodiac profiling cast (20 November 1996),
- first acoustic transect (22 November 1996),
- start of cruise (11 January 1997),
- end of cruise (13 February 1997),
- arrival of paleo team (3 March 1997),
- last profiling cast (18 March 1997),
- acoustic transect (21 March 1997),
- last LTER bird observation (16 April 1997),
- departure of water-column research teams from Palmer Station (4 April 1997), and
- bird and paleo departure from Palmer Station (17 April 1997).

In table 2, each line summarizes one cycle of standard sampling (from table 1). Initial event number, month begin, day begin, day end, and year are given in the first five columns. The sixth column summarizes the types of standard days included in this particular cycle, and a prime indicates a subset of that standard day. Acoustic transects, hydrographic and optical profiling, phytoplankton sampling, targeted krill tows for physiological condition, and instantaneous growth-rate experiments are given in the next columns followed by general comments.

Some changes in the sampling program were necessary from past seasons (Baker et al. 1996). With six LTER personnel for the 1996–1997 season (1/S016; 1/S032; 1/S028; 1/share; 2/S035) rather than 10 as in 1995–1996 (3/S016; 1.5/S032; 2.5/S028; 3/S035), the daily sampling week had to be reduced by

- sampling five stations instead of nine for weekly profiling hydro-bio-optics;
- sampling for phytoplankton twice weekly at two stations instead of four;
- conducting growth experiments every 2 weeks instead of weekly; and
- dropping krill collection by dives, standard tows, and phosphate measurements.

Further, only the sum of nitrite and nitrate were measured rather than the individual components. Nutrients taken on station at the start of the season were run concurrently with cruise samples when additional personnel were available. The hardware and software for high-performance liquid chromatography and nutrient analysis remained the same as last year. Equipment upgrades included addition of an anemometer for wind speed and a thermometer for air temperature on the zodiac Roze. Also this season, the satellite network link LES9 provided two blocks of approximately 5 hours of online time per day making possible FTP file transfer of data and real-time electronic communication. The data transfer served as both a method of data archive as well as the conduit enabling real-time data analysis at home institutions.

In addition to standard chlorophyll samples run in replicate for the greater than 0.45-micrometer (µm) phytoplankton at selected depths, the <20-µm fraction was sampled at the 50 percent light level [ranging from 2.5 meters (m) to 19 m]. Hydrographic profiles were also run as requested at station Janus (Karentz personal communication) and at the pier (Amos personal communication). Concurrent deployment with the stations' salinity-temperature-depth (STD) instrument will permit intercomparison studies.

During the 1996–1997 U.S. Antarctic Program season, there was no consolidated ice in September 1996. High winds throughout the month of October contributed to ice movement, and the last of the pack ice left on 29 October. Brash ice

Table 1. Palmer LTER 1996–1997 standard sampling: Water column and Adélie penguin

*NOTE: Standard sampling events include acoustics (bio-ac, Biosonics 120 KHz), discrete sample for chlorophyll analysis (chl), conductivity-temperature-depth (ctd, Seabird), high-performance liquid chromotography of phytoplankton pigments (hplc), instantaneous growth rate (igr), targeted tow for krill (krilltarg, Furuno 50 KHz), microscopic analysis of net plankton (net, >5 µm), inorganic nutrient analysis (nuts), photosynthetically active radiation (par), physiological condition (phycon), microscopic analysis of picoplankton (pico, 0.5–5.0 µm), particulate organic carbon (poc), production photosynthesis versus irradiance (Ppi), primary production simulated-*in-situ *(Psis), profiling radiometer (prr, BSI), discrete sample for salinity analysis (sal), transparent exopolymer particles (tep), and standard zooplankton tows (trwl). Station locations include aquatic inshore A through E within 3.2-kilometer (2-mile) limit of Palmer and islands Humble (Hu), Torgersen (To), Christine (Ch), Cormorant (Co), and Litchfield (Li).*

Date	Frequency	Location	Activity
Oct–Mar	Weekly	Palmer Basin	Zodiac: water column sampling
	Day 1	A to E	ROZE: bio-ac
	Day 1	E and B	ROZE: profile ctd, prr/flt, chlsf, salsf
	Day 1	E and B	LEGEND: profile par, hplc, nuts, poc, Ppi (1), Psis, tep, net, pico chlsf, salsf
	Day 1	BON, GAM	ROZE: chl, sals
	Day 2	—	LAB: conclude 24-hr experiments extract hplc and run prod
	Day 2	Area	RDUKE: krilltarg (50 KHz) for igr, phyconl
	Day 2	—	LAB: igr experiments (every 2 weeks)
	Day 3	—	LAB: chl, pigments, length freq
	Day 4	J to F	ROZE: bio-ac
	Day 4	E, J, and H	ROZE: profile ctd, prr/flt, chlsf, salsf
	Day 4	E and B	LEGEND: profile par, hplc, nuts, poc, Ppi, Psis, tep, net, pico chl, salt for S032
	Day 5	—	RDUKE: weather, krilltarg (if not day 2)
	Day 5	—	LAB: conclude 24-hr experiments (Pp) extract hplc and run prod
	Day 6	—	LAB: chl, analysis
		—	LAB: conclude igr experiments
01 Oct–15 Nov	Once/2 days	Hu	Arrival chronology of breeding adults
01 Oct–15 Mar	Daily	Hu, To	Adult overwinter Age-specific survival/recruitment
01 Oct–15 Mar	Weekly	Li, Ch, Co	Adult overwinter Age-specific survival/recruitment
15–30 Nov	Once/colony	Hu, To, Li, Ch, Co	Breeding population size
15 Nov–30 Jan	Daily	Hu, To	Adult breeding chronology and success (chicks creched per pair)
05 Jan–25 Feb	Once/5 days	To	Chick diet composition and meal size
05 Jan–25 Feb	Daily	Hu	Adult foraging trip duration
15–30 Jan	Once/colony	Hu, To, Li, Ch, Co	Chicks creched per colony
01–25 Feb	Once/2 days	Hu	Chick weights at fledging
15 Feb–25 Mar	Weekly/colony	Hu, To, Li, Ch, Co	Colony-specific breeding chronology

Table 2. Palmer LTER event log overview season 1996–1997

*NOTE: See table 1 for definition of standard sampling week. Events include acoustics (bio-ac, Biosonics 120 KHz), discrete sample for chlorophyll analysis (chl), conductivity-temperature-depth (ctd, Seabird), high performance liquid chromotography of phytoplankton pigments (hplc), instantaneous growth rate (igr), targeted tow for krill (krilltarg, 50 KHz), microscopic analysis of net plankton (net, >5 µm), inorganic nutrient analysis (nuts), photosynthetically active radiation (par), physiological condition larvae (phycon), microscopic analysis of picoplankton (pico, 0.5–5.0 µm), particulate organic carbon (poc), production photosynthesis versus irradiance (Ppi), primary production simulated-*in-situ *(Psis), profiling radiometer (prr, BSI), discrete sample for salinity analysis (sal), transparent exopolymer particles (tep), and standard zooplankton tows (trwl).*

Event number	Month	Day Begin	End	Year	Standard day	bio-ac	ctd/prr/ chl/sal	hplc/ nuts/poc	net Ppi	Psis	tep	krilltarg	phycon	igr	Comments
	11	11	20	96	Arrive										Arrive Palmer
1	11	20	21	96	1'2'			EB	E	EB	B				ctdfail; prr_flotation
25	11	22	23	96	123	AC	EB	EB	EB	EB	B	C	C	C	Brash AC
58	11	25	28	96	1345	AE;JF	EB;HJ;Js	EB	EB	EB	B				Krill CD&J-spume
101	12	2	8	96	12345	AC;JF	BE;dk;E;HJ	BE	BE	BE	B	J	J	J	Winds cancel
174	12	10	16	96	123456	AE;JK	EB;HJ;E	EB	EB	EB	B	D;SP;G;C; Csalp	C	C	Krill; heavy fog
251	12	17	19	96	14'2'3	AE;JF	EB;HJ	EB	EB	EB	B				
298	12	24	31	96	1243'5'6	AE;JF	EB;pier;E;HJ	EB	EB	EB	B	D;Dsalp;A	A	A	
376	1	2	7	97	123456	AE	EB;E;HJ	EB	EB	EB	B	No krill			
	1	11		97	Cruise										LTERJAN97 begin
445	1	16	7	97											Krill_feed_exps
	2	12	13	97	Cruise end							Dock			LTERJAN97 end
461	2	18	21	97	1'326			EB	EB	EB	B	Dock			High winds for JI bio-ac
485	2	24	28	97	1342'5	A;BE	EB;E;pier;E; HJ	EB	EB	EB	B				
554	3	3	7	97	123	AE;JF	EB	EB	EB	EB	B	E-A			
593	3	8	11	97	1'2'3'	A;C/ D;JF		EB	EB	EB	B	No krill			
622	3	12	16	97	12'4'6	JF	HJ;EB	EB	EB	EB	B	ArthH			
665	3	18	22	97	1234'6	AE;JF	EB	EB	EB	EB	B	3*C	C	C	Krill A-D
722	4	4	4	97	2'							SWI			Depart Palmer water colm
	4	14	14	97											Winter chl sampling begin
	4	17	17	97											Depart Palmer bird/paleo

continued to appear sporadically through April, accompanied by high winds. This pattern differed from that of 1995–1996 (Baker et al. 1996) when the spring and summer were preceded by a heavy-ice winter, and pack ice did not begin to clear from the nearshore Palmer region until November 1995. Preliminary data show seasonal progression in selected parameters through the spring and summer (figure), providing an overview of the season. The 1996–1997 season showed average to low chlorophyll biomass with initial surface phytoplankton blooms of 5–10 milligrams per cubic meter (mg m^{-3}) in November at station B and in December at station E. Chlorophyll concentrations remained below 1–3 mg m^{-3} through January, followed by another short bloom reaching 5 mg m^{-3} occurring in February 1997 at station E. The nitrate-nitrite showed less pronounced bloom activity this season compared with last season.

Between 22 November and 21 March, 14 acoustic transects were run from stations A to E (figure, block *C*), and 14 from F to J. Acoustic biomass in the spring and early summer was generally less than 100 grams per square meter (g m^{-2}), whereas from mid-January to mid-February acoustic biomass was between 100 and 500 g m^{-2}, decreasing to extremely low values in late February and early March. Length frequency distributions of antarctic krill collected with target tows indicated that age class 1 and 2 krill between 9 and 30 millimeters (mm) dominated the catch in the spring and early summer. Salps were abundant on the surface in late spring (mid- to late December) but did not exclude the krill. Some of the reproductive events associated with breeding chronology of Adélie penguins on Humble Island this season (Fraser et al. 1997) are noted by diamonds in the figure (block *C*). The breeding success of these penguins was 1.47 chicks creched per pair, repre-

senting a small decrease relative to last year.

The LTER seasonal observations of the marine environment, the lower-trophic level abundance and distributions for the area, and the seabird observations at nesting sites near Palmer were recorded from October 1996 to March 1997. The sampling event log, participant list, and other project information for the season are available online (*http://www.icess.ucsb.edu/lter*).

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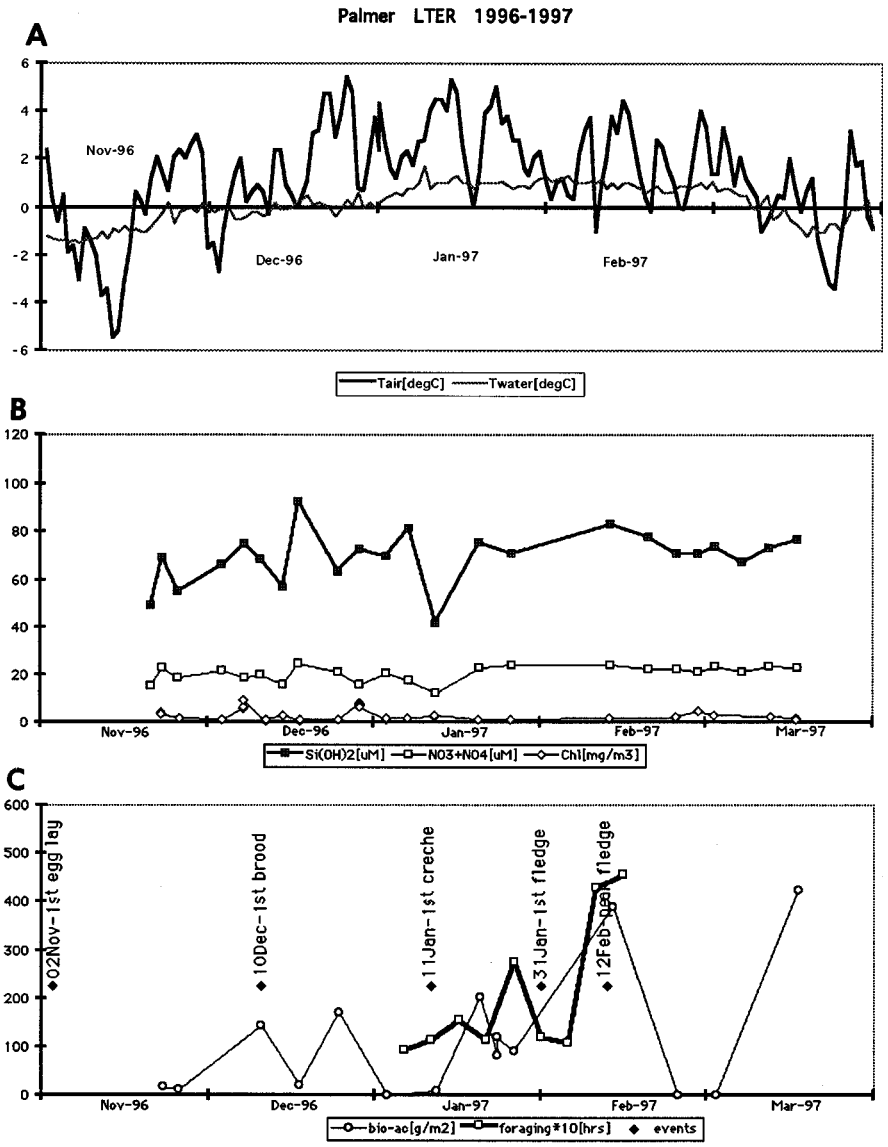

A. Air temperature (in °C; solid line) and water temperature (in °C; boxes) at Palmer Station for the 1996–1997 season. *B.* Surface chlorophyll (in mg m^{-3}; filled diamonds), nitrate+nitrite (micromolar; open squares), and silicate (micromolar; filled squares) at station E for the 1996–1997 season. *C.* Krill abundance (in g m^{-2}; open circles) from transect A to E and Adélie penguin foraging (in hours; open squares). Diamonds indicate day of first egg laying, first brood, first creche, first fledging, and peak fledging at Humble Island for the 1996–1997 season.

Palmer LTER: Annual January cruise for 1997 (*PD*97-1)

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Each year since 1993, the Palmer Long-Term Ecological Research (LTER) program has surveyed a mesoscale study region west of the Antarctic Peninsula with a standard grid that was set up at the initiation of the program (Waters and Smith 1992). During the 1997 cruise aboard the R/V *Polar Duke* (*PD*97-1), sampling occurred between 11 January and 13 February. The cruise plan (table) included standard cardinal transect lines (figure 1), high-density sampling within the foraging range of Adélie penguins nesting near Palmer Station (figure 2), periodic visits to the stations near Palmer, and spatial variance transects. Three of the five major cruise objectives for 1997 are common to all January cruises:

- to document interannual variability in various physical and biological variables along and offshore at the mesoscale in the LTER study area,
- to investigate the linkage between marine resources and Adélie penguins during a time of peak food requirements for the chicks, and
- to maintain seasonal sampling at the stations near Palmer Station.

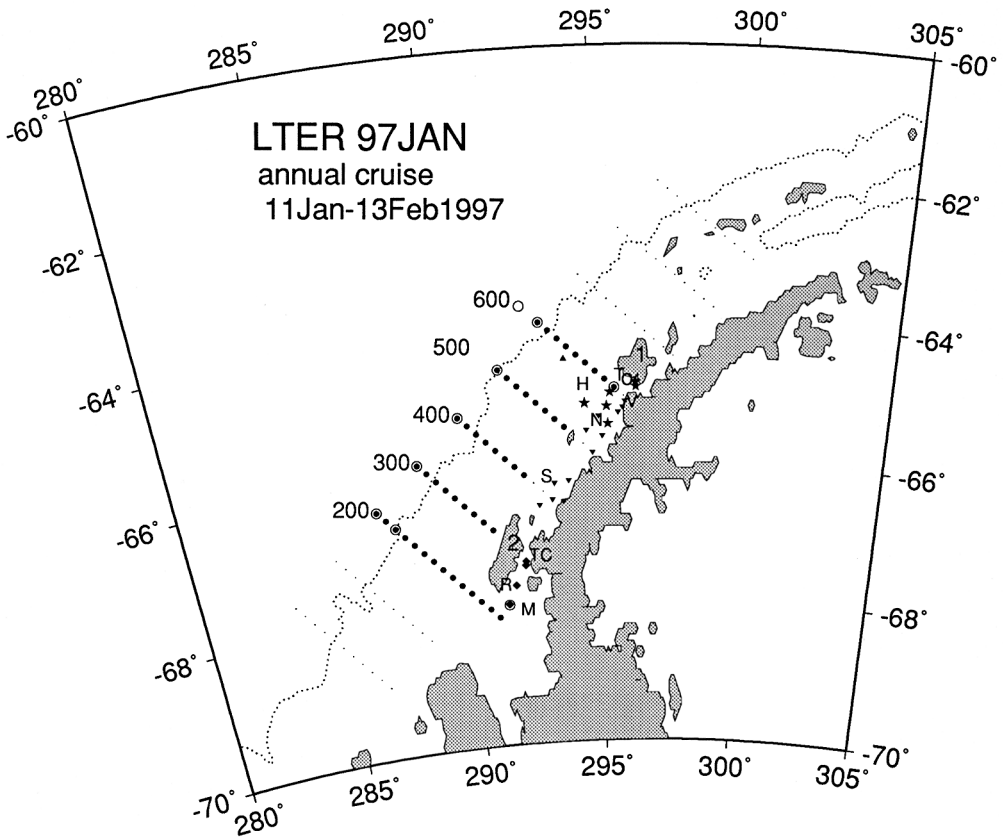

Figure 1. The cardinal stations of the Palmer LTER regional grid (dots) off the Antarctic Peninsula are overlaid to indicate standard station sampling (large dots) and conductivity-temperature-depth (CTD) sampling (circles) during *PD*97-1. Labeled are Anvers Island (1), Adelaide Island (2), Torgersen Island (T), Palmer Station (O), Rothera Station (R), Vernadsky Station (V), Hugo AWS (H; 64°957'S 65°941'W), sediment trap (triangle), northern stations (N; inverted triangle), southern stations (S; inverted triangle), Marguerite Bay (M; diamond), Tickle Channel (TC; diamond), and hydrographic parameters only stations (star). The 1,000-m bathymetry line (dotted) is shown.

Palmer LTER January 1997 (PD97-1) cruise overview

NOTE: Daily events summarized include LTER transect lines (grid line), LTER nearshore stations (grid inshore), high density grid (HD), picket lines (PL), zodiac operations, CTD casts, and automatic weather station (AWS). The proportion of time spent on each activity du ring the cruise is summarized.

Month	Day	Cruise day	Grid	Inshore high-density and picket	Transect, multi, search, zodiac	Other information
Jan	5					Depart Palmer; XBT sampling
Jan	6					
Jan	7					
Jan	8				H	Hugo penguin census; arrive Palmer
Jan	9					
Jan	10					
Jan	11	1		B-J		LFA onboard/film
Jan	12	2	500			500.060; 080; 100; 120
Jan	13	3	500			500.140; 160; 180; 200; weather
Jan	14	4			T(550)	Transect: offshore to Grandidier (550.240–550.010)
Jan	15	5	550			
Jan	16	6	600.040			600.040C; 060; 080; 100
Jan	17	7	600			600.120; 140; 160; 180; 200
Jan	18	8		P (3.7)		600.240C; Hugo Trap
Jan	19	9		B-J	Z*3 (bird)	Torgersen Island beach count; Palmer visitors
Jan	20	10		P*2 (3.7+10)		Salps; krill; whales
Jan	21	11		HD1		Targeted tows
Jan	22	12	600.030		Z*3 (bird)	Humble Island beach count; Palmer DAS repair
Jan	23	13			S1	Search Palmer N-Bismark St; LFA broadcast
Jan	24	14		HD1r		
Jan	25	15	600.040	B; E; H; J	S2	Search Palmer
Jan	26	16	600.040		S3; multi	Targeted tows
Jan	27	17	400			400.040; 060; 080; 100
Jan	28	18	400			400.120; 140; 160; 180; 200C
Jan	29	19	300			300.200C; 180; 160; 140
Jan	30	20	300			300.120; 100; 080; 060; 040
Jan	31	21			T250	Transection to offshore (250.005–250.200)
Feb	1	22	200			200.200C; 180; 160C
Feb	2	23	200			200.140; 120; 100; 080; 060
Feb	3	24	200			200.040; 020; 000; -020
Feb	4	25	200		Z*1 (chk)	200.-040; -060; Ginger Island; Rothera visit
Feb	5	26			Z*1 (diet)	Marguerite Bay; British Antarctic Survey aboard; photosynthetically available radiation; Ginger Island diet sample
Feb	6	27			Z*1 (ice)	Tickle Channel; ice sample; Wyatts Island
Feb	7	28	S		Z*2 (ice)	Zodiac in/out ice; in south Darbel Bay (380.010; 400.000)
Feb	8	29	S			Crossing ceremony; in south Crystal (440.000; 420.015)
Feb	9	30			T (inshore)	Transect; inshore
Feb	10	31	N		Z*1 (ice)	In north Grandidier (520.030; 500.000; 530.005; 550.030)
Feb	11	32	N			575.010; In north Lem (585.010; 595.013); Vernadsky visit
Feb	12	33	600.040	B-J		600.040C
Feb	13	34				Dock Palmer
Feb	14					
Feb	15					Depart Palmer; Gerlache; Dallman Bay
Feb	16		700		S4	XBT 700 line
Feb	17					
Feb	18					
Feb	19					
Feb	20					

These nearshore stations are within 3.7 kilometers (km) of Palmer Station and sampled from zodiacs from November through March to document interannual variability in seasonal patterns (Baker et al., *Antarctic Journal,* in this issue). The fourth objective this year was to document spatial variance of multiple physical and biological parameters on both on/offshore and alongshore transects. The fifth objective was to initiate cooperative studies with the British Antarctic Survey (BAS) making a visit to Rothera Station (figure 1). In addition, the R/V *Polar Duke* participated in a broadcast of *Live from Antarctica 2* from Palmer Station in late January. Questions from middle school students were answered real-time by those onboard through use of satellite communications. Finally, personnel aboard participated in an expendable bathythermograph study directed by Janet Sprintall of Scripps Institution of Oceanography during the southbound crossing.

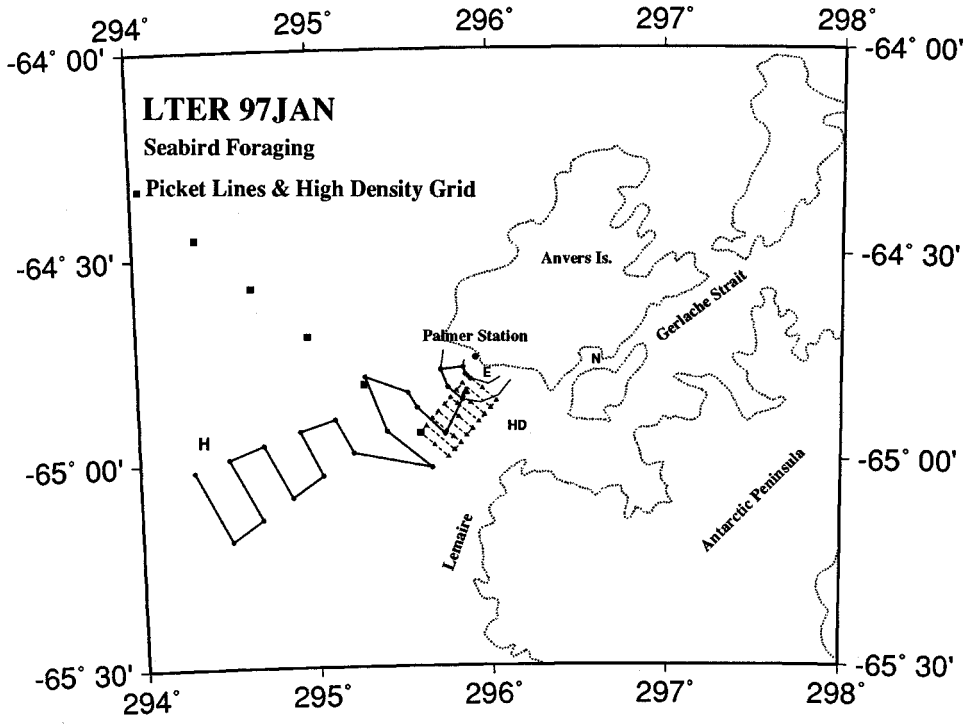

Figure 2. Sampling area near Palmer Station on Anvers Island with the Neumeyer (N) and Gerlache Strait to the East. Locations are shown for inshore station (E) of the Palmer nearshore stations and the Hugo AWS (H). The 3.7-km and 10-km picket lines, the multi-picket line (solid line), and the high-density grid (HD; dashed line) are shown. The LTER regional grid 600 line stations 040, 060, 080, 100, 120 are marked (filled squares).

Standard measurements at stations 20 km apart on cardinal transect lines included seabird community composition as well as the following water column characteristics:

- optics and hydrography,
- gases,
- microbial parameters,
- bacterial production,
- plant pigments,
- primary production, and
- plant physiology.

Bioacoustic surveys and net tows for zooplankton and krill were centered on each station, and physiological condition determined for krill collected. Underway surface measurements between stations included

- temperature,
- salinity,
- fluorescence,
- seabird community composition, and
- carbon dioxide partial pressure (pCO_2), as measured with a carbon dioxide equilibrator system.

Sea ice was encountered only in the southern part of Grandidier Channel (inside north), the inner reaches of Crystal Sound (inside south), and Tickle Channel (TC) in northern Marguerite Bay. Only one bad weather day was logged, preventing sampling at the two outermost stations on the 500 cardinal transect line. Chlorophyll-*a* concentrations were an order of magnitude lower in the northern area of the Peninsula grid in comparison with January 1996. Further, there was less of an onshore-to-offshore biomass gradient and fewer phytoplankton communities dominated by Cryptomonads and Prymnesiophytes. In the southern area of the Peninsula grid, biomass was generally less than 1 milligram per cubic meter (mg m^{-3}), although a large phytoplankton bloom was found within Marguerite Bay having surface chlorophyll values ranging from 10 to 30 mg m^{-3} and water-column-integrated-to-30-m values from 2 to 4 mg m^{-3} that were coincident with low pCO_2 values. Diatoms and the Prymnesiophyte Phaeocystis sp. dominated the phytoplankton community. A mixture of salps and krill was found at many stations, and antarctic krill abundances were at average levels.

In addition to the mesoscale survey, intensive sampling was conducted within the foraging area of Adélie penguins whose reproductive success and foraging ecology were being studied simultaneously by investigators at Palmer Station. Surveys were conducted at Torgersen and Humble Islands in conjunction with zodiac tracking of Adélie penguins. The relative distributions of the predator (Adélie penguins) and prey (antarctic krill) were observed on 3.7- and 10-km picket-line transects (Smith et al. 1995) and on high-density grids (figure 2). Only seabird counts were performed on the picket lines farther than 10 km from Palmer Station. The 10-km × 20-km high-density grid (figure 2), as described for January 1995 (Quetin et al. 1995), was repeated twice. These seabird censuses showed higher numbers of Adélie penguins foraging

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

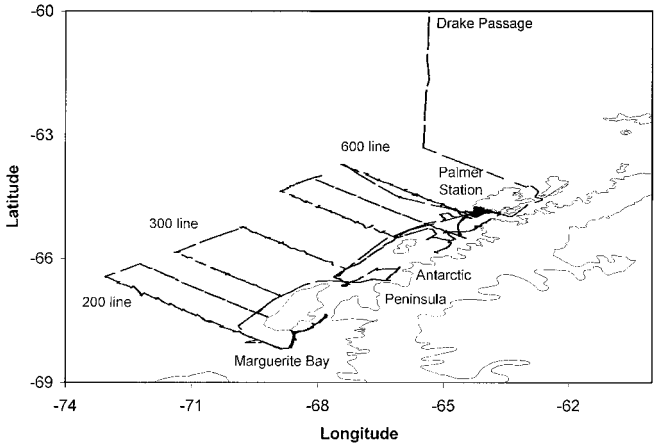

Figure 1. Ship track of the R/V *Polar Duke* during the 1996–1997 LTER field season showing underway measurement locations. The LTER grid is located off the Antarctic Peninsula and the grid lines extend perpendicular to the peninsula to a distance of approximately 200 kilometers from the coast.

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

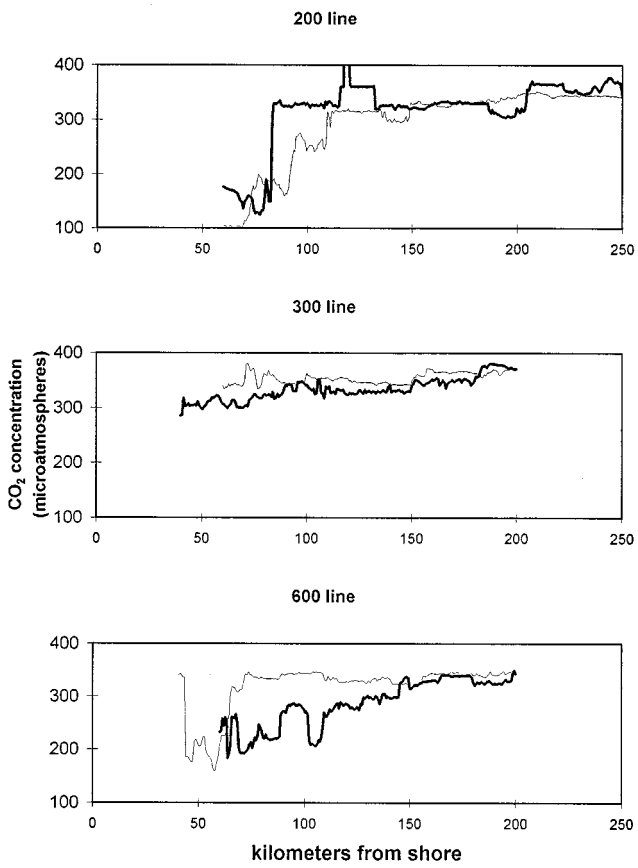

Figure 2. Surface water CO_2 concentrations in microatmospheres, for samples collected on the 200, 300, and 600 lines of the LTER grid. Thick dark lines represent data from the 1995–1996 LTER field season and the thin dark lines represent data from the 1996–1997 LTER field season.

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.

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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-

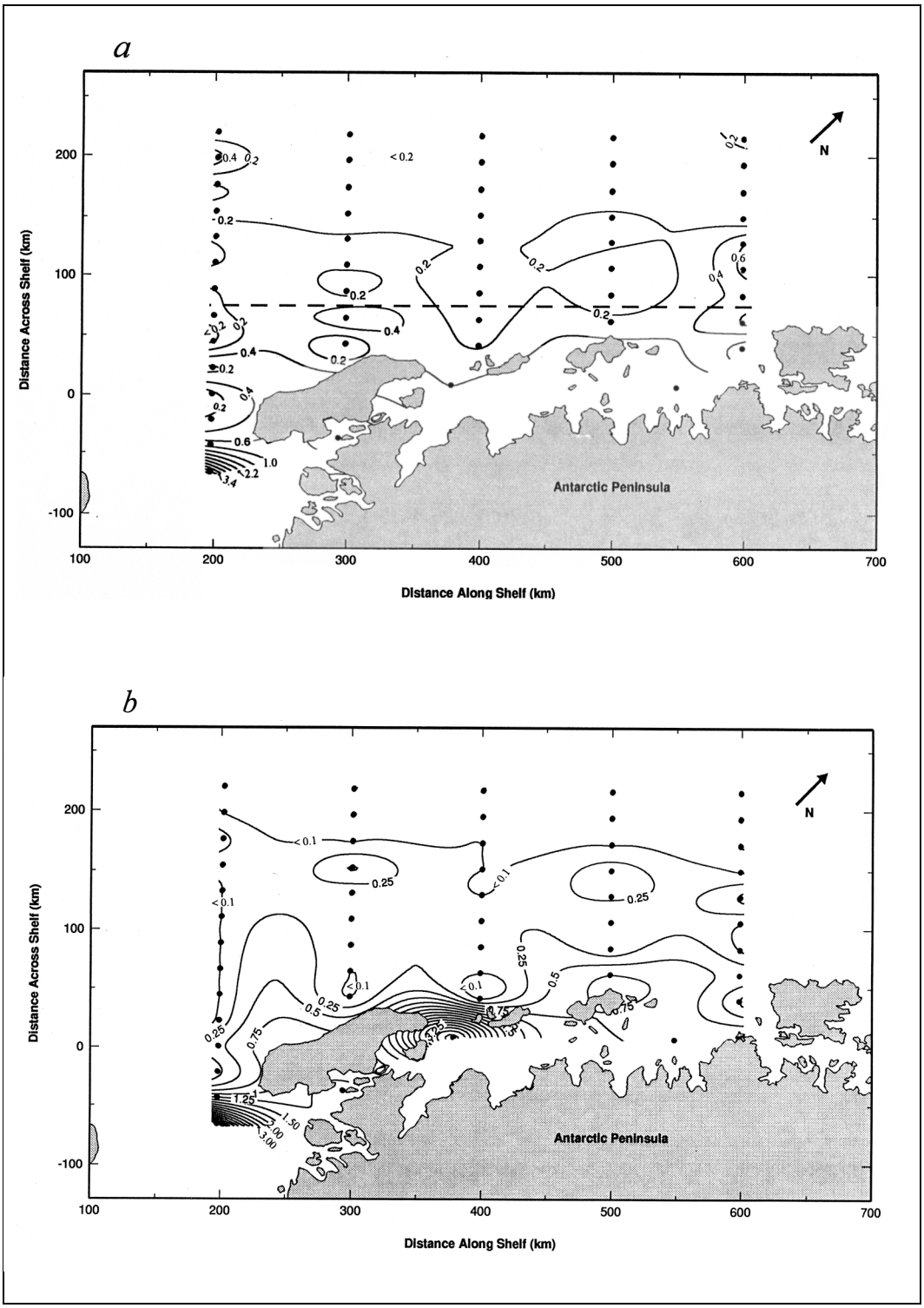

Figure 1. *A.* α-glucosidase, and *B.* ß-glucosidase activities across the surface of the LTER grid during *PD*97-01. Lowest AGase activities were recorded seaward of the dashed line on *A*. Solid circles indicate the positions where samples were collected. Contours are presented as nanomoles of substrate hydrolyzed per liter per day; contour intervals are *A*, 0.2 and *B*, 0.25.

face and decreased rapidly below the 13 percent light level (approximately 50 meters) (figure 3).

LAPase activities in 0.8-micrometer Nuclepore-filtered seawater with organic or inorganic nitrogen (N) [histidine, leucine, proline, tryptophan, phenylalanine, tyrosine, glycine, imidazole, ammonium (NH_4), nitrate (NO_3)] nutrient additions applied separately at 1 micromolar (μ*M*)—N were generally repressed only by phenylalanine and tyrosine through 48-hour incubations. That no other N-source consistently affected the activity of any of these enzymes or increased bacterial numbers, the latter determined through flow cytometry (Monger and Landry 1993) may in part result from low organic nutrient diversity (Griffiths, Caldwell, and Morita 1984); during RACER II, a mixture of 18 amino acids (Sigma AA-S-18) enhanced bacterial numbers by 8.5-fold over a 72-hour incubation (Bird personal communication). Inorganic N availability rarely limits bacterial production in the southern oceans, and concentrations applied here were below those generally found in this area.

Our cross-site study has so far shown that microbial populations at these sites respond differently to tyrosine. At station ALOHA, AGase and LAPase activities are strongly enhanced. Furthermore, although LAPase activities at ALOHA are considerably lower, greatest reductions in activity with depth at that site occur below approximately 125 meters.

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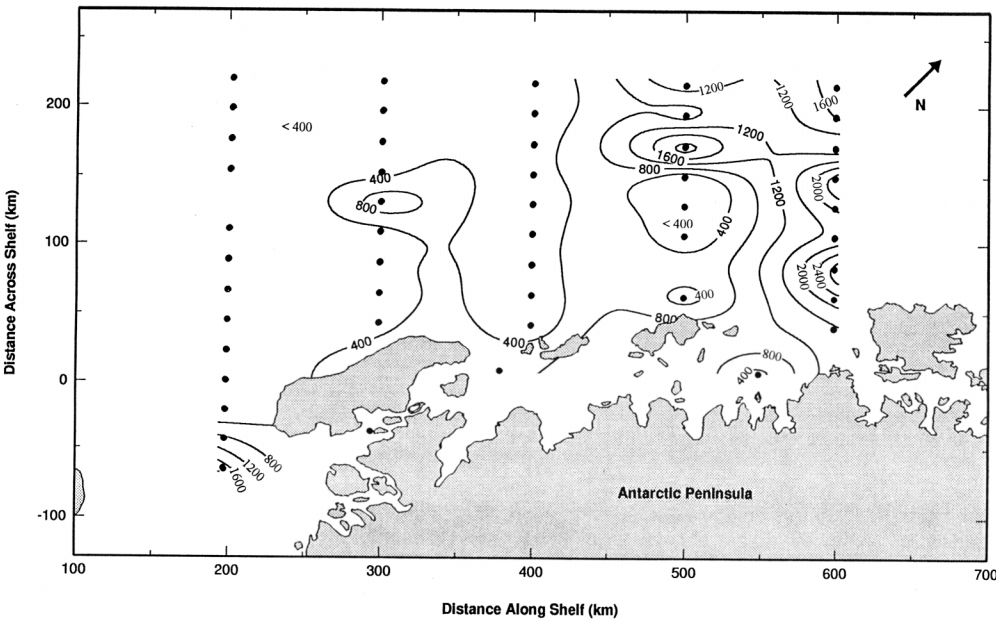

Figure 2. LAPase activities across the surface of the LTER grid during *PD*97-01. Solid circles indicate the positions where samples were collected. Contours are presented as nanomoles of substrate hydrolyzed per liter per day; contour interval is 400.

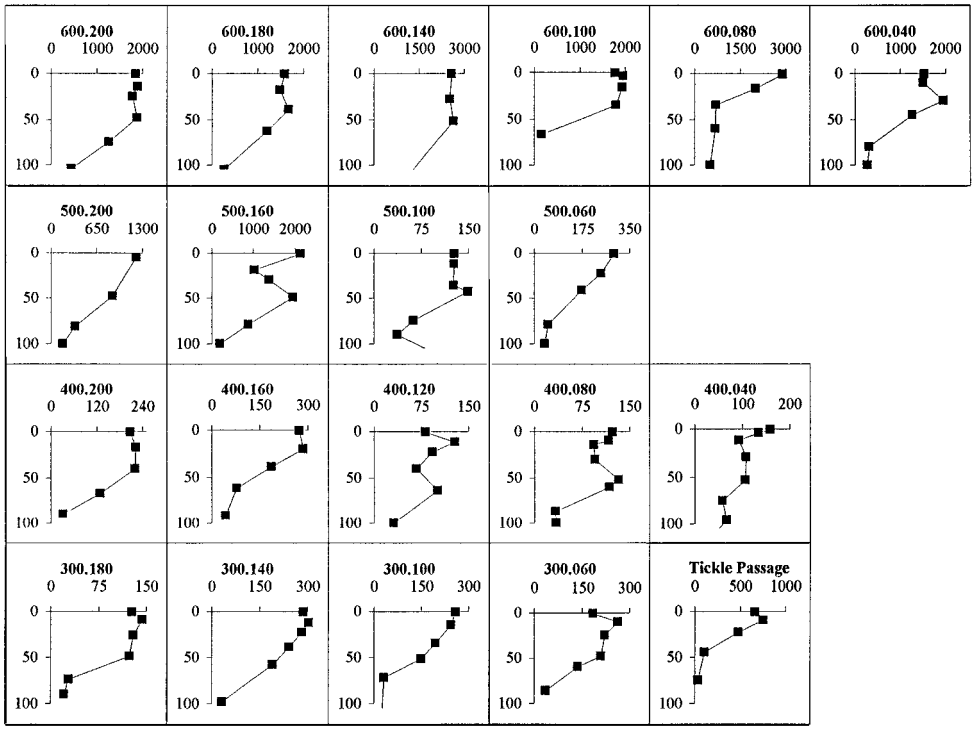

Figure 3. LAPase activities often fell by one order of magnitude at the 13 percent light level (approximately 50 m). x-axis is nanomoles of substrate hydrolyzed per liter per day. Station numbers are in bold.

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Palmer LTER: Stable interannual successional patterns of phytoplankton communities in the coastal waters off Palmer Station, Antarctica

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Over the austral spring/summer periods from November 1991 through January 1994, water column profiles were obtained at the Long-Term Ecological Research (LTER) program station B (Sta B in figure 1) for concurrent determinations of physical and biological parameters related to phytoplankton dynamics. A Seabird® CTD (SEACAT SBE 19-03) was profiled free-fall from surface to near bottom from a Mark V Zodiac®. The instrument samples at a rate of 2 hertz. At a lowering rate of approximately 5 meters per second, approximately four samples per meter were retrieved. Along with the physical measurements, 615 discrete water column samples were collected for pigment determination in 5-liter GoFlo bottles within a few hours of solar noon. Samples were transported in dark bottles within 30 minutes of collection to Palmer Station (figure 1) for analyses. A more detailed description of the sampling strategy is given by Moline and Prézelin (1996, 1997).

Aliquots of all whole-water samples were analyzed for the algal pigments using reverse-phase high-performance liquid chromatography procedures of Wright et al. (1991). Specific details of the sample processing and pigment identification are described elsewhere (Moline and Prézelin 1996; Claustre, Moline, and Prézelin 1997). Pigment data were used to estimate phytoplankton standing crop (chlorophyll-*a*) and as chemotaxonomic markers to differentiate between algal groups. The four taxonomic groups that dominated the phytoplankton communities in the study area over the 3 years were diatoms, prymnesiophytes, cryptophytes, and chlorophytes. From the class-specific accessory pigments and the total chlorophyll-*a*, the percentage contribution of each taxonomic group to the overall biomass was calculated using multiple regression techniques (Everitt et al. 1990; Claustre et al. 1997). This approach indicated that the dominant accessory pigments (fucoxanthin, alloxanthin, 19'-hexanoyloxyfucoxathin (HF) + 19'-butanoyloxyfucoxathin (BF) and chlorophyll-

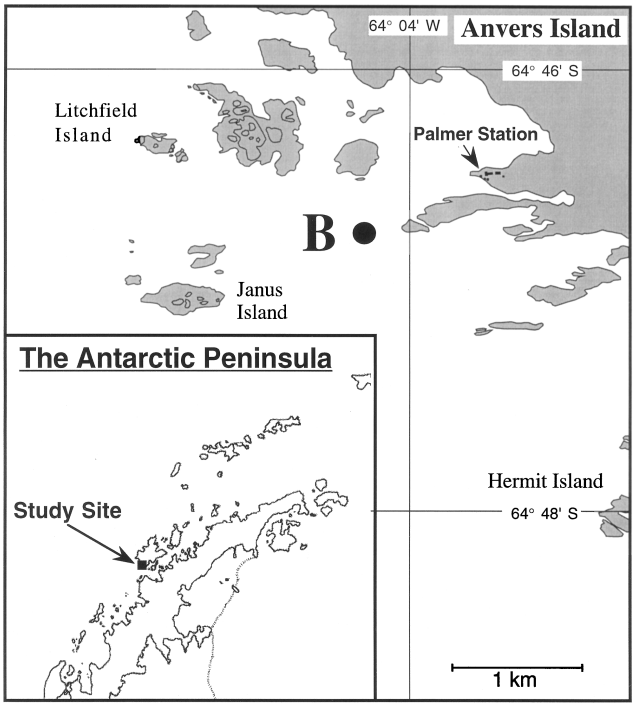

Figure 1. Location of LTER sampling station B (64°46.45'S 64°03.27'W) with respect to Palmer Station and the Antarctic Peninsula (inset). (km denotes kilometer.)

b) explained 99 percent of the variability in the measured chlorophyll-*a* (figure 2*A*).

High interannual variability in peak phytoplankton standing stock [2.3–29.2 milligrams of chlorophyll-*a* per cubic meter (mg chl *a* m^{-3})] and integrated chlorophyll-*a* was evident during the 3-year sampling period from 1991 to 1994 (figure 2*B*). Seasonal and annual patterns were primarily driven by water column stability influenced by local wind stress, which varied dramatically between years (Moline and Prézelin 1996). In 1991–1992, during an extended period of low-velocity winds, the depth of the mixed layer shallowed and a large bloom developed (figure 2*B*, Moline and Prézelin 1996, 1997; Moline et al. 1997). In contrast, during the 1992–1993 season, continual daily average wind speeds greater than 12 meters per second resulted in low biomass accumulation (figure 2*B*). Low biomass was measured after the ice broke out during the 1993–1994 season as a result of high wind speeds. As with the first year, however, the surface bloom in December 1993 was associated with periods of low wind stress (Moline and Prézelin 1996).

Despite high interannual variability in chlorophyll-*a* at station B from 1991 to 1994, a constant and repeated pattern in the succession of the phytoplankton groups was observed. Prymnesiophytes (as indicated by HF+BF) accounted for up to 50 percent of the biomass in the early spring (1993–1994), during periods of substantial ice cover (figure 3). By November in all 3 years, the majority of the phytoplankton biomass was composed of primarily (up to 90 percent) diatoms (fucoxanthin). These populations dramatically declined in December all 3 years. Diatoms were replaced by significant surface populations (>75 percent) of cryptophytes during the summers (figure 3). Chlorophytes were ubiquitous throughout the study period; however, they never accounted for more than 20 percent of the total phytoplankton biomass.

The sequence of dominance (and decline) of diatoms, prymnesiophytes, and chlorophytes could not be explained by hydrographic, nutrient

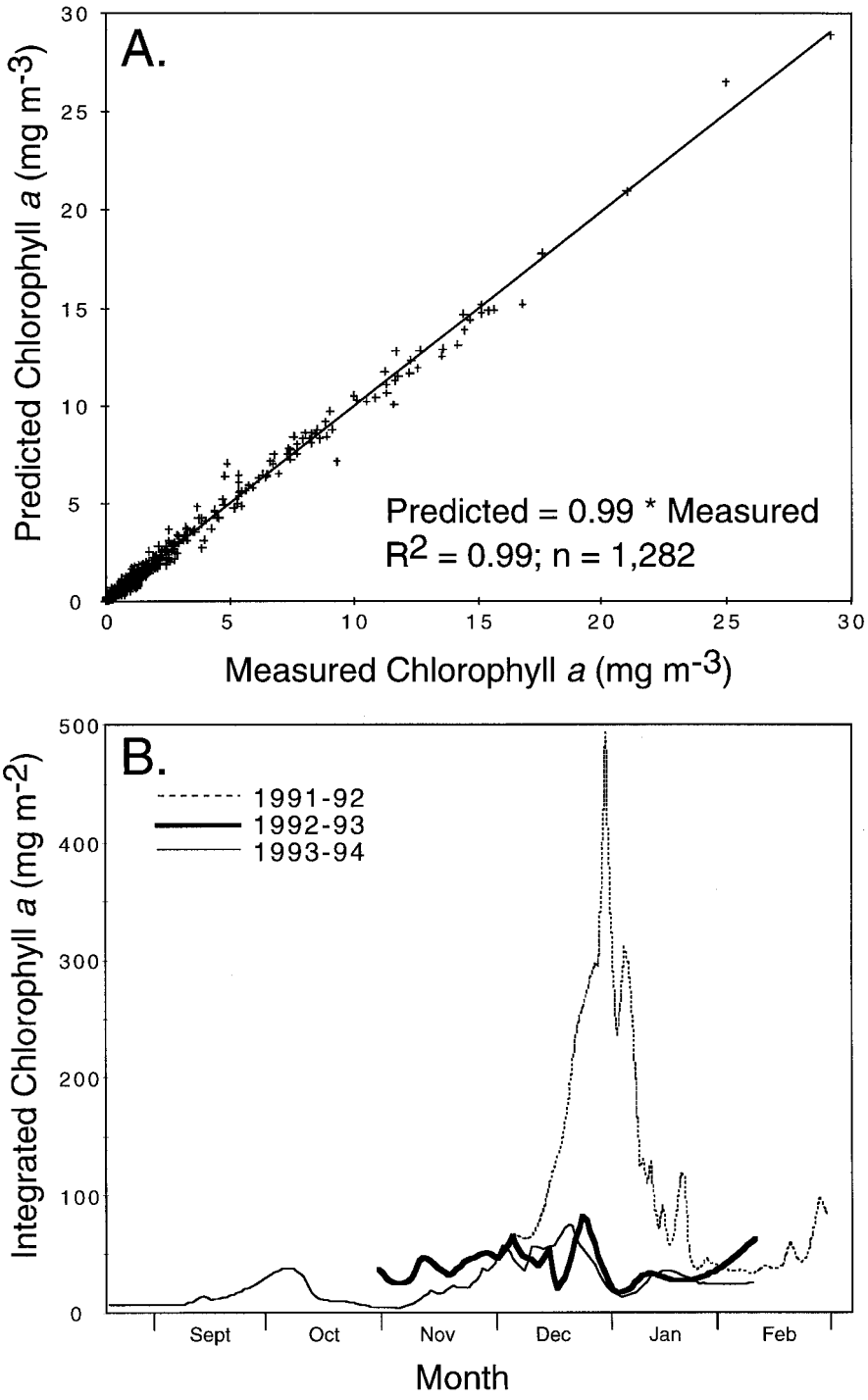

Figure 2. *A.* Measured chlorophyll-*a* versus predicted chlorophyll-*a* from multiple regression analyses (see text) on all samples collected from LTER nearshore stations B and E from 1991 to 1994 (see Moline and Prézelin 1996). *B.* Interannual variation in the depth-integrated chlorophyll-*a* at station B from 1991 to 1994.

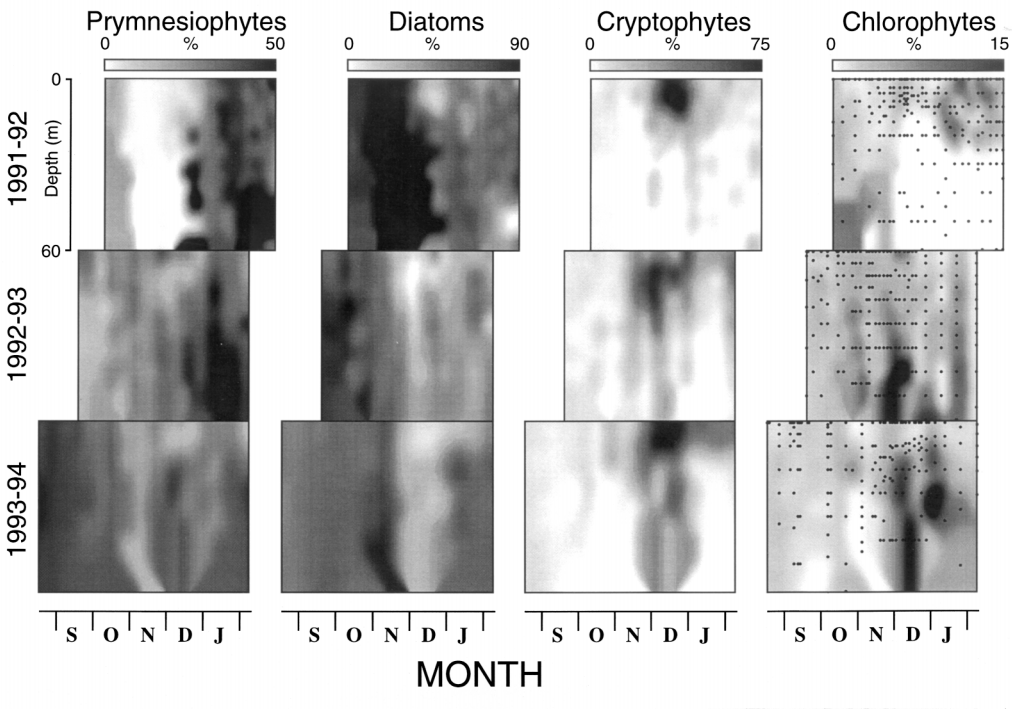

Figure 3. The seasonal variation in depth distribution of the percentage of total chlorophyll-*a* concentration by four phytoplankton groups at LTER station B from 1991 to 1994. Note the differences in the percentage scale for each taxonomic group. Overlayed on the contours for chlorophytes is the depth/time distribution of discrete samples (filled circles).

fields and light fields. The transition to cryptophytes, however, coincided with the initiation of glacial meltwater input to the coastal waters and was significantly dependent (MANOVA, $p<<0.001$) on the relatively high-temperature/low-salinity water characteristic of the meltwater lens (Moline unpublished data).

The occurrence of cryptophytes also correlated with the daily mean air temperature measured during the 3-year study period (figure 3*B*). When mean air temperatures exceeded the freezing point, the percentage of cryptophytes to the total biomass increased significantly from approximately 5 percent to approximately 15 percent (ANOVA; $P<0.05$). As the mean temperature increased to 1–2°C, a highly significant increase was noted in the percentage cryptophytes to approximately 30 percent (ANOVA; $P<<0.001$). Overall, the difference was highly significant between samples greater than 0°C and those less than 0°C (ANOVA; $P<<0.001$), and this finding supported the contention that changes in phytoplankton community structure were in response to the formation of glacial meltwater.

Mean air temperatures along the Antarctic Peninsula have increased significantly (2–3°C) over the past 50 years (King 1994). The increased temperature will likely alter the spatial extent and timing of glacial meltwater runoff, which is already a significant geographic feature of the Antarctic Peninsula during summer months, extending 80–100 kilometers offshore.

We hypothesize that, over large timescales, the consistency in seasonal phytoplankton succession may prove a more robust predictor for "creeping" environmental change in antarctic coastal waters than will highly variable biomass and primary production indices.

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