Antarctic Marine Living Resources (AMLR) Program

The U.S. Antarctic Marine Living Resources (AMLR) program: 1997–1998 field season activities

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The U.S. Antarctic Marine Living Resources (AMLR) program has developed and conducted a research plan tailored to the goals of the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), part of the Antarctic Treaty System. The Convention manages antarctic fisheries to conserve targeted species, while also taking into account the impact fishing activities might have on other living organisms in the antarctic ecosystem. CCAMLR's unique management regime has come to be known as the "ecosystem approach." In keeping with CCAMLR's mandate, the impact of the krill (*Euphausia superba*) fishery upon dependent predators must be understood.

The AMLR program monitors finfish and krill fisheries, projects sustainable yields where possible, and formulates management advice and options. In addition, the program conducts field research with the long-term objective of describing the functional relationships between krill, their predators, and their environment. The field program is based on two working hypotheses:

- Krill predators respond to changes in the availability of their food.
- The distribution of krill is affected by both physical and biological aspects of their environment.

For eight consecutive seasons, the AMLR field program included a research cruise near Elephant, Clarence, and King George Islands, which are among the South Shetland Islands at the tip of the Antarctic Peninsula. Land-based studies were conducted at a field camp on Seal Island, off the northwest coast of Elephant Island. Because Seal Island was found to be unsafe due to landslide hazards, however, research at the camp was discontinued. Beginning in the 1996–1997 season, the AMLR study area was expanded to include a larger area around the South Shetland Islands, and a new field camp was established at Cape Shirreff, Livingston Island (figure 1). The 1997–1998 season continued with descriptive surveys of the pelagic ecosystem in the expanded AMLR study area and studies on the reproductive success and feeding ecology of pinnipeds and seabirds at Cape Shirreff. In addition, a bottom trawl survey was conducted to describe the abundance and distribution of bottom fish in the South Shetland Islands area. As in the past, research was also conducted at Palmer Station, a U.S. station on Anvers Island farther south on the Peninsula.

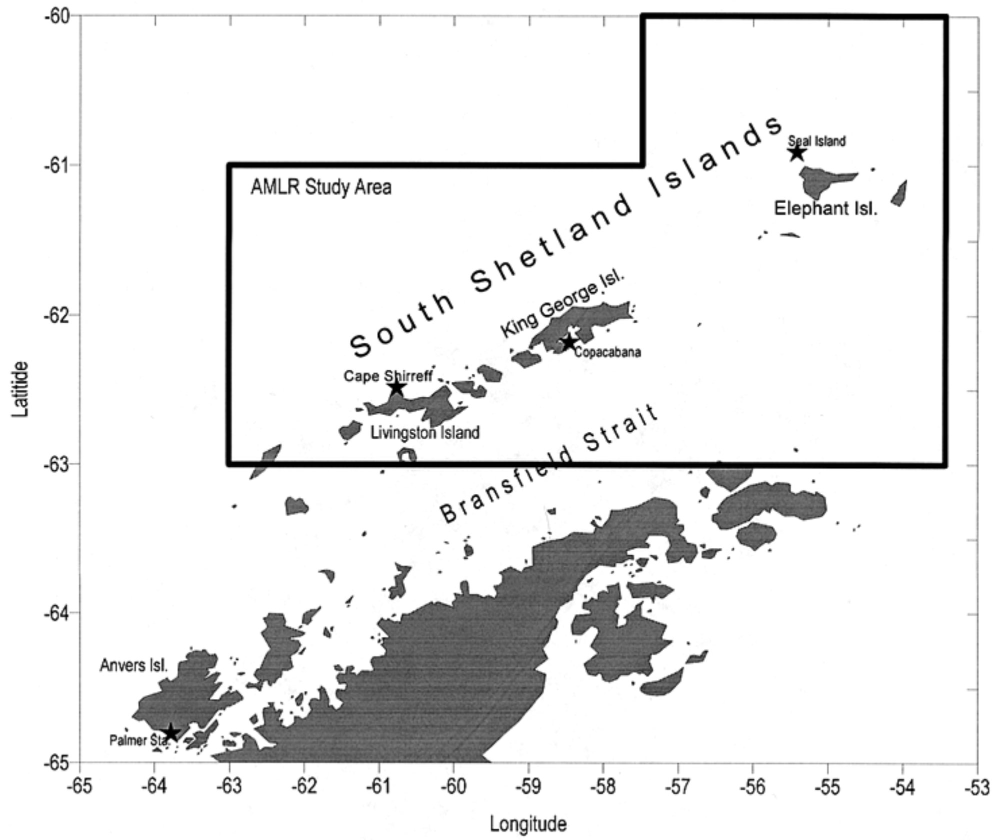

Figure 1. Locations of the U.S. AMLR field program: research cruise near Elephant, Clarence, King George, and Livingston Islands (AMLR study area); and land-based studies at Cape Shirreff and Palmer Station.

The specific objectives of the 1997–1998 field season were the following:

- to map the physical structure of the upper 750 meters, including the thermohaline composition, oceanic fronts, water-mass boundaries, surface currents, eddies, and turbulent mixing;
- to map the distribution of phytoplankton biomass and production;
- to map the distribution of zooplankton (krill and other species), including the horizontal and vertical variations in krill density and demographic characteristics;
- to conduct bottom trawls at selected sites around the South Shetland Islands to provide baseline estimates of abundance, species size and composition, and demographic structure of fish species;
- to describe the reproductive success, attendance behavior, feeding ecology, and diving behavior of seabirds and pinnipeds at Cape Shirreff; and
- to describe the reproductive success, feeding ecology, and growth rates of Adélie penguins (*Pygoscelis adeliae*) throughout the reproductive season at Palmer Station.

The cruise was conducted aboard the chartered research vessel *Yuzhmorgeologiya*. The ship departed Punta Arenas, Chile, on 1 January 1998 to begin Leg I of the cruise; the leg was completed on 31 January. Following a port call, Leg II was conducted 3 February to 5 March. After another port call, Leg III was conducted 9 March to 7 April.

During Legs I and II, a large-area survey of 107 conductivity-temperature-depth (CTD)/carousel and net sampling stations, separated by acoustic transects, was conducted in the expanded AMLR study area (Survey A on Leg I, Survey D on Leg II, figure 2). Acoustic data were collected at three frequencies with 38, 120, and 200 kilohertz transducers. Data for physical oceanography, primary productivity, and krill distribution and condition studies were collected during the surveys. Operations at each station included:

- recording vertical profiles of temperature, salinity, oxygen, photosynthetically available radiation, light-beam attenuation, and fluorescence;
- collecting discrete water samples at standard depths for analysis of chlorophyll-*a* content, primary production rates, inorganic nutrients, dissolved oxygen, phytoplankton cell size and species composition, and phytoplankton biomass; and
- deploying a 1.8-meter (6-foot) Isaacs-Kidd Midwater Trawl (IKMT) to obtain samples of zooplankton and micronekton.

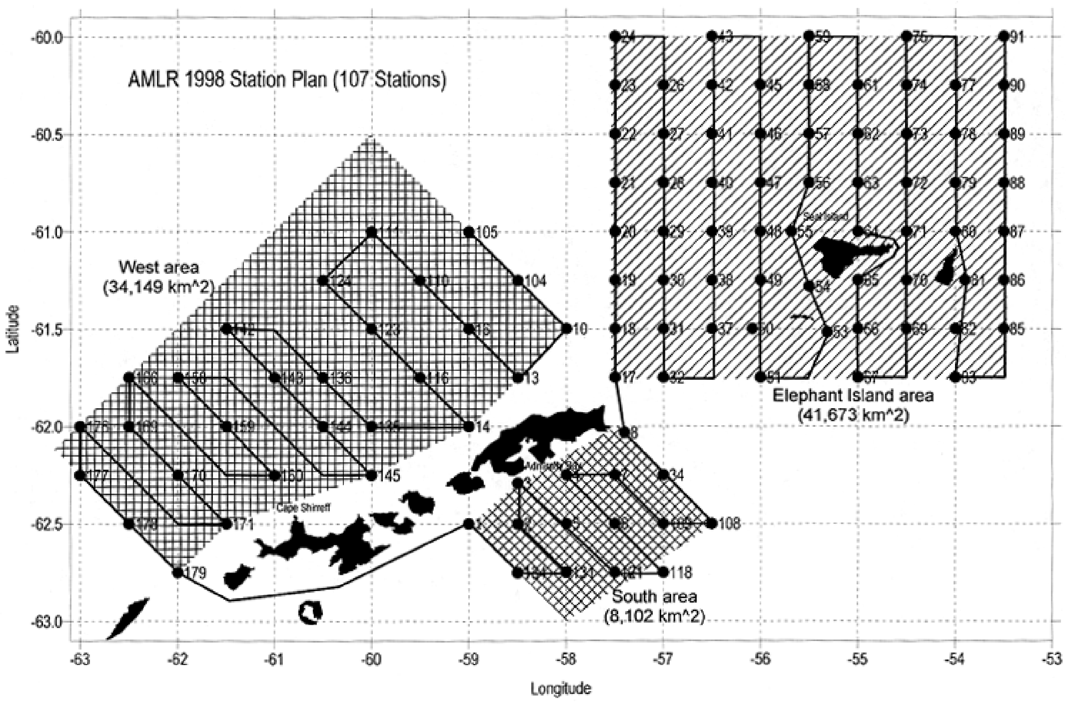

Figure 2. The large-area surveys conducted on Leg I (Survey A, Stations A001-A179) and on Leg II (Survey D, Stations D001-D179). Stations are located in three areas: stations to the west of Livingston and King George Islands are designated the "West area," those to the south of King George Island are designated the "South area," and those around Elephant Island are called the "Elephant Island area."

Following the large-area surveys on Legs I and II, cross-front transects of CTD stations were conducted between Elephant and King George Islands and also north of Livingston Island to describe water-mass structure. Acoustic data were collected during the transits between CTD stations. Directed sampling experiments were also accomplished using an IKMT outfitted with a coarse mesh net and a multiple-opening-closing-net-environmental-sampling-system (MOCNESS).

During Leg III, 75 bottom trawls were conducted at selected stations on the shelf surrounding the South Shetland Islands; 74 of these trawls were successfully retrieved. Other operations on Leg III included acoustic data collection, underway measurements of meteorological and sea-surface conditions, CTD casts at selected sites, and deployments of an underwater camera and video system.

The field camp at Cape Shirreff was occupied from 28 November 1997 to 28 February 1998. The field team completed several major construction projects on structures at the camp. Seabird research at Cape Shirreff included studies of reproductive success, breeding chronology, foraging ecology, and growth rates of chinstrap (*Pygoscelis antarctica*) and gentoo (*Pygoscelis papua*) penguins. Pinniped research included a census of all pinniped species, monitoring of antarctic fur seal (*Arctocephalus gazella*) pup production and growth rates, observations of female fur seal attendance behavior, collections of fur seal scat and milk samples for diet studies, descriptions of fur seal foraging and diving behavior, and tagging of 500 fur seal pups for future demographic studies. A four-person field team occupied the closed Seal Island camp from 28 January to 6 February 1998. During their stay, the team dismantled remaining structures and retrograded building materials, garbage, equipment, and supplies from the island. Fieldwork at Palmer Station was initiated on 1 October 1997 and completed on 4 April 1998; studies on aspects of the ecology of Adélie penguins were conducted.

AMLR program: Temporal and spatial variability of antarctic krill density near South Shetland Islands as estimated from acoustic surveys

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Since 1992, the Antarctic Marine Living Resources (AMLR) program has conducted acoustic surveys near Elephant Island during the same portions of the austral summer and using a reasonably consistent survey design. The primary objectives of these surveys were

- to map the mesoscale (10s of kilometers) dispersion of krill (*Euphausia superba*);
- to estimate their biomass; and
- to determine their association with predator foraging patterns, water-mass boundaries, spatial patterns of primary productivity, and bathymetry.

In 1998, the survey grid was expanded to include two additional areas to the northwest of the South Shetland Islands (west area) and to the south of King George Island (south area) (figure 1). This report focuses on both the interseasonal variability of the 1992 through 1998 time series of krill density estimates from the Elephant Island area and the intraseasonal variability (space and time) of the krill biomass throughout the entirety of the now larger AMLR survey area.

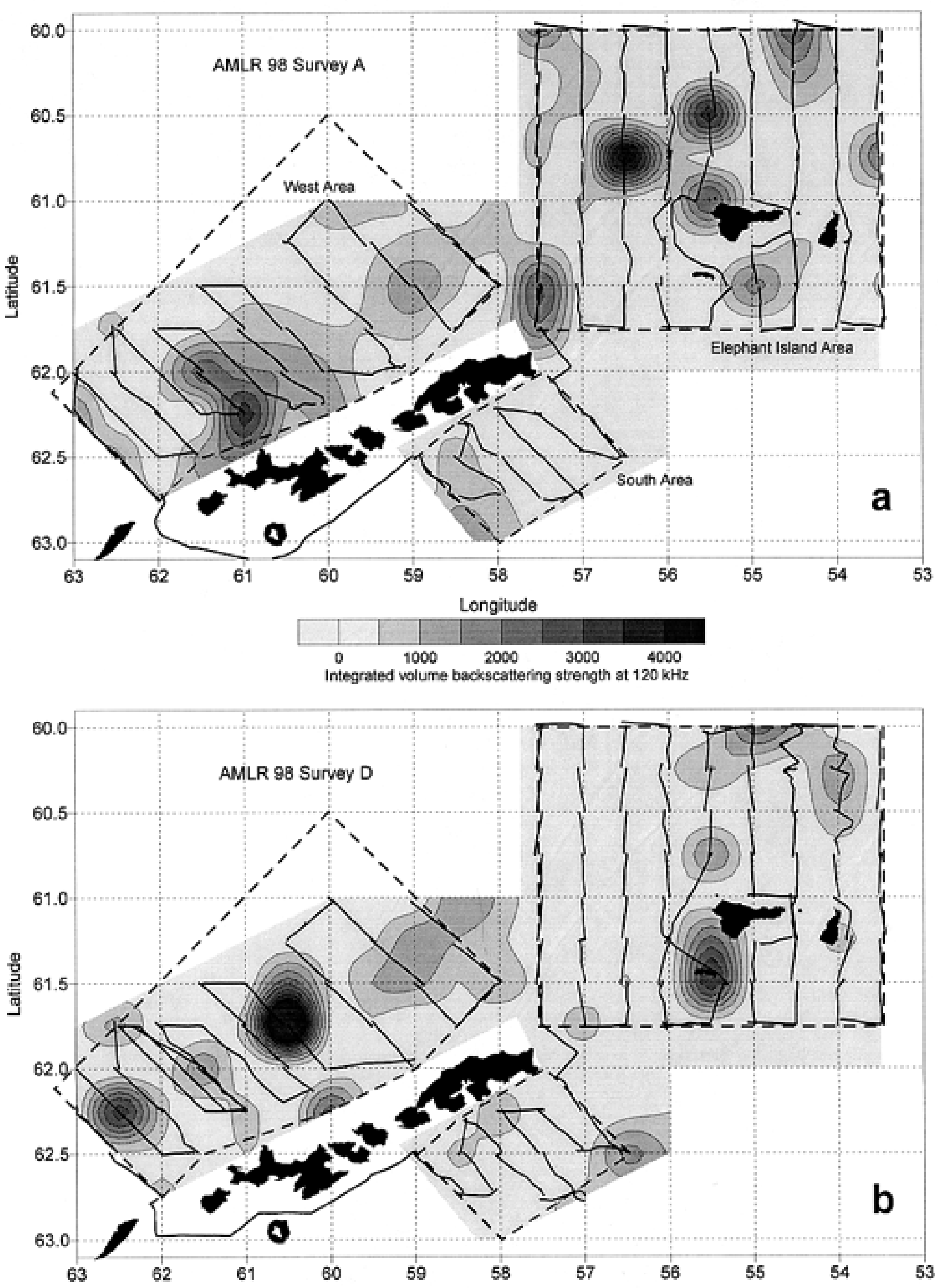

Figure 1. Integrated volume backscattering strength at 120 kHz for Survey A and Survey D. Transect lines are indicated but not station positions. Elephant Island, west, and south areas are indicated by dashed lines.

Acoustic data were collected using a multifrequency echo sounder (Simrad EK500) configured with downlooking 38, 120, and 200 kilohertz (kHz) transducers mounted in the hull of the ship. System calibrations were conducted before and after the surveys, using standard sphere techniques while the ship was at anchor. During the surveys, pulses were transmitted every 2 seconds at 1 kilowatt for 1.0 milliseconds duration at 38 and 120 khz, and 0.6 milliseconds at 200 kHz. For the purposes of generating distribution maps, the bottom return, surface turbulence, and system noise were eliminated from the echograms. The remaining volume backscatter was attributed to biological scatterers, integrated over depth [from 15–250 meters (m) for the 38 kHz data, 15–225 m for the 120 kHz data, and 15–175 m for the 200 kHz data] and averaged over 185.2 m (0.1 nautical mile) distance intervals.

A 30×15 cell grid was imposed on the survey area. Integrated volume backscattering values were interpolated at grid nodes using the method of triangular interpolation and contoured; portions of the grid outside of the survey area were masked. To generate a krill biomass density estimate, all volume backscattering at 120 kHz was assumed to be from krill. Integrated volume backscattering strength per unit sea surface area was scaled to estimates of krill biomass density by applying a factor equal to the quotient of the weight of an individual krill and its backscattering cross-sectional area, summed over the sampled length frequency distribution for each survey (Hewitt and Demer 1993). Total biomass was estimated by treating the mean biomass density on each of nine north-south transects in the Elephant Island area as an independent estimate of the mean density over the survey area (Jolly and Hampton 1990; Hewitt and Demer 1993). Biomass estimates for the west and south areas were calculated in a similar fashion from parallel transects oriented northwest-southeast.

The Elephant Island area time series of krill suggests a 6-year periodicity (table, figure 2), which may be expected because successful year-classes propagate interannually through the population. Biomass was at a 7-year low in 1994 following very poor reproductive success in 1992 and 1993; the 7-year high was observed in 1997 as a result of recruitment from a very strong 1995 year-class (Siegel and Loeb 1995).

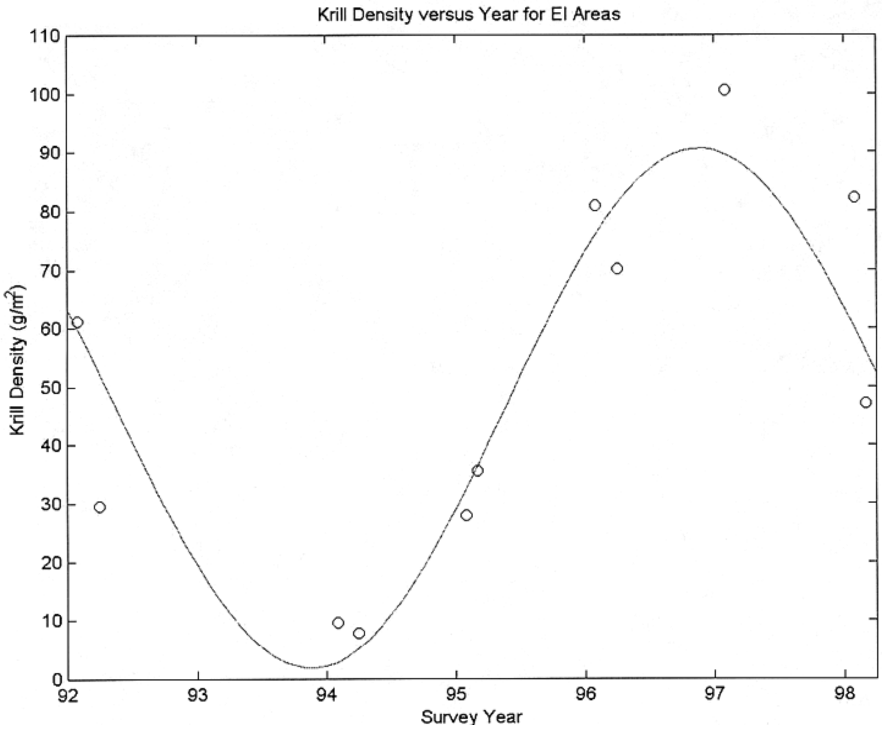

Figure 2. Time series of krill biomass density in the Elephant Island area from austral summer 1991–1992 to 1997–1998. Data from 1993 were omitted because of uncertainty in the system calibration.

Krill biomass density [$\rho(t)$] in the Elephant Island survey area from 1992 through 1998 was modeled using the following cyclical function:

$$\rho(t) = A + B\cos\left\{\frac{2\pi t}{6yrs} + \phi_1\right\}$$

where t is time (years), and *A* is the mean value of the series and *B* and Φ_1 are the amplitude [in grams per square meter (g/m^2)] and the phase (radians) of the 6-year cyclical component. The model is used to provide an aid to the visual interpretation of time-series fluctuations, as well as a provisionary method for prognostication.

The observed variations in krill density were quantified by estimating the model parameters using the Gauss-Newton method (Deuflhard and Apostolescu 1980). The resultant model of temporal variability in krill density is plotted over the time series of observed density estimates in figure 2.

$$\rho = 46.27 - 44.33\cos\left\{\frac{2\pi t}{6} + 2.22\right\}$$

The model falls well within the uncertainty of the density estimates (table) and predicts declining krill biomass densities for the years 1999 and 2000 of 19.5 and 2.3 g/m^2, respectively, assuming the cyclical pattern holds.

Mean krill biomass density for surveys conducted from 1992 through 1998

NOTE: 1993 estimates were omitted because of calibration uncertainties. The coefficients of variation (CV) are calculated using the methods described in Jolly and Hampton (1990) and describe measurement imprecision due to the survey design. Other contributions to measurement uncertainty (e.g., calibration, diel vertical migration, target strength estimation, species delineation, and so forth) are not included in these values.

Survey		**Mean density (g/m^2)**	**Area (km^2)**	**Biomass (10^3 tons)**	**CV (%)**
Elephant Island area					
1992	Survey A	61.20	36,271	2,220	15.8
	Survey D	29.63	36,271	1,075	9.2
1994	Survey A	9.63	41,673	401	10.7
	Survey D	7.74	41,673	323	22.2
1995	Survey A	27.84	41,673	1,160	12.0
	Survey D	35.52	41,673	1,480	24.2
1996	Survey A	80.82	41,673	3,368	11.4
	Survey D	70.10	41,673	2,921	22.7
1997	Survey A	100.47	41,673	4,187	21.8
1998	Survey A	82.26	41,673	3,428	13.6
	Survey D	47.11	41,673	1,963	14.7
West area					
1998	Survey A	78.88	34,149	2,694	9.9
	Survey D	73.32	34,149	2,504	16.6
South area					
1998	Survey A	40.99	8,102	332	16.3
	Survey D	47.93	8,102	388	12.2
Seal Island small area surveys					
1992	Survey B	101.27	7,203	729	22.2
	Survey C	58.90	7,203	424	22.6
1994	Survey B	12.02	7,203	87	8.8
	Survey C	13.46	7,203	97	21.9
1995	Survey B	41.30	7,203	297	19.6
	Survey C	67.59	7,203	487	20.7

This decline may have implications when interpreting the results of a multinational, multi-ship survey of krill in the southwest Atlantic sector of the Southern Ocean, conducted in the summer of 1999–2000 and coordinated by the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR employs a general yield model to set precautionary limits on the krill harvest in the southwest Atlantic. The model is currently scaled to a krill biomass survey conducted in 1981, a period when krill density near the South Shetland Islands was high relative to the 1990s (Siegel, de la Mare, and Loeb 1997). If the density of krill in the South Shetlands continues to follow the cycle described above, and if the density in the South Shetlands is representative of the southwest Atlantic sector, then a low biomass of krill can be expected during the 1999–2000 survey. An additional complication is the suggestion by Loeb et al. (1997) that the frequency of strong krill year classes has decreased since 1981 and that a lower equilibrium level of krill may be expected. If a low biomass estimate results from the 1999–2000 survey, then CCAMLR will have difficulty in determining whether the 1981 and 2000 biomass estimates represent two extremes of a cyclically varying population abundance or a decreasing trend in the krill population in the southwest Atlantic. In this context, the annual regional surveys conducted by national programs of CCAMLR members are highly valuable and their continuation should be encouraged.

During the AMLR 1998 Survey A, high concentrations of krill were mapped along and immediately downstream of a bathymetric shoal to the northwest of Elephant Island (figure 1*B*). Additional high-density areas were found near the shelf break to the north of Livingston Island, to the northeast end of King George Island, and to the south of Nelson's Passage in Bransfield Strait. Higher levels of volume backscattering strength at 38 kHz, compared to 120 and 200 kHz, were mapped along the shelf break to the north of the South Shetland Islands and are thought to be associated with scattering from myctophid fish, but efforts to confirm this suspicion using directed net sampling and underwater video observations were inconclusive.

During the AMLR 1998 Survey D, high krill densities were found in the northeast corner of the grid, surrounding Gibbs Island to the southwest of Elephant, and in the southeast corner of the south area. In the west area, high krill concentrations were again mapped along the shelf break to the north of the archipelago. It is conceivable that distribution changes between surveys resulted from transport of the zooplankton biomass to the northeast with the prevailing currents (compare figure 1*A* and 1*B*). Similar distributional changes were not observed in the 38 kHz data, which is consistent with the hypothesis that the dominant scattering at 38 kHz is from nekton.

Krill biomass estimates for the west and south areas (table) did not decline from Survey A to Survey D as they did in the Elephant Island area. Biomass densities in the west area were comparable to that in the Elephant Island area during Survey A, whereas biomass densities in the South area were approximately half of the other areas. This can be contrasted with the series of small-area surveys conducted from 1992 to 1995 along the north side of Elephant Island (within the foraging range of krill predators monitored at Seal Island). Krill biomass densities from these surveys followed the cyclical pattern described by the biomass densities in the greater Elephant Island area but were 25–90 percent higher (table).

These results suggest that the availability of krill to land-breeding krill predators is highest at Seal Island, lower at Cape Shirreff, and lowest at Admiralty Bay. If the 1998 observations are indicative of the usual dispersion of prey throughout the South Shetland Islands, predators at Admiralty Bay and Cape Shirreff may be more affected by periods of low krill abundance than those at Seal Island. In the longer term, predator populations at Admiralty Bay and Cape Shirreff may be food limited whereas populations at Seal Island may be limited by other factors such as availability of and access to breeding sites.

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AMLR program: Chlorophyll-*a* concentrations in the area around South Shetland Islands and Elephant Island, January to March 1998

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The major objective of the phytoplankton component of the U.S. Antarctic Marine Living Resources (AMLR) program is to improve our understanding of the food reservoirs available to grazing zooplankton populations. Special attention in this program is paid to the trophodynamics between phytoplankton and krill, because krill play such an important role in the diet of many higher trophic levels such as fish, birds, seals, and whales. Our AMLR program studies include documenting the distribution, biomass, and species composition of phytoplankton throughout the euphotic zone, in addition to assessing the role and importance of physical, optical, and chemical variables in the upper water column that affect the rate of primary production. In this article, we describe chlorophyll-*a* concentrations in the euphotic zone and how the profiles of chlorophyll-*a* concentrations characteristically vary in some of the different water zones (see Amos, Wickham, and Rowe, *Antarctic Journal*, in this issue) found in the AMLR study area. For a description of the survey area and locations of the 107 stations (Survey A on Leg I; Survey D on Leg II), see Martin, Hewitt, and Holt (*Antarctic Journal*, in this issue).

The distribution of phytoplankton in surface waters was estimated continuously during the AMLR cruise by sensors (fluorometer and transmissometer) on a clean water-intake line, as well as in depth profiles [0 to 200 meters (m)] at every conductivity-temperature-depth (CTD)/carousel station. The CTD/carousel unit included a submersible fluorometer and eleven 10-liter Niskin bottles, which were closed at standard depths between 5 and 200 m. Concentrations of chlorophyll-*a* were measured on 100 milliliter (mL) samples from the Niskin bottles by concentrating the phytoplankton onto GF/F glass fiber filters, extracting the photosynthetic pigments in absolute methanol (Holm-Hansen and Riemann 1978), and measuring fluorescence (Holm-Hansen et al. 1965).

Chlorophyll-*a* concentrations in surface waters were fairly low and more uniform throughout the survey area as compared to previous years (figure 1). The lowest concentrations [0.05 to 0.2 milligrams per cubic meter (mg m^{-3})] during both legs were found in Drake Passage waters (Water Zone I) and in the area around Elephant Island. The highest chlorophyll-*a* concentration in surface waters during Leg I was 1.5 mg m^{-3} to the north of King George Island (figure 1*A*). Chlorophyll-*a* concentrations were slightly higher during Leg II; the greatest concentrations (3.0 mg m^{-3}) were found to the north of Livingston Island (figure 1*B*).

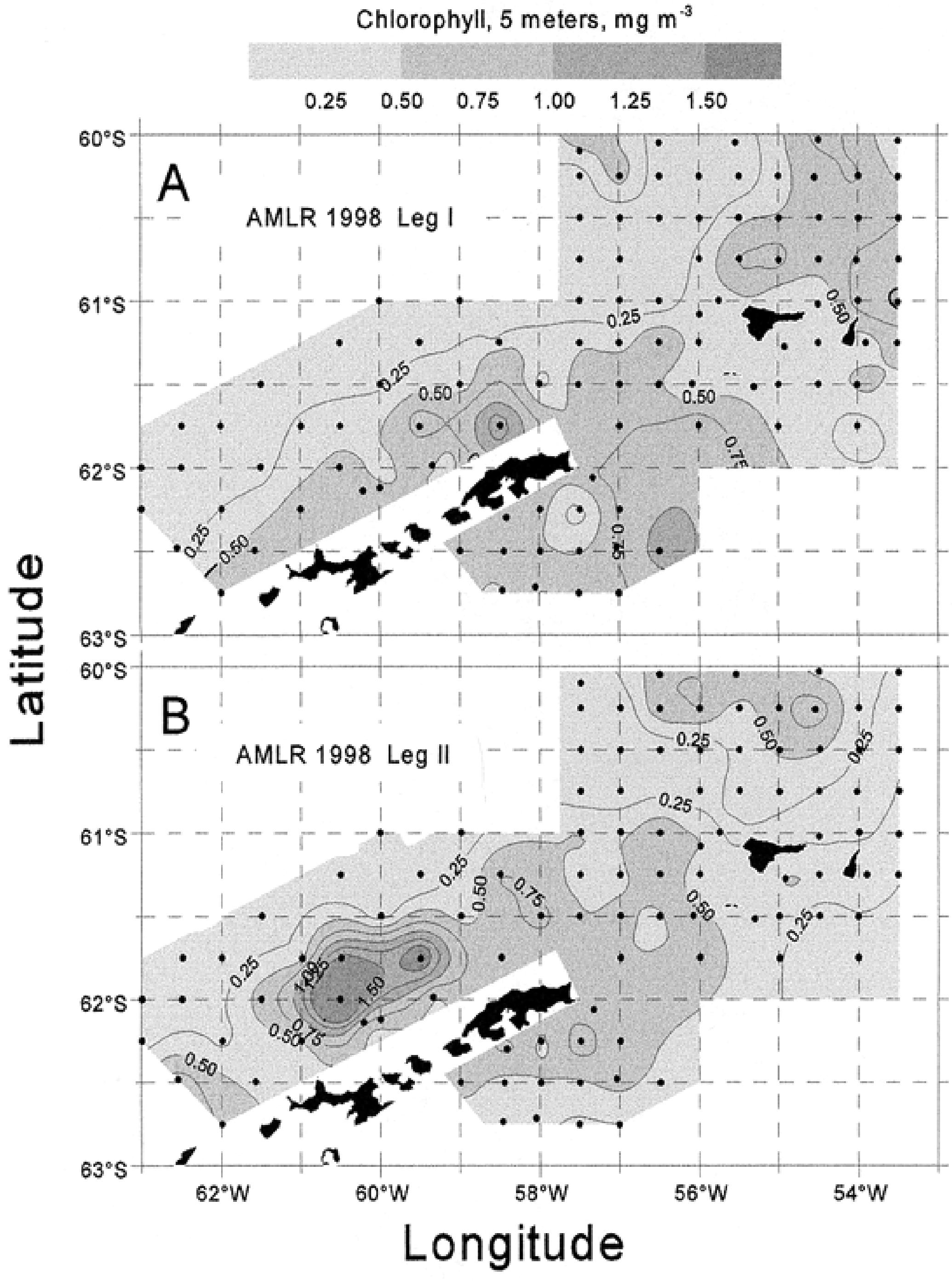

Figure 1. Contour map of chlorophyll-a concentrations in surface waters (approximately 5 m depth) throughout the AMLR survey grid. (A) Survey A, Leg I (8–25 January 1998); (B) Survey D, Leg II (8–25 February 1998). The scale at the bottom refers to chlorophyll-a concentrations in milligrams per cubic meter (mg m^{-3}).

The pattern of integrated chlorophyll-*a* values for the upper 100 m of the water column during Leg II was similar to that for 5-m chlorophyll-*a* values. The lowest values were 10–15 milligrams per square meter (mg m^{-2}), and the highest values were 80–90 mg m^{-2} at Station D003 to the south of King George Island and at Stations D104 and D144 to the north of the South Shetland Islands (figure 2). Integrated values for chlorophyll-*a* during Leg I are not available because a shortage of methanol used for extraction of photosynthetic pigments limited our analyses to just the upper 50 m of the water column.

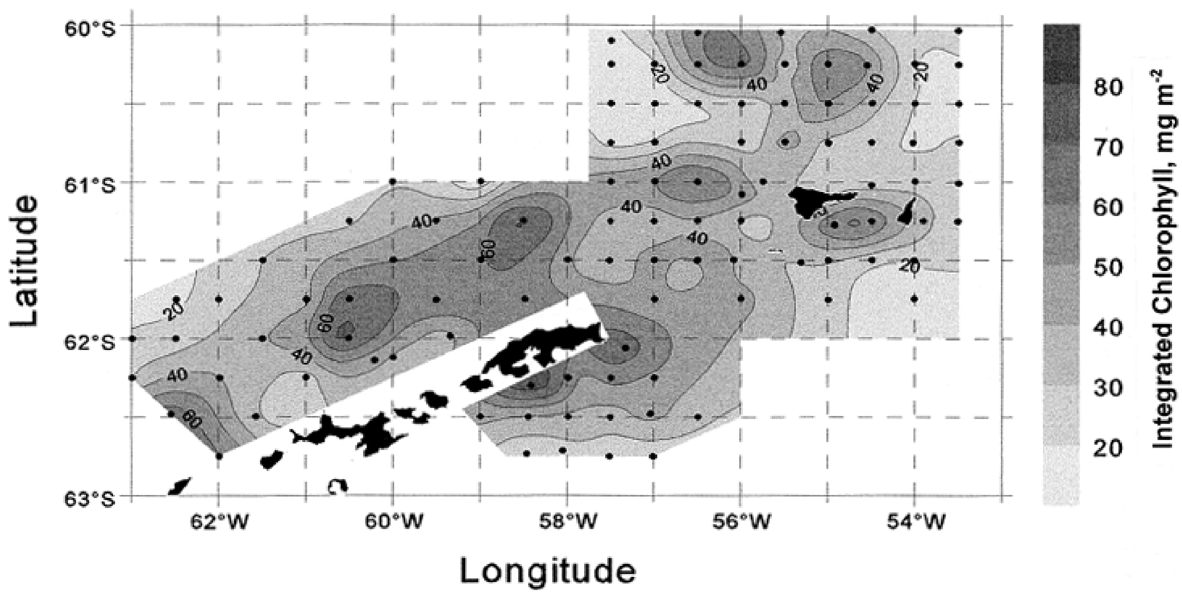

Figure 2. Contour map of integrated chlorophyll-a concentrations (mg chl-a m^{-2}, 0 to 100 m) throughout the AMLR survey grid during Leg II.

Profiles of chlorophyll-*a* concentrations with depth are generally different for the major water masses encountered in the AMLR study area (Holm-Hansen et al. 1997). Examples of this from the 1998 AMLR cruise are shown in figure 3. The chlorophyll-*a* profile at Station A178, typical of Water Zone I, shows low chlorophyll-*a* values in surface waters and a pronounced maximum at approximately 75 m depth (figure 3*A*). In contrast to this, stations in Water Zone IV (Bransfield Strait waters) have greater chlorophyll-*a* concentrations, which are uniformly distributed throughout the upper mixed layer and they have no subsurface maximum (figure 3*B*). The decrease of *in vivo* fluorescence in the upper 15 m in figure 3*B* is caused by photoinhibition of chlorophyll-*a* fluorescence by solar radiation. The highest chlorophyll-*a* concentration during Leg I was found at 50 m depth at Station A108 (figure 3*C*), which is located in Water Zone V (Weddell Sea waters). The very irregular trace for *in vivo* fluorescence is indicative of the presence of chain-forming diatoms, which was confirmed by microscopic observations. A subsurface peak of chlorophyll-*a* as seen in figure 3*C* is not typical of stations in Water Zone V, but it is likely that this chlorophyll-*a* maximum at 50 m is the result of the diatom assemblage settling from surface waters to deeper waters, as has been noted previously in Bransfield Strait (Holm-Hansen and Mitchell 1991).

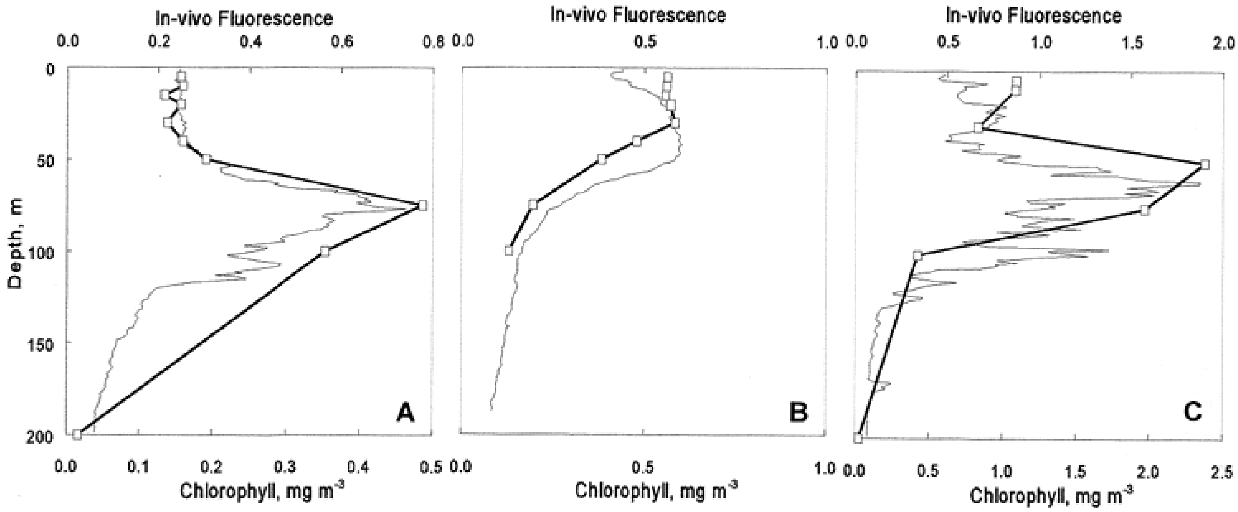

Figure 3. Representative profiles of chlorophyll-a concentrations in the upper water column (0 to 200 m) in three different water zones within the AMLR survey grid. (*A*) Station A178 in Water Zone I; (*B*) Station A145 in Water Zone IV; (*C*) Station A108 in Water Zone V. The open squares show the chlorophyll-a concentrations in mg m^{-3}, and the thinner continuous lines show* in vivo *chlorophyll-a fluorescence as recorded with the profiling fluorometer. Note changes in scales in the three subfigures.

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AMLR program: Inorganic nutrient concentrations in the area around South Shetland Islands and Elephant Island, January 1998

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The phytoplankton component of the U.S. Antarctic Marine Living Resources (AMLR) program is concerned with the environmental factors that influence the distribution, biomass, and species composition of the phytoplankton assemblages. As part of the phytoplankton work, inorganic nutrient concentrations have been measured throughout the study area with two major objectives in mind:

- to provide the required data to determine if macronutrient concentrations might be limiting rates of primary production within the survey grid, and
- to help determine to which of the six different water zones (see Amos, Wickham, and Rowe, *Antarctic Journal*, in this issue) each of the survey stations belongs.

For a description of the survey area and locations of the stations (Survey A on Leg I; Survey D on Leg II), see Martin, Hewitt, and Holt (*Antarctic Journal*, in this issue).

Water samples for nutrient analysis were obtained from 10-liter Niskin bottles attached to the conductivity-temperature-depth (CTD)/carousel unit (see Amos et al., *Antarctic Journal*, in this issue), which was deployed at 105 stations during Leg I (1–31 January 1998). A water sample was taken at 5 meters (m) depth at every station, and at depths of 5, 10, 15, 20, 30, 40, 50, 75, and 100 m at 11 stations where primary productivity measurements were made. In addition, samples were obtained at Station X002 at depths of 10, 50, 100, 500, 750, 1,000, 1,500, and 2,000 m. Acid-cleaned high-density polyethylene bottles of 50 milliliters (mL) capacity were rinsed four or five times with water directly out of the Niskin bottle before filling with approximately 35 mL. The sample bottles were then frozen in an upright position and maintained at -20°C or lower until time of analysis. The samples were analyzed at the Universidad Católica de Valparaiso with an auto-analyzer following the techniques described by Atlas et al. (1971). Nitrate and nitrite were not determined separately, so that the term "nitrate" refers to the sum of nitrate plus nitrite.

Data in figure 1 reveal no dramatic gradients or areas of depletion throughout the AMLR survey grid for either nitrate (figure 1*A*) or phosphate (figure 1*B*). Silicic acid concentrations, in contrast, are much lower in waters to the north of the South Shetland Islands and Elephant Island; the sharp nutrient gradient lies in near proximity to the continental shelf break (figure 1*C*). The slightly elevated concentrations of silicic acid at

Stations A024 and A026 in the northwest corner of the survey grid have not been detected in previous AMLR studies and are indicative that mixing with waters of higher silicic acid concentrations has occurred in this region. This conclusion is also supported by the elevated concentrations of chlorophyll-*a* recorded at these two stations (see Hewes et al., *Antarctic Journal*, in this issue).

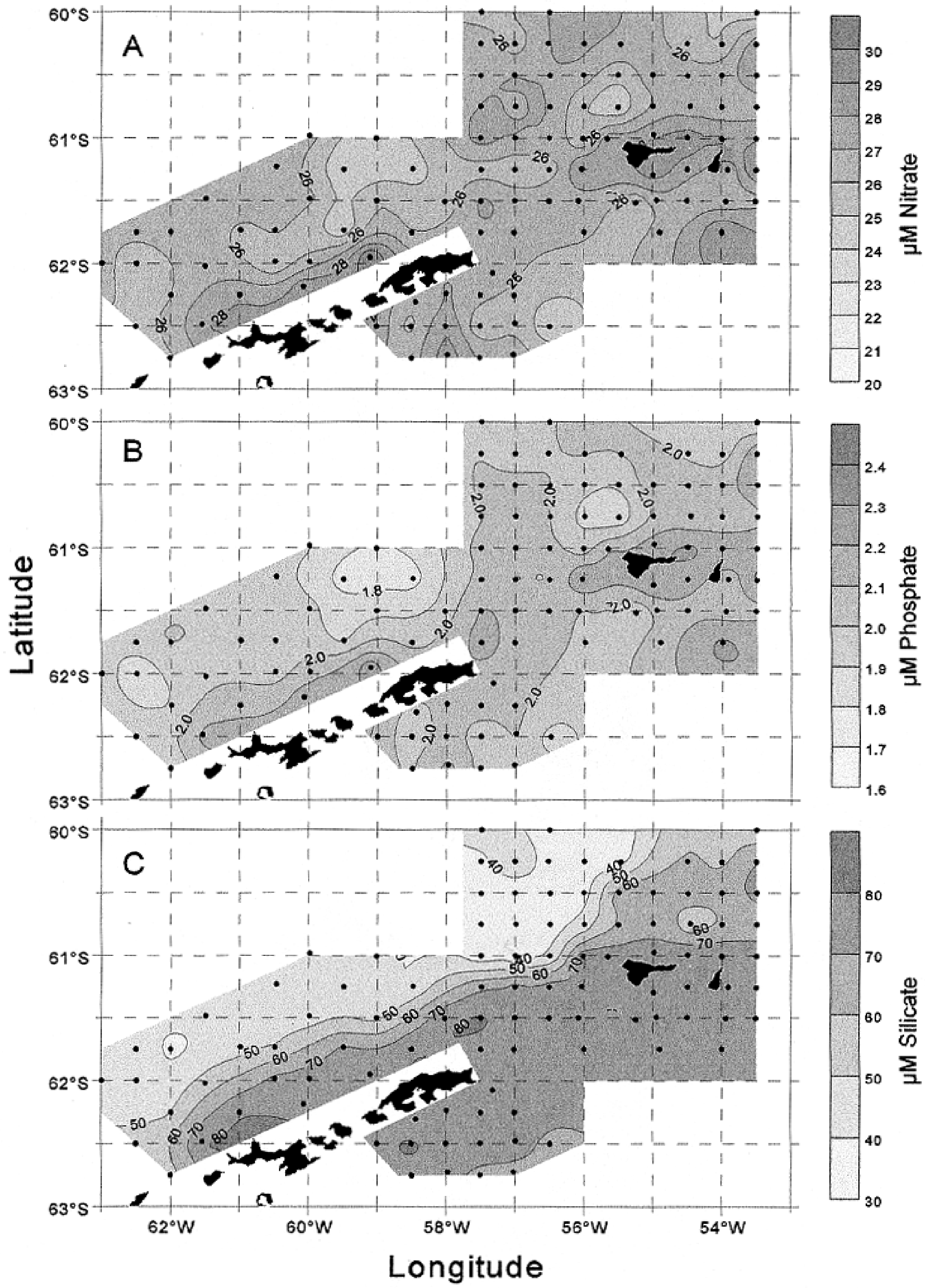

Figure 1. Micromolar (µM) inorganic nutrient concentrations at 5 meters depth throughout the AMLR survey during Leg I (Survey A): (A) nitrate, (B) phosphate, and (C) silicic acid.

The low silicic acid [$Si(OH_4)$] concentrations in Water Zone I as compared to concentrations of either phosphate (PO_4) or nitrate (NO_3) are shown in figure 2. The relative ratios of phosphate/nitrate are not significantly different for the six water zones (figure 2*A*), whereas the ratios of silicic acid concentrations to nitrate concentrations "separate" into two distinct groups: mean silicic acid concentrations are 42±8 micromolar (µ*M*) for Water Zone I stations and are 73±7 µ*M* for all stations in Water Zones II-VI (figure 2*B*). The atypical ratios of silicon to nitrogen (Si/N) at the two outlier stations (A047 and A073) shown in figure 2*B* most likely are caused by mixing of waters from different water zones.

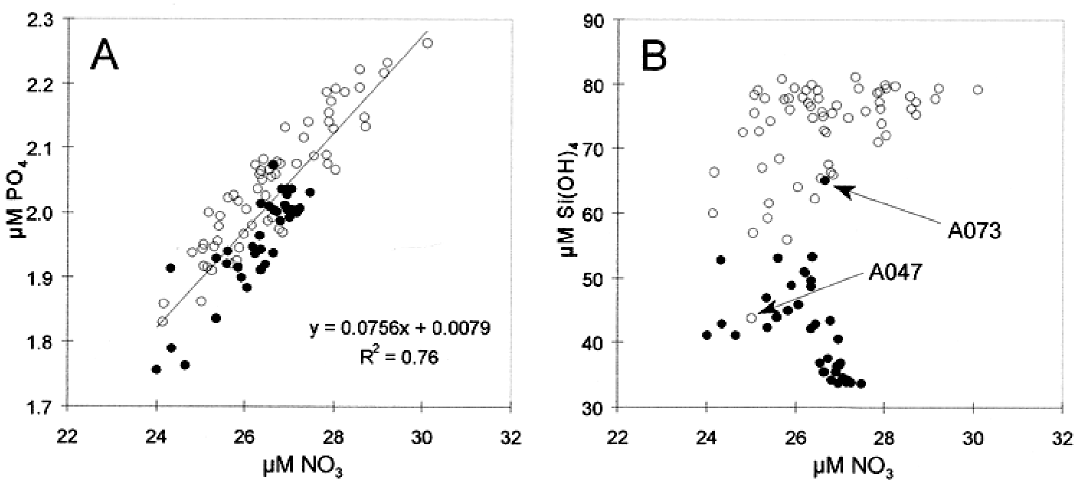

Figure 2. Plots of the relative ratios of macronutrient concentrations at 5 meters depth throughout the AMLR survey during Leg I: (A) phosphate vs. nitrate, (B) silicic acid vs. nitrate. Data from all stations located in Water Zone I are indicated by solid circles.

Data in figure 3 show that the low silicic acid [$Si(OH_4)$] concentrations found in surface waters throughout Water Zone I are also typical for the upper 100 m of the water column. The relatively low silicon concentrations at Station A108 (Water Zone V) apparently is the result of active uptake of silicon by phytoplankton. The phytoplankton assemblages at this station were predominately large diatoms, and the chlorophyll-*a* concentrations were the greatest recorded during Leg I (see Hewes et al. *Antarctic Journal*, in this issue).

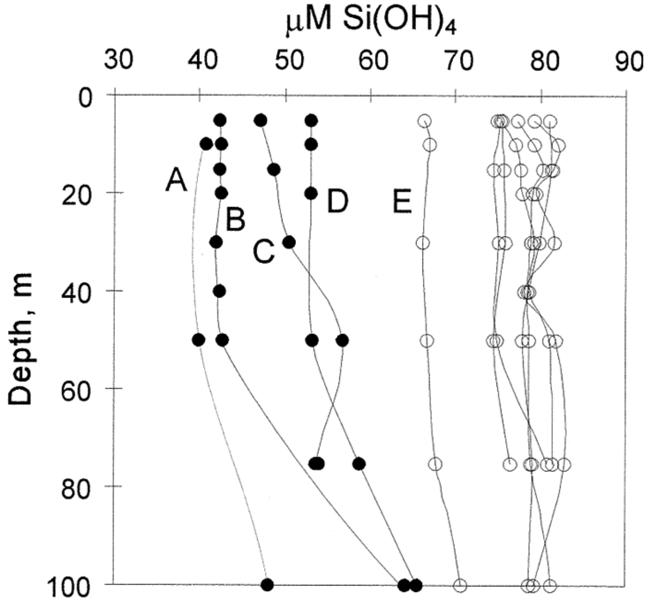

Figure 3. Silicic acid concentrations in the upper 100 meters of the water column at 11 stations during Leg I. The stations and the water zones to which the stations have been assigned are (A) Station X002 (Water Zone I); (B) Station A169 (Water Zone I); (C) Station A026 (Water Zone I); (D) Station A178 (Water Zone I); (E) Station A108 (Water Zone V). The six stations with high silicate [$Si(OH)_4$] concentrations are A004, A014, A018, A037, A131, and A145, which are located in Water Zones II, IV, and VI.

This research was supported by National Oceanic and Atmospheric Administration (NOAA) Contract 50ABNF600013. Grateful acknowledgment is extended to the officers and crew of the R/V *Yuzhmorgeologiya* for their excellent support during all field operations. Shipboard personnel included J. Maturana, C.D. Hewes, and O. Holm-Hansen.

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AMLR program: Krill populations in the Elephant Island area, January and February 1998

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Antarctic krill (*Euphausia superba*) is the keystone species of the antarctic food web. It constitutes the main prey species for penguins, other seabirds, seals, whales, and fish in the seasonal pack-ice zone; it is also fished commercially. The U.S. Antarctic Marine Living Resources (AMLR) program conducts annual surveys near Elephant, King George, and Livingston Islands during austral summer months to monitor krill distribution, abundance, and population structure relative to their land-based predators (Martin, Hewitt, and Holt, *Antarctic Journal*, in this issue).

Krill data were derived from net samples taken at established AMLR survey stations during 8–25 January 1998 (Survey A) and 8–25 February 1998 (Survey D). Sampling was done using a 1.8-meter (6-foot) Isaacs-Kidd Midwater Trawl (IKMT) fitted with a 505-micrometer mesh plankton net. Flow volumes were measured using a calibrated General Oceanics flow meter mounted in front of the net. All tows were fished obliquely to a depth of 170 meters (m) or to about 10 m above bottom in shallower waters. Tow speeds were about 2 knots. Fresh or freshly frozen specimens were processed on board. All krill were analyzed from samples containing fewer than 150 individuals. For larger samples, 100 to 200 individuals were measured, sexed, and staged. Measurements were made of total length [millimeters (mm)]; stages were based on the classification scheme of Makarov and Denys (1981). Density is expressed as numbers per 1,000 cubic meters (m^3) water filtered. Data are presented for the total large-area survey (figures 1*A* and 1*B*; 104 stations) and the more restricted "Elephant Island Area" (61 stations). The latter represents the historically sampled area used for long-term analyses of the Antarctic Peninsula marine ecosystem.

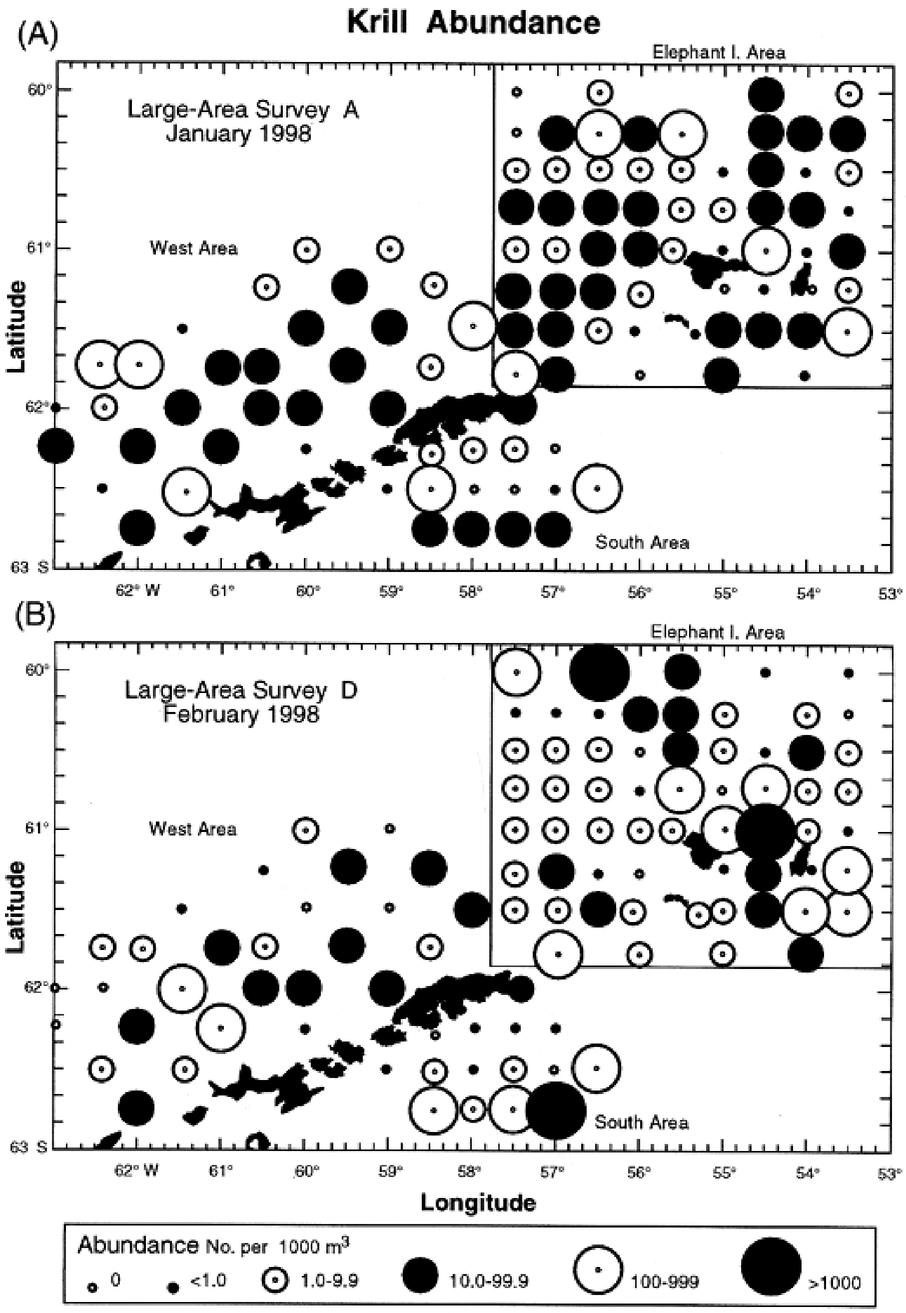

Figure 1. Krill abundance in IKMT tows collected during (A) Survey A, January 1998, and (B) Survey D, February 1998. The outlined stations are included in the "Elephant Island area" and used for between-year comparisons.

Krill occurred in 92 percent of samples collected during Survey A. Largest catches (182–493 per 1,000 m^3) were made west and south of King George Island (figure 1*A*). Mean and median krill abundance in the Elephant Island area (respectively, 27.1 and 10.2 per 1,000 m^3) was similar to that of the entire survey area (36.8 and 10.7 per 1,000 m^3; table 1), reflecting the rather even distribution of catch sizes across much of the survey area. Krill lengths ranged from 15 to 54 mm and had 22 to 25 mm and 33 to 45 mm length modes (figure 2A). These modes correspond to 1-year-old (i.e., the 1996–1997 year class) and a mix of 2- and 3-year-old individuals (1995–1996 and 1994–1995 year classes). Older krill (4 years and older) were virtually absent as indicated by few individuals larger than 50 mm. Within the Elephant Island area (figure 2*B*), krill were predominantly 39 to 46 mm in length (3 years old, 49 percent) with a minor contribution by 24 to 26 mm sizes (7 percent). Here mature stages made up half (50 percent) of the total krill, followed by immature (32 percent) and juvenile (18 percent) stages (table 2). Relatively few of the mature females had mated; only small proportions had spermatophore packets attached to the thelycum (stage 3b), ovarian development (3c), were gravid (3d), or spent (3e). Presence of krill larvae in occasional samples indicated that some spawning occurred during December and early January, but their mean abundance was low (Loeb, Siegel, and Armstrong, *Antarctic Journal*, in this issue).

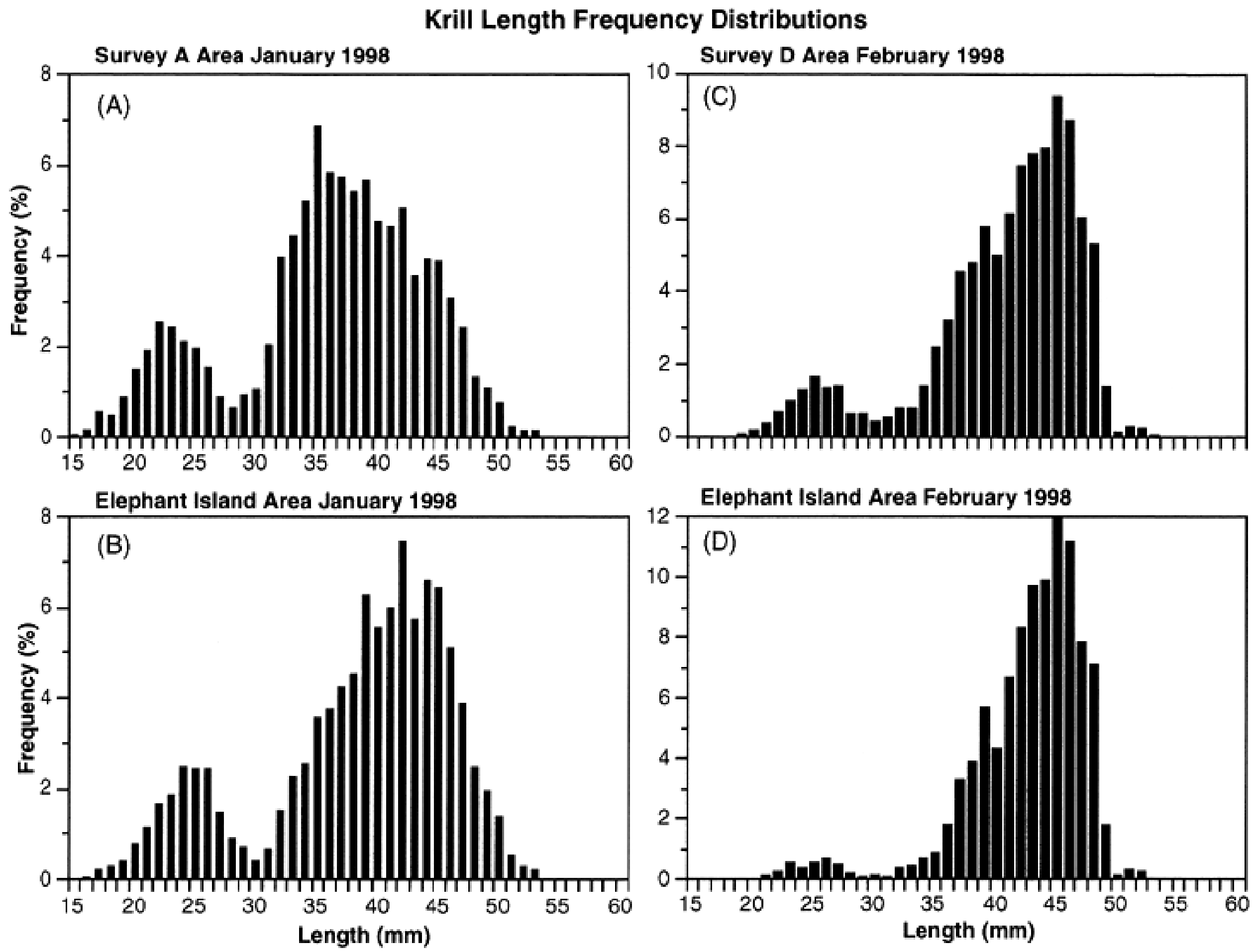

Figure 2. Overall length frequency distribution of krill collected in the (A, B) Survey A and Elephant Island areas, January 1998, and (C, D) Survey D and Elephant Island areas, February 1998.

Table 1. Krill abundance in the large survey area and Elephant Island area during January and February 1998. Abundance estimates are numbers per 1,000 cubic meters.

	January		February	
	Survey A	**Elephant Island**	**Survey D**	**Elephant Island**
Number of samples	104	61	104	61
Number of krill	13,649	6,275	59,700	44,147
Mean	36.8	27.1	133.5	162.6
Standard deviation	68.9	42.3	620.4	768.3
Median	10.7	10.2	4.1	4.5

Krill were present in 89 percent of Survey D samples. The two largest catches were in the Elephant Island area in offshore Drake Passage water (5,667 per 1,000 m^3) and over the eastern shelf of Elephant Island (2,212 per 1,000 m^3); the third largest catch (1,846 per 1,000 m^3) was south of King George Island (figure 1*B*). The substantially larger mean vs. median abundance estimate in the Elephant Island area and large associated standard deviation (table 1) reflect the patchy krill distribution there compared to Survey A. Krill lengths ranged from 19 to 53 mm (figures 2*C* and 2*D*). Individuals smaller than 30 mm (1996–1997 year class) contributed less than 4 percent of the total collected in the Elephant Island area; krill 40 mm and larger (1994–1995 year class) constituted 75 percent of the individuals there. Accordingly, mature stages made up 71 percent and juveniles 4 percent of krill in the Elephant Island area. The female maturity stage composition (table 2) indicates only minimal spawning activity by late February. This finding is supported by low numbers of larvae collected during Survey D (Loeb et al., *Antarctic Journal*, in this issue).

Table 2. Maturity stage composition of krill collected in the Elephant Island area, January and February 1998. Advanced stages are proportions of mature females that are 3c–3e in January and 3d–3e in February.

Stage	January (%)	February (%)
Juveniles	18.4	3.6
Immature stages	31.7	25.4
Mature stages	49.9	71.0
Females:		
F2	9.1	6.9
F3a	21.4	10.9
F3b	9.0	11.8
F3c	1.0	3.0
F3d	0.3	1.3
F3e	0.7	0.1
Advanced stages	6.2	5.2
Males:		
M2a	8.5	1.9
M2b	8.4	6.6
M2c	5.7	10.0
M3a	3.1	17.5
M3b	14.4	26.2
Male:female ratio	1:1	2:1
Number measured	3,600	3,153

Changes in mean and median krill abundance between January and February surveys (table 1), reflect change from relatively uniform to patchy catch size (figures 1*A* and 1*B*). This change was associated with a substantial change in krill maturity composition, with marked reductions in proportions of juvenile and immature stages and dominance by mature stages (table 2). Changes in length, age, maturity stage composition, and distribution result from seasonal onshore migration of different age classes (Siegel 1988; Siegel, de la Mare, and Loeb 1997).

The relatively small proportions of juveniles collected during 1998 resulted from poor recruitment success of the 1996–1997 year class. This correlation was predicted, given relatively high salp abundance and delayed krill spawning during summer 1997 (Loeb 1997). Poor recruitment success in 1996–1997, like that of the 1995–1996 year class, followed a winter with below average sea-ice development. Numerical dominance by large mature krill reflects high recruitment success of the 1994–1995 year class relative to those from subsequent years. The proportion of advanced female maturity stages (gravid and spent, 5.2 percent) during February 1998 was one of the lowest noted in the past 7 years suggesting a greatly delayed spawning season. This delayed spawning was associated with massive salp concentrations in the area and theoretically results from competition with salps for food resources (Siegel and Loeb 1995; Loeb et al. 1997). Extremely low larval krill abundance is further evidence of little spawning activity and/or poor egg and larval survival during the summer spawning season. It is likely that another year of poor recruitment will result from this delayed spawning. With low absolute recruitment from the 1996–1997 and 1997–1998 year classes and an aging population structure, reduced krill population size may be expected in the Antarctic Peninsula region next summer.

I greatly appreciate the help in sample collection and onboard processing provided by Wesley Armstrong, Rachel Johnson, Elizabeth Linen, Michael Force, Charles F. Phleger, Volker Siegel, Kimberly Dietrich, and Matthew Nelson.

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AMLR program: The zooplankton assemblage sampled during austral summer 1998 compared to those sampled in 1993 to 1997

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A wide variety of zooplankton taxa was represented in the Isaacs-Kidd Midwater Trawl samples during the U.S. Antarctic Marine Living Resources (AMLR) program's austral summer 1998 surveys. Like krill (*Euphausia superba*), some of these are important components of the antarctic food web. Notable among these are copepods, salps, and the euphausiid *Thysanoessa macrura.* Absolute and relative abundances of these taxa have demonstrated marked interannual variations over the past 6 years.

Sampling specifics are presented in Loeb (*Antarctic Journal*, in this issue). Freshly collected samples were analyzed onboard. Many of the samples were quite large due to abundant salps. All salps were removed from samples of 2 liters (L) or less and enumerated. For larger catches, the numbers of salps in 1- to 2-L subsamples were used to estimate abundance. For samples with fewer than 100 individuals, the two salp life stages (aggregate/sexual and solitary/asexual) were enumerated, and internal body length (Foxton 1966) was measured to the nearest millimeter (mm). Representative subsamples of at least 80 salps were analyzed in the same manner for larger catches. After removal of salps, krill, and adult fish from small samples or subsamples, the remaining zooplankton were analyzed. All larger organisms (e.g., amphipods, other euphausiids) were sorted, identified to species if possible, and enumerated. The smaller constituents (e.g., copepods, krill larvae) in representative aliquots were then enumerated using dissecting microscopes. Density is expressed as numbers per 1,000 cubic meter (m^3) water filtered. Data are presented for the total large-area survey (figures 1*A* and 1*B*; 104 stations) and the more restricted "Elephant Island area" (61 stations). The latter represents the historically sampled area used for long-term analyses of the Antarctic Peninsula marine ecosystem.

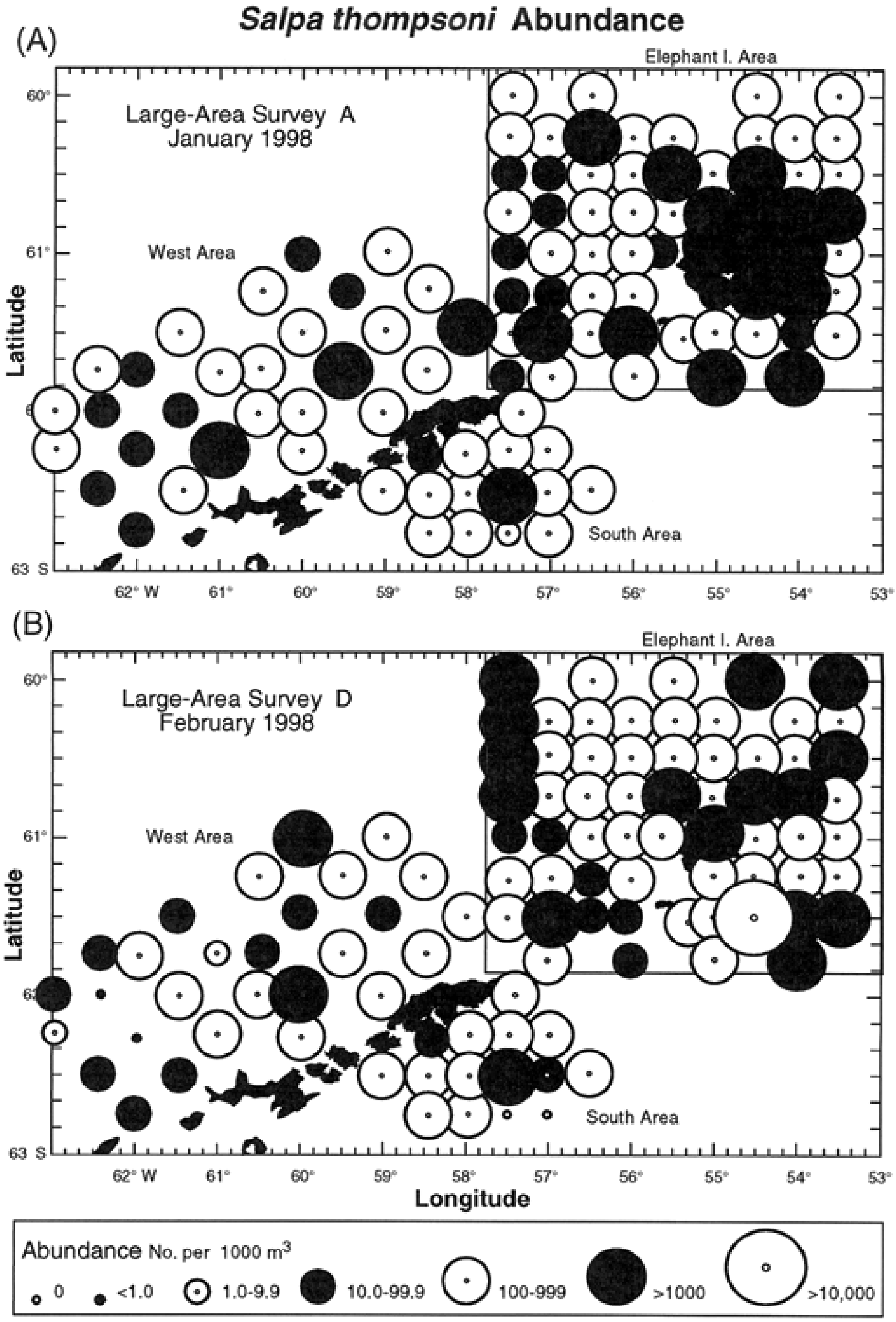

Figure 1. Distribution and abundance of* Salpa thompsoni *in (*A*) Survey A, January 1998 and (*B*) Survey D, February 1998.

Table 1. The most abundant zooplankton taxa collected in the large survey areas January and February 1998

NOTE: F is frequency of occurrence (%) in 104 samples each survey. Only those taxa with mean abundance of at least 0.5 per 1,000 cubic meters during one or both surveys are included. L indicates larval forms.

	Survey A—January 1998				Survey D—February 1998		
Taxon	**F(%)**	**Mean**	**SD**	**Median**	**F(%)**	**Mean**	**SD**
Salpa thompsoni	100.0	808.2	1,538.7	323.7	98.1	689.1	1214.6
Thysanoessa macrura	100.0	180.8	411.6	79.8	100.0	177.4	292.5
Copepods	94.2	56.5	80.3	25.8	97.1	119.0	179.6
Ihlea racovitzai[a]	5.8	41.5	326.6	0.0	61.5	51.5	99.4
Euphausia superba	92.3	36.8	68.9	10.7	89.4	133.5	620.5
Vibilia antarctica	96.2	13.2	17.1	7.8	96.2	8.0	10.5
Chaetognaths	42.3	8.9	31.9	0.0	61.5	10.7	26.3
Limacina helicina	73.1	8.1	12.9	3.4	37.5	0.8	1.8
Ostracods	51.0	4.8	11.7	0.4	43.3	5.4	16.8
Sagitta gazellae	27.9	1.9	6.0	0.0	18.3	0.3	1.0
Cyllopus magellanicus	64.4	1.9	3.1	0.5	81.7	5.6	11.6
Polychaetes	28.8	1.5	8.5	0.0	13.5	0.3	1.2
Tomopteris spp.	31.7	1.3	9.1	0.0	8.7	0.0	0.0
Diphyes antarctica	37.5	1.1	2.6	0.0	29.8	0.4	1.0
E. superba (L)	11.5	1.0	4.5	0.0	12.5	1.6	14.1
Spongiobranchaea australis	45.2	0.9	1.7	0.0	38.5	0.8	2.8
Clione limacina	38.5	0.9	2.3	0.0	10.6	0.1	0.4
Primno macropa	26.0	0.7	1.9	0.0	49.0	1.9	3.5
Radiolarians	27.9	0.7	1.5	0.0	28.8	0.9	0.6
Lepidonotothen larseni (L)	23.1	0.5	1.5	0.0	13.5	0.1	0.6
Eukrohnia hamata	13.5	0.5	2.1	0.0	4.8	0.5	4.6
Cyllopus lucasii	20.2	0.5	1.8	0.0	57.7	1.6	2.9
Euphausia triacantha	7.7	0.3	1.5	0.0	11.5	0.6	2.2
Euphausia frigida	5.8	0.2	1.0	0.0	29.8	9.3	34.2
Dimophyes arctica	2.9	0.1	0.6	0.0	16.3	0.4	2.6
T. macrura (L)	1.9	0.0	0.2	0.0	13.5	2.6	16.3
Total number of taxa	65				62		

[a]*Ihlea racovitzai* was first identified at the end of Survey A, so values presented here are not representative of the survey area in January.

Sixty-five taxonomic categories were identified in the January Survey A samples. The most abundant of these are listed in table 1. The salp *Salpa thompsoni* was present in all samples and, with mean and median abundances of 808.2 and 323.7 per 1,000 m^3, respectively, was the numerically dominant zooplankton taxon. These salps occurred in abundance throughout the entire survey area, although greatest densities occurred within the Elephant Island area (figure 1*A*). Over 92 percent were the chain-forming aggregate stage. Production of this stage by overwintering solitary stage individuals may, under benign conditions, lead to massive salp population blooms during spring and summer months (Foxton 1966). Apparently, conditions during 1997–1998 were highly favorable for salp production.

T. macrura also occurred in all samples and ranked second in overall abundance with a mean of 180.8 per 1,000 m^3. Copepods were relatively frequent in samples and ranked 3 in overall mean abundance (56.5 per 1,000 m^3). Although a second Southern Ocean salp species, *Ihlea racovitzai*, was noted only in six samples, its mean abundance was 41.5 per 1,000 m^3, and so it ranked 4. Krill (*E. superba*) constituted the fifth most abundant taxon. Other relatively frequent taxa were chaetognaths; the pteropods *Limacina helicina, Spongiobranchae australis,* and *Clione limacina*; amphipods *Vibilia antarctica, Cyllopus magellanicus*, and *Hyperiella dilatata*; ostracods; and the siphonophore *Diphyes antarctica* (table 1).

February Survey D samples contained 61 taxa, the most abundant of which are presented in table 1. *S. thompsoni* was present in 102 of 104 large-area survey samples and in all 61 Elephant Island area samples and was the most abundant taxon. Most of the largest salp catches (more than 1,000 per 1,000 m^3) were in the Elephant Island area (figure 1*B*). The largest catch of *S. thompsoni* was 93 liters, collected at night southeast of Elephant Island. At this time, large numbers of salp chains were observed near the surface, and salps clogged the ship's engine intake filter. Salp density here was estimated at nearly 11,000 per 1,000 m^3 water filtered and 1,800 salps per 1 m^2 sea surface area. As during January, the vast majority of *S. thompsoni* (97 percent) were the aggregate stage.

T. macrura again occurred in 100 percent of samples and was second in abundance. Krill and copepods, respectively, ranked 3 and 4 in mean abundance. *I. racovitzai* was present in 61 percent of samples and was the fifth most abundant taxon. Its distribution was distinctive in that virtually all individuals were collected south of a strong frontal zone extending across the survey area (figure 2). Greatest concentrations were encountered just south of the frontal zone, south of King George Island, and south of Clarence Island.

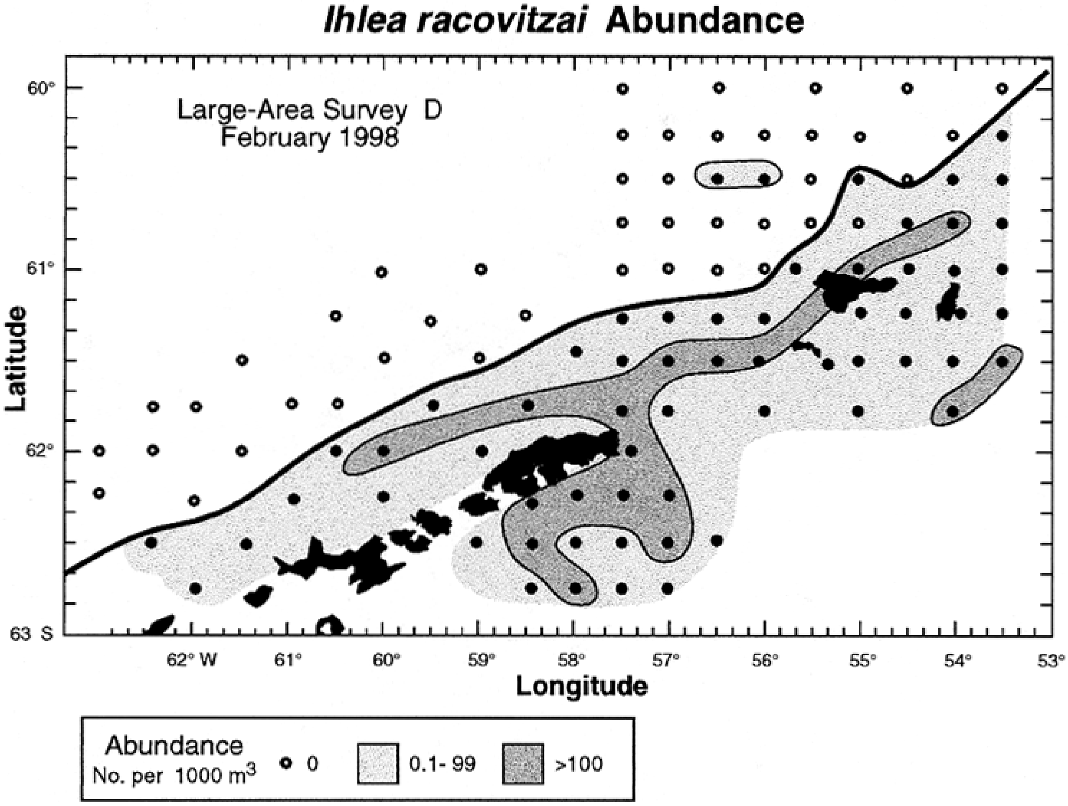

Figure 2. Distribution and abundance of* Ihlea racovitzai *in the Survey D area, February 1998.

Overall, zooplankton taxonomic composition and abundance were similar between the two surveys (table 1). Among the five numerically dominant taxa, only copepods exhibited a significant seasonal abundance difference, with substantially larger catches in February (Z test, $P = 0.05$).

Table 2. Averaged January–March abundance values for numerically dominant zooplankton taxa in the Elephant Island area, 1993 to 1998

NOTE: Abundance is mean number per 1,000 cubic meters. Ranks are provided for the 10 most abundant taxa each year. n.a. indicates that the taxon was not enumerated. L indicates larval form.

	1998		1997		1996		1995		1994		1993	
Taxon	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**
Salpa thompsoni	1	748.7	2	713.4	6	24.3	7	16.2	2	670.9	1	1284.3
Thysanoessa macrura	2	179.1	3	142.8	3	125.1	5	128.9	3	99.3	2	96.5
Copepods[a]	3	87.8	1	925.2	1	1090.7	1	1920.9	1	1565.8	4	19.1
Euphausia superba	4	85.1	4	35.4	4	109.6	9	10.1	4	22.8	3	39.6
Ihlea racovitzai	5	46.5		n.a.		n.a.		n.a.		n.a.		n.a.
Vibilia antarctica	6	10.6	9	5.3		0.8		0.2	7	9.1	7	1.6
Chaetognaths	7	9.8	6	20.6	5	38.3	3	188.0		n.a.	5	4.6
Ostracods	8	5.1	10	5.2	9	7.5	6	26.6		n.a.		n.a
Euphausia frigida	9	4.7	5	29.8	10	5.5	8	13.3	5	14.9	6	2.3
Limacina helicina	10	4.4		1.4	7	17.8		1.0		0.2		0.0
Cyllopus magellanicus		3.7		3.6		1.8		0.4	8	5.3		0.7
***E. superba* (L)**		1.3	7	20.1	8	8.3	2	1912.9		n.a.		n.a.
***T. macrura* (L)**		1.3	8	13.9	2	361.5	4	146.4		n.a.		n.a.
Cyllopus lucasii		1.0		1.4		0.2		0.5	9	3.4	10	1.0
Euphausia triacantha		0.4		1.1		0.6		1.6		1.1	9	1.0
Themisto gaudichaudii		0.3		3.2		3.7	10	4.2	6	11.2	8	1.6
Clio pyramidata		0.1		0.0		0.0		2.7	10	2.8		0.1

[a]Copepod abundance for 1993 is based on the January value only and so is probably an underestimate.

Presence of large numbers *I. racovitzai* during 1998 was unique to AMLR surveys, but this species was also reported to be quite abundant in the Antarctic Peninsula region during February 1986 (Esnal and Daponte 1990) and December 1990–January 1991 (Nishikawa et al. 1995). Foxton's (1971) distribution map of *I. racovitzai*, based on 1924–1951 *Discovery* investigation material, indicates that although this species was quite abundant north and east of the Weddell Sea, it was rarely collected in the Antarctic Peninsula region. It appears that the circulation pattern during summer 1998, as well as 1986 and 1990–1991, resulted in advection of this species into the region. This phenomenon could be fairly recent and related to climate warming and environmental change (Loeb et al. 1997).

The zooplankton assemblage in the Elephant Island area during summer months has varied widely over the past 6 years; these changes have been associated with shifts between salp and copepod dominance (table 2). Taxonomic abundance relationships during 1998 were most similar to those during 1993 when *S. thompsoni* was the numerically dominant taxon followed by *T. macrura,* copepods, and krill. These two "salp years" contrast strongly with 1995 and 1996 when copepods were the numerical dominant followed by larval krill (1995) or larval *T. macrura* (1996). Changes in mean abundance of copepods and *S. thompsoni* between these two regimes ("salp years" and "copepod years") were one to two orders of magnitude. The intervening "transition years," 1994 and 1997, also share similar taxonomic abundance relationships; copepods were the dominant taxon, followed by *S. thompsoni*, *T. macrura*, krill, and *Euphausia frigida*. Percent similarity index values (PSIs) resulting from between-year comparisons of the proportions of each taxon are highest between the two "transition years" (82) and the two "salp years" (74) and lowest between "salp years" and "copepod years" (6 to 24). A relatively low PSI value from comparison of the two "copepod years" (54) reflects between-year variability in abundance of other taxa during this regime.

We greatly appreciate the help in sample collection and onboard processing provided during the 1998 cruises by Rachel Johnson, Elizabeth Linen, Michael Force, Charles F. Phleger, Volker Siegel, Kimberly Dietrich, and Matthew Nelson. We also thank the numerous assistants who have helped with this work during the 1993–1997 AMLR cruises.

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AMLR program: Physical oceanography of the Elephant Island area, summer 1998

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The physical oceanography group of the Antarctic Marine Living Resources (AMLR) program surveyed the waters of the South Shetland Islands from Elephant to Livingston Island, parts of the Drake Passage, and the Bransfield Strait for the ninth field season during the 1998 austral summer (Martin, Hewitt, and Holt, *Antarctic Journal*, in this issue). The aim is to study the relationship between physical and biological processes and the variability on interannual and seasonal scales. AMLR 1998 was the third cruise to be conducted aboard the research ship *Yuzhmorgeologiya*. Some new stations were added to the north of Livingston Island, and some of the original 91 large-area survey stations were dropped. One hundred fourteen conductivity-temperature-depth (CTD)/carousel casts were made on each of the first two legs of the cruise, and 22 casts were made on Leg III, for a total of 250 casts. The CTD/carousel unit also included dissolved oxygen, fluorometer, transmissometer, and photosynthetically available radiation (PAR) sensors. Ninety days of continuously acquired weather, sea temperature, salinity, water clarity, chlorophyll, and solar radiation data were collected to provide complete coverage of surface environmental conditions encountered throughout the AMLR study area. CTD profiles were limited to 750 meters (m) depth (or to within a few meters of the ocean floor when the depth was 750 m, or less). To define frontal boundaries, three cross-shelf transects were made to depths of 2,000 m.

As before, we classify and group stations with similar vertical temperature/salinity (T/S) characteristics (Amos and Lavender 1991) and have identified five water zones, designated I through V. The water zones are based on the T/S curves from the surface to 750 m (or to the bottom in water shallower than 750 m). For example, Water Zone I is based on these multiple characteristics:

- warm, low salinity surface water;
- a strong subsurface temperature minimum (called "Winter Water" or WW, at approximately -1°C and salinity of 34.0 parts per thousand); and
- a distinct T/S maximum near 500 m (called "Circumpolar Deep Water" or CDW).

Water Zone I is the oceanic water of the Drake Passage. In the Bransfield Strait and south of Elephant Island, Water Zone IV dominates. Here bottom waters are around -1°C, and the subsurface extremes are far less prominent, although a slight “crook” in the curve is characteristic. In between are transition zones, where adjacent water zones mix. A few shallow stations on the South Shetland Islands shelf close to the islands show little vertical structure and are grouped as a sixth zone (Holm-Hansen et al. 1997). Figure 1 shows the composite T/S scatter diagram for all stations of Survey A (8–25 January

1998). During January, it appeared that 1998 would be a "cold year," with surface temperatures not reaching 3°C. The sea surface warmed up in February and March, when waters in Water Zone I reached above 3.5°C. Note the split in the region between the WW T-min and the CDW T-max, indicating the difference between upper and lower CDW (figure 1).

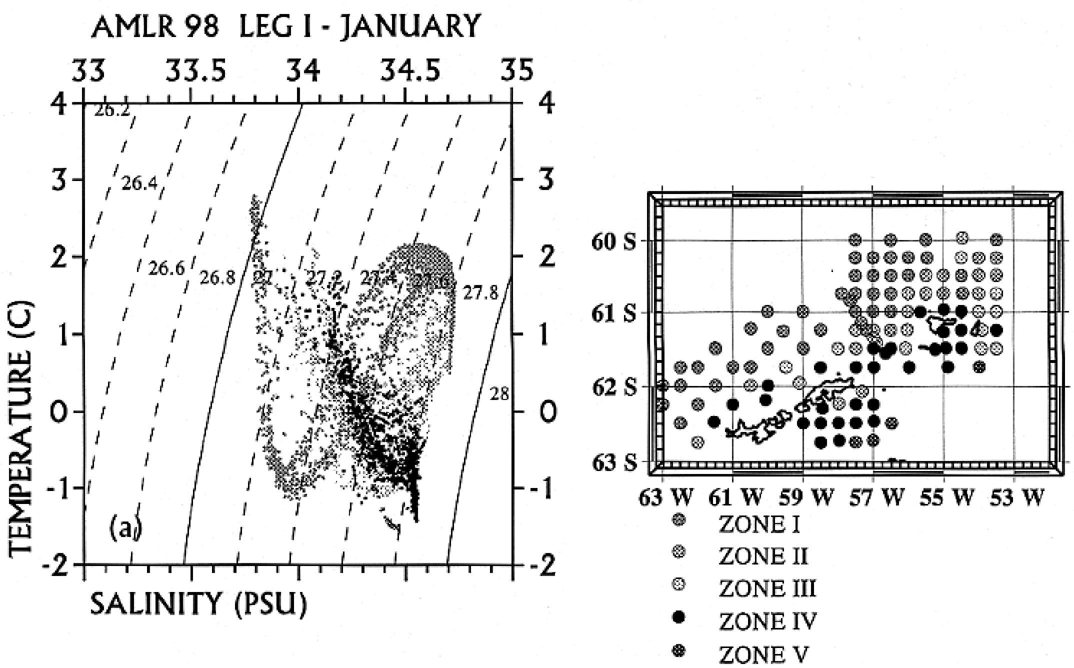

Figure 1. T/S scatter diagram for all CTD stations made during AMLR 1998, Leg I (January 1998). Points are shaded by zones with similar T/S characteristics; locations and zones are identified in the inset station map. (PSU denotes practical salinity units.)

For AMLR 1998, we made extensive use of Ocean Data View 40 (ODV4.0) software, developed at the Alfred-Wegener-Institut (AWI) by Dr. Reiner Schlitzer. This software is freely available from AWI via the Internet (http://www.awi-bremerhaven.de/GPH/ODV). Its strength is in the ease and rapidity by which one can visualize vertical oceanographic sections and horizontal surfaces in color on a PC or Macintosh and produce color copy using today's inexpensive printers. Special conditions or outliers can instantly be pinpointed using the mouse and groups of stations can be isolated by time, depth, location, or parameter range. Figure 2 is a section along the 57°W meridian in February, constructed using ODV4.0. Reproduction is less satisfactory here in gray scale than in the color of the original, but features of a typical section extending from the oceanic water of the Drake Passage in the north to the Bransfield Strait in the south are clear. Waters, generally colder than 0°C, fill the Bransfield Strait. Potential temperature in the Drake Passage shows the WW T-min near 100 m, and the CDW T-max greater than 2°C near 400 m with the associated salinity maximum and oxygen minimum. The shelf slope front is delineated at the surface by temperature, salinity, and density (Sigma-0), and subsurface by temperature and dissolved oxygen. There is no subsurface density boundary. Figure 2 also shows the T/S relationship of the stations used to construct the sections. Surface conditions over the AMLR survey area are contoured in figure 3. The front is most easily seen in surface salinity and density.

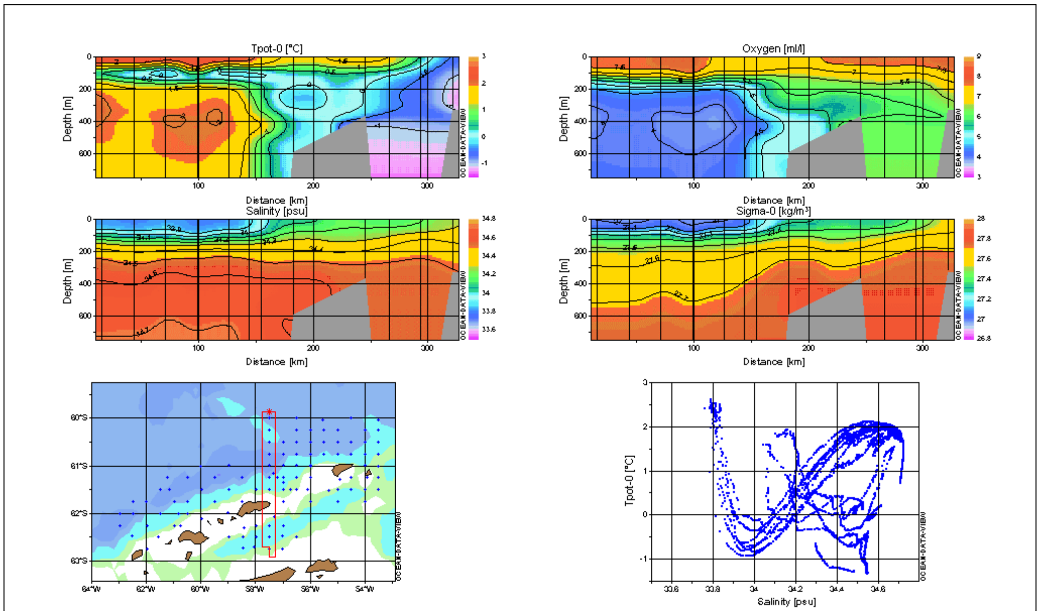

Figure 2. Potential temperature, dissolved oxygen, salinity, and density (Sigma-0) sections along the 57°30'W meridian. North is to the left of each panel. Station locations shown in the map, lower right. The T/S curves for stations used in the sections are shown in lower right panel. Diagram produced with ODV4.0 software (see text). (psu denotes practical salinity units. km denotes kilometer. ml/l denotes milliliters per liter. kg/m^3 denotes kilogram per cubic meter. T_{pot} denotes potential temperature.)

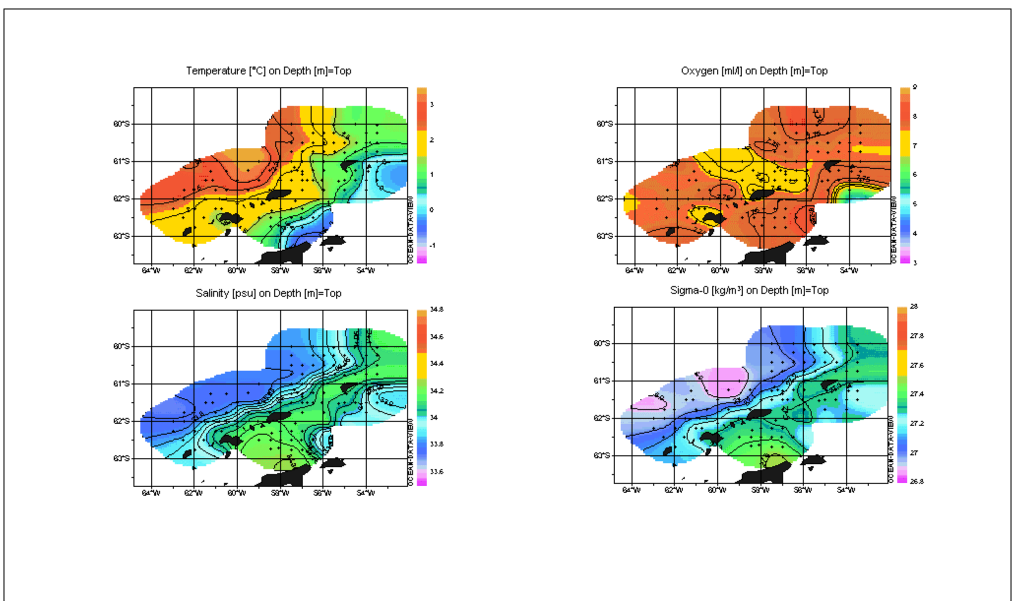

Figure 3. Surface distribution of temperature, dissolved oxygen, salinity, and density (Sigma-0) during February and early March 1998 (AMLR 1998, Leg II). Diagram produced with ODV4.0 software (see text). (psu denotes practical salinity units. ml/l denotes milliliters per liter. kg/m^3 denotes kilogram per cubic meter.)

We know that certain aspects of the physical oceanography correlate with the biology of the AMLR study area, such as the phytoplankton and nutrient distribution (Holm-Hansen et al. 1997). The hydrography as related to the distribution of other, more mobile organisms, such as krill and other zooplankters, remains more elusive. Loeb et al. (1997) demonstrate the importance of sea-ice variability to dominance of krill or salps. Also, during AMLR cruises, we often see a correspondence between the pycnocline and *Myctophid* fish abundance (for example) as revealed in the acoustic profile (Hewitt personal communication 1988). The general hydrographic characteristics of the upper waters in the AMLR region are similar from year to year. Our investigations target the changes in the surface conditions and subsurface layers of potential importance to the biological regime such as the WW T-min. Organisms descending vertically in the stably stratified upper 200 m of the water column may experience temperature changes from 4°C to -1.5°C and back to nearly 2°C. This layer is the one sampled by the net sampling program (Loeb, *Antarctic Journal*, in this issue). January 1998 saw cold surface waters and an extensive WW layer. By February and early March, surface waters warmed to typical late summer values of 3.5°C in the Drake Passage, while the WW warmed and eroded but remained distinct. We are investigating the relationship between the winter sea surface temperatures from satellite observations, and the following summer's WW layer as measured during AMLR cruises.

This work was accomplished under NOAA Contract 50ABNF600015 to the University of Texas at Austin. We are most grateful to Captain Igor Zhelyabovskiy and the crew of the R/V *Yuzhmorgeologiya* for their handling of the ship in the difficult fog and ice conditions this year. Valeriy Kazachenok and Andrey Mikhaylov ably assisted the physical oceanography group.

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AMLR program: An unusual South Shetlands weather event

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On 17–18 March 1998 during Cruise Leg III of the Antarctic Marine Living Resources (AMLR) program, the research ship *Yuzhmorgeologiya* experienced an unusually vigorous storm while working in the Elephant and Clarence Islands region of the South Shetland Islands. Leg III was devoted to bottom-trawling operations and conductivity-temperature-depth stations. Wind velocities are often variable in this region, especially around Clarence Island, but for several days in mid-March, a typical strong northwesterly had been blowing.

Not so typical at that latitude was a high sea-level pressure that peaked at 1012.9 kilopascals (kPa) on 13 March. The pressure dropped for several days, and on 17 March the decline became erratic: an 8-kPa drop occurred in one hour, producing a 28 meters per second (m s^{-1}) gust. Trawling was temporarily halted because of the high winds and the ship hove-to in the lee of Clarence Island.

The air temperature rose during this period to a maximum of 15.4°C at 1912 universal time (UT). This air temperature is the highest measured during the 9 years of the AMLR program where meteorological parameters have been recorded and may be one of the highest temperatures measured in Antarctica. The high occurred during daylight, 4 hours after local apparent noon. Air temperature varied dramatically, ranging from 3.1°C to the 15.4°C record on 17 March. On 18 March at 0244 UT, a wind gust of 40.0 m s^{-1} was recorded. A low pressure of 979.1 kPa occurred shortly after that and, almost coincidentally with the peak winds, a high temperature of 14.5°C was measured. Air temperature dropped to 0.4°C by the afternoon as the winds shifted to the south and moderated. On 19 March, temperatures dropped to a low of -2°C.

During the storm, a low cloud cover persisted, but seas were not high, presumably because of the protection of Clarence Island. One interesting feature of the event was the change in humidity. During most of the AMLR cruises, humidity is near 100 percent, and persistent fog is a normal feature. The humidity dropped to 41 percent and was nearly inversely related to the air temperature throughout the weather event. Sea temperature remained unremarkable throughout those days, averaging around 1°C. The meteorological data from 17 and 18 March are plotted in figure 1*A*. A gap in all recording occurred in the early hours of 17 March and the sea-water system clogged during part of the storm on 18 March. No sea surface measurements were recorded during this period.

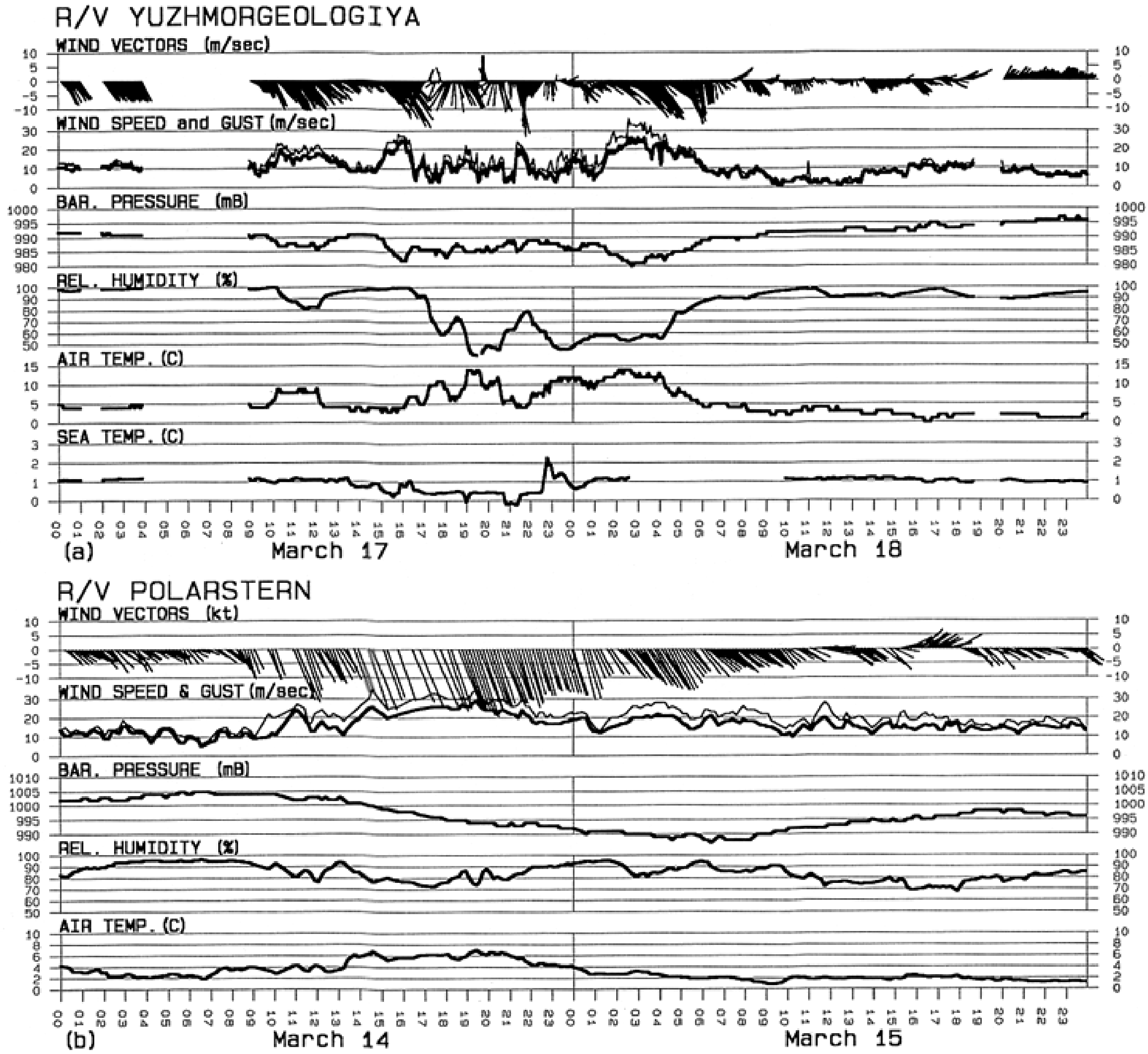

Figure 1. **A*****. Meteorological conditions recorded by R/V*** **Yuzhmorgeologiya** ***during 17-18 March 1998. Wind vectors shown in top panel. North is up. Wind gust shown (light line) above wind speed (heavy line) in second panel from top.*** **B*****. Ten-minute averaged data meteorological conditions as recorded by R/V*** **Polarstern** ***during 14–15 March 1998. Note different scales used for barometric pressure and air temperature in*** **A** ***and*** **B*****. Data in*** **B** ***are used by permission from the Alfred-Wegener-Institut (see Koenig-Langlo and Marx 1997). All data are subject to correction.***

Table 1. Temperature and relative humidity as measured by the R.M. Young weather system and by psychrometer.

Date/time	R.M. Young		Psychrometer	
	Temperature (ºC)	Relative humidity (%)	Temperature (ºC)	Relative humidity (%)
17 March 1998 1109 universal time	8.6	91.1	9.1	86
17 March 1998 1728 universal time	10.1	72.6	10.8	69

Although verification of the highest temperature was not made independently, psychrometer readings were taken at intervals to compare with the R.M. Young weather system used on *Yuzhmorgeologiya*. Table 1 shows comparisons made during the warm event.

To see if this event was local or more widespread, meteorological records for the month of March 1998 from various land stations and one research vessel were examined. Data were obtained from the National Climatic Data Center (NCDC) online archives (http://www.ncdc.noaa.gov/oa/climate/climatedata.html , Climate Visualization site) and from the Web site of the research ship *Polarstern* (http://www.awi-bremerhaven.de/MET/Polarstern/met.html). Other ships may have been in the area, and a search for more data will be made.

Polarstern was in the Bransfield Strait in mid-March and experienced a similar weather event 14–15 March. Data from their 10-minute record are plotted in figure 1*B*. In the record, northwesterly winds peaked at 28.6 m s^{-1} at 1925 UT, 14 March with a gust of 34.4 m s^{-1}. Air temperature peaked at the same time at 7.1°C, and humidity and surface pressure dropped from their highs earlier in the day. *Polarstern* stayed in the region through 17 and 18 March but reported no unusual conditions on those days, some 290 kilometers southwest of the *Yuzhmoregeologiya*'s position. In table 2 the highest temperatures and surface pressures for March 1998 are listed for each of several stations and the two ships. Figure 2 shows the ships' cruise tracks and locations of stations in the South Shetland area listed in table 2.

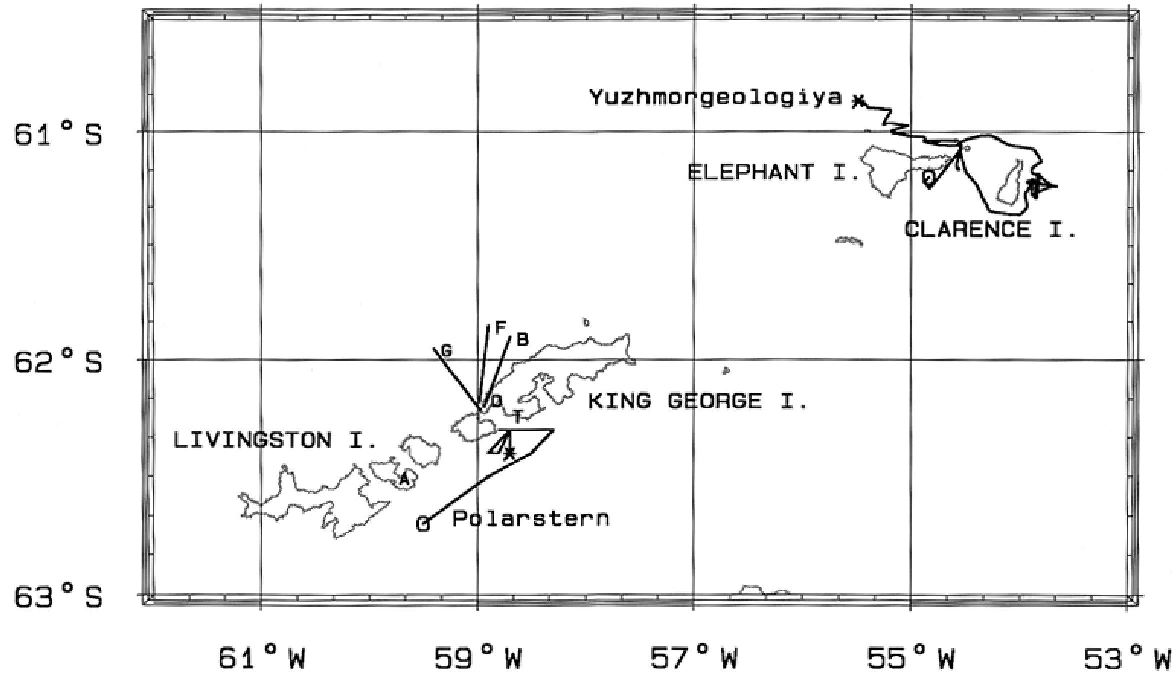

Figure 2. Cruise tracks of the research ship* Yuzhmorgeologiya *on 17–18 March 1998 and R/V* Polarstern *on 14–15 March 1998. Circle shows start of tracks; * indicates end of tracks. Also shown are some of the stations where temperature and pressure measurements were used in table 2. (A denotes Arturo Prat; B, Bellingshausen; D, Dinamet: G, Great Wall; E, Eduardo Frei; and T, Teniente Jubanay.)

Stations on South Georgia and South Sandwich Islands are included for comparison. Most temperature maxima for the month occurred on 13 or 14 March. The 15.4°C measured aboard *Yuzhmorgeologiya* was by far the highest. It is interesting to note that to the east of the Antarctic Peninsula, noted as the coldest part of the region (Smith, Stammerjohn, and Baker 1996), a high of 8.8°C was recorded at Vicecomodoro Marambio Station on Seymour Island on 25 March. Almost all stations recorded the highest surface pressure for the month on 13 March.

Table 2. Air temperature and surface barometric pressure extremes (highs), March 1998

Station or ship	Latitude (S)	Longitude (W)	Maximum air temperature[a]		Maximum barometric pressure[b]	
			Date	Temperature	Date	Pressure
Vicecomodoro Marambio	64°14'	56°43'	25	8.8	13	1002.6
Racer Rock	64°10'	61°32'	14	2.8	—	—
Bernardo O'Higgins	63°19'	57°54'	23	4.6	13	1005.8
Arturo Prat	62°30'	59°41'	25	5.8	13	1006.4
R/V *Polarstern*	62°18'	58°42'	14	7.0	13	1005.4
Teniente Jubany	62°14'	58°38'	14	7.4	13	1006.2
Great Wall	62°13'	58°58'	16	3.9	13	1007.1
Bellingshausen	62°12'	58°56'	13	4.0	13	1006.0
Eduardo Frei	62°11'	58°59'	6	4.2	13	1004.9
Dinamet–Uruguay	62°10'	58°50'	13	5.1	13	1006.1
R/V *Yuzhmorgeologiya*	61°15'	53°43'	17	15.4	13	1012.9
South Tule Island	59°27'	27°19'	31	5.4	14	1004.1
Grytviken South Georgia	54°16'	36°30'	17	14.5	29	1011.4

[a]In °C.

[b]In millibars.

Klinck and Smith (1996) show that a predictive relationship can be established between surface pressure, winds, and air temperature when comparing ship and land station observations in the peninsula region. In the case of the event experienced on AMLR 1998 Leg III, it would appear that although there are some similarities, conditions are not readily explicable by the passage of a typical antarctic cyclonic storm. The source of warm, dry air in the lee of an ice-capped mountainous island, with hurricane force wind gusts blowing over 1°C surface waters remains a mystery. The highest antarctic temperature reported in the general literature is 15°C at Vanda Base on 4 January 1974 (Krause and Flood 1997).

The work was carried out under NOAA Contract 50ABNF600015 to the University of Texas at Austin. The author wishes to thank the captain and crew of the R/V *Yuzhmorgeologiya*, and especially Charles Rowe, who maintained the underway instrumentation during the arduous conditions of Leg III.

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AMLR program: Linking prey distribution and abundance with reproductive success in antarctic fur seals; foraging range and diet of females rearing pups

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Marine coastal and pelagic environments of the Southern Ocean are characterized by seasonal high productivity. Over the last several decades, it has become clear that these environments, although generally productive, also undergo considerable inter- and intra-annual variability. Consequently, available prey resources for vertebrate predators can be highly variable spatially and temporally. The U.S. Antarctic Marine Living Resources (AMLR) program has empirically measured the temporal and spatial variability of prey resources of the northern South Shetland Islands region of the Antarctic Peninsula. One of the objectives of the AMLR program has been to measure how krill predators respond to changes in the availability of their food source. In 1997, a field camp designed for on-land study of vertebrate krill predators was established at Cape Shirreff, Livingston Island. The study area used by the AMLR program to systematically study changes in physical and biological oceanography of the region was extended south to encompass areas where land-based predators breeding at Cape Shirreff may forage (see Martin, Hewitt, and Holt, *Antarctic Journal*, in this issue).

Antarctic fur seals, a subpolar migratory Otariid with a short lactation period (4.5 months), is an increasingly dominant marine predator of the South Shetlands region. Its life history pattern, characterized by foraging trips (ranging from 0.5 to 7 days at sea) alternating with 2-day shore visits to provide for a single offspring, allows us to measure maternal investment on the same temporal and spatial scale as measurements of distribution and abundance of various prey species.

Knowledge of a species' foraging range and diet is an essential element to understanding the ecology of land-based marine predators. Female antarctic fur seals must acquire enough food resources within a particular range of their breeding rookery to meet their energy demands as well as that of their pups. Previous studies of the foraging range of fur seals breeding in the South Shetland Islands took place at Seal Island, one of the northern most islands. Animals were tracked at sea using very-high-frequency transmitters and shipboard receiving equipment. The number of animals that could be tracked and the distance covered were limited with such a system because a ship can track only one animal at a time and often only to limited distances. More recently developed technology allows us to track many more animals simultaneously using satellite-linked telemetry.

Fur seal diets can be varied and consist primarily of diurnally migrating prey. The antarctic fur seal forages primarily on krill in the northern regions of its breeding range. Diet of animals breeding in the South Shetland Islands, however, may be more variable. Foraging on different prey species may have different costs and benefits, and that variation can affect growth of offspring and reproductive success. Diet for female fur seals can be measured in two ways: analysis of hard parts found in scats, and molecular analysis of the fatty acid composition of milk lipid. Long-chained fatty acids found in lipid stores (milk and adipose) have been proven reliable indicators of diet in many marine and terrestrial mammals (Brandorff 1980; Reidinger et al. 1985; Rouvinen and Kiiskinen 1989; Iverson, Frost, and Lowry 1997) including antarctic fur seals (Iverson, Arnould, and Boyd 1997). Scat analysis for diet is problematic in that the information collected is indicative of only the last meal or at best the previous day. Fatty acid signature analysis of milk, however, integrates dietary information for the entire preceding trip. It is, thus, a measure incorporating diet information over a more appropriate temporal scale.

Measures of foraging range and diet of predators are important for understanding how reproductive success of predators is linked to physical and biological oceanography of the region. Two of our primary objectives for the 1997–1998 field season at Cape Shirreff, Livingston Island were to

- measure foraging range of female fur seals rearing pups using ARGOS satellite-linked telemetry and
- measure diet using scats and milk fatty acid signature analysis.

We instrumented 11 females with ARGOS satellite-linked transmitters and time-depth recorders for a single trip to sea from 8 to 27 February 1998 (figure 1). Foraging trips averaged 4.6 days (range: 3.2–6.8 days). We had 421 successful at-sea satellite locations (average: 8.3/day/female), after the data were filtered to eliminate positions that required females to travel more than 4 meters per second. The mean distance traveled offshore was 98 kilometers (km) ±24.9. The maximum distance traveled offshore was 142 km. All females foraged within the bounds of the AMLR study area. Females foraged in three areas:

- over the continental shelf [in waters less than 500 meters (m) deep],
- along the shelf-break (at the 500-meter depth contour), or
- over deep water (deeper than 1,000 m).

Information on fur seal diet was collected from scats of captured animals as well as from beaches and from dietary fatty-acid profiles of milk. Sixty-eight milk samples were collected for fatty-acid analysis. We report only the information from scat analysis. In total, 53 scats and enemas were collected throughout the season. Forty-two samples contained identifiable hard parts such as fish bone, krill chitin, and squid beaks. Scats containing fish constituted 61.9 percent, krill 57.2 percent, and squid 14.3 percent (figure 2).

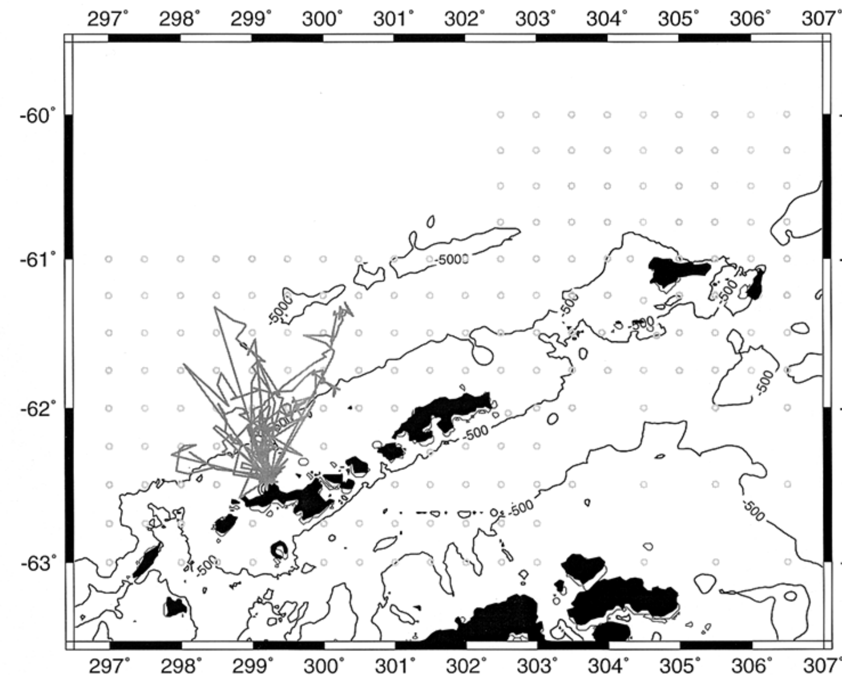

Figure 1. Foraging track lines for 11 female antarctic fur seals rearing pups at Cape Shirreff, Livingston Island, Antarctica (62°28'07"S 60°46'10"W). The AMLR study area is overlaid on fur seal track lines.

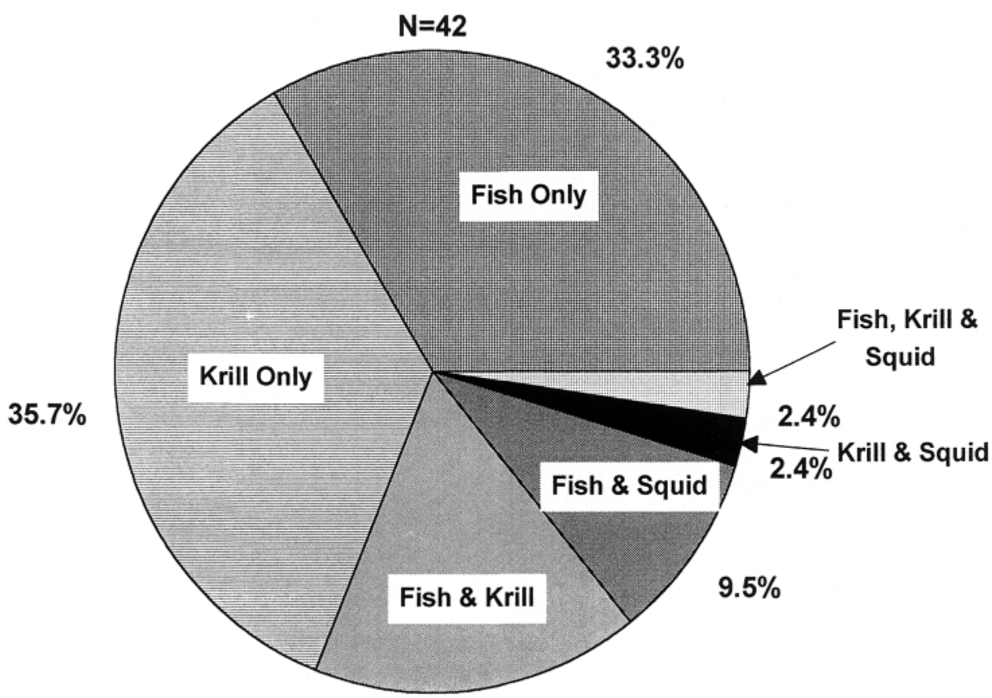

Figure 2. Composition of antarctic fur seal diet in 1997–1998 at Cape Shirreff, Livingston Island, Antarctica (62°28'07"S 60°46'10"W).

Female antarctic fur seals rearing pups at Cape Shirreff, Livingston Island, foraged within the bounds of the AMLR study area. Diet was variable and consisted of fish, krill, and cephalopods.

In future studies, we will quantify the foraging costs and maternal investment in pups associated with different foraging locations and diets observed in populations of South Shetland antarctic fur seals. We will determine the energetic costs and benefits of different foraging patterns by simultaneous measurements of energy expenditure, food intake, dive depth, duration, time of day, dive frequency, swim speed, and foraging location. We will determine composition of diet through collections of scats and by analysis of milk fatty acid profiles. All measurements will coincide with shipboard surveys to be conducted by the AMLR program. Daily updates of foraging locations of individual female seals equipped with satellite-linked telemeters will enable simultaneous assessments of physical and biological oceanography at foraging sites.

This research will enable us to link biological (prey composition, distribution, and abundance) and physical characteristics of the foraging environment with foraging success, maternal investment, and reproductive success for a free-ranging marine vertebrate predator, the antarctic fur seal.

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AMLR program: Standing stock biomass of six species of finfish around Elephant Island and the lower South Shetland Islands from the 1998 U.S. AMLR bottom trawl survey

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Commercial fishing for finfish in the South Shetland Island chain was conducted from 1978–1979 through 1988–1989. Within 2 years after the fishery was developed, catches substantially declined, leading the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) to impose a moratorium on taking finfish from the South Shetland Islands from 1989–1990 to 1997. Since the moratorium, there has been one German bottom trawl survey around Elephant Island (Kock 1998) in the 1996–1997 split year and no surveys in the lower South Shetland Islands (King George Island to Livingston Island). The objective of this survey was to provide baseline information about the health of fish stocks in the South Shetland Island chain. From this survey, we compute estimates of total and spawning stock biomass for six antarctic finfish species: *Chaenocephalus aceratus*, *Champsocephalus gunnari*, *Chionodraco rastrospinosus*, *Gobionotothen gibberifrons*, *Lepidonotothen squamifrons*, and *Notothenia coriiceps*.

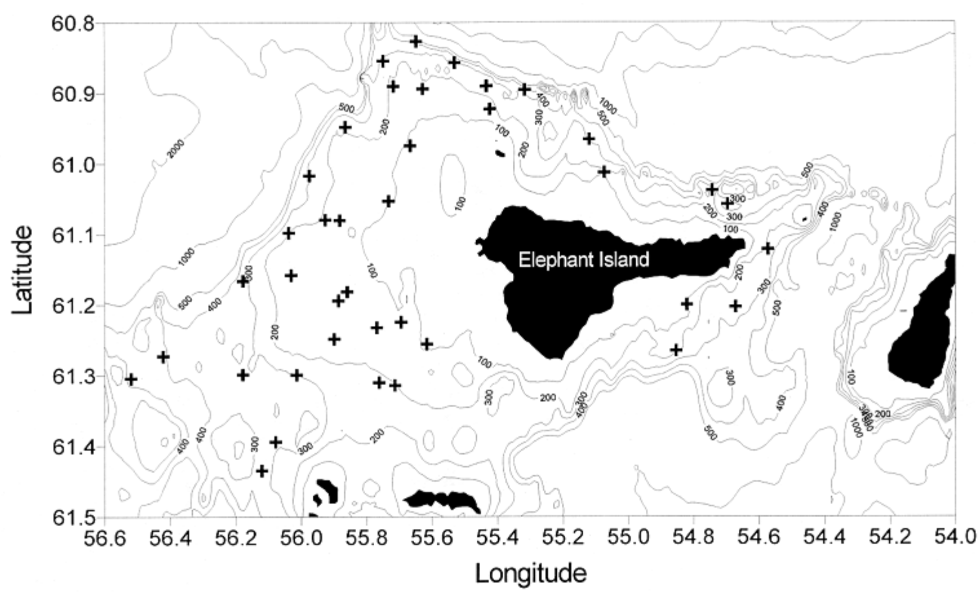

Figure 1. Location of hauls around Elephant Island.

The fishing gear used to conduct the survey was a "Hard Bottom Snapper Trawl" with vented V-Doors, and a net sonde system to record the trawl mouth dimensions. Trawling operations were conducted aboard the R/V *Yuzhmorgeologiya* 12 March 1998 through 1 April 1998. Separate trawl surveys, based on random-depth stratified designs, were conducted for Elephant Island and the lower South Shetland Islands. There were 39 hauls around Elephant Island (figure 1) and 35 hauls in the lower South Shetland Islands (figure 2). In total, 10,551.1 kilograms (kg) (34,867 individuals) of 45 different fish species were captured from all hauls—7,420 kg (24,917 individuals) of 35 species from the Elephant Island area, and 3,131 kg of 40 species from the lower South Shetland Islands. Species examined here constitute a majority of all catches (table 1).

For each haul, total weight of individual species captured was summed and standardized to one square nautical mile of area swept using the average trawl mouth width and bottom distance covered. Estimates of standing stock biomass were computed by stratum using the Delta-lognormal maximum likelihood estimator (Pennington 1983; de la Mare 1994). To compute spawning stock biomass, information on maturity from the survey was used to separate spawners (maturity stage 3–5) from immature or developing fish. Total and spawning biomass estimates were computed for the lower South Shetland Islands and Elephant Island separately and combined as one stock.

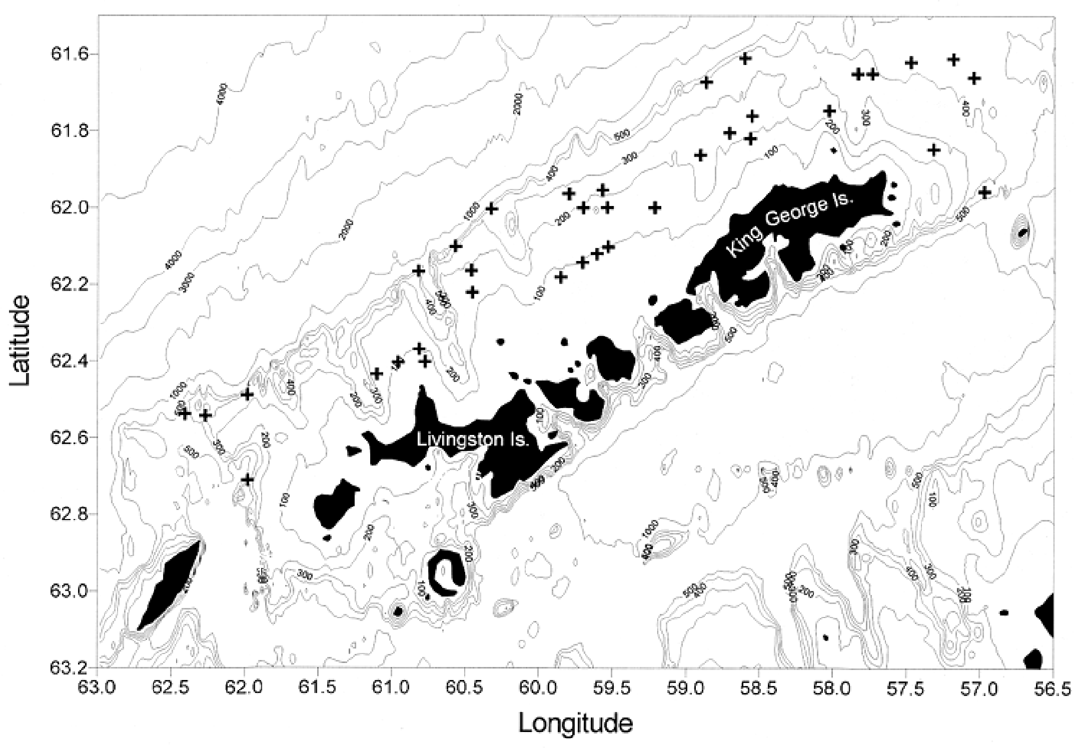

Figure 2. Location of hauls in the lower South Shetland Islands.

Table 1. Total and mature yield (in kilograms) of selected species from the 1998 U.S. AMLR trawl survey

	Elephant Island		Lower South Shetland Islands	
Species	**Total yield**	**Mature yield**	**Total yield**	**Mature yield**
Chaenocephalus aceratus	273.4	137.5	232.2	65.1
Champsocephalus gunnari	1,447.7	25.0	283.6	73.1
Chionodraco rastrospinosus	144.6	85.6	200.9	139.5
Gobionotothen gibberifrons	5,022.3	3,091.7	754.9	153.5
Lepidonotothen squamifrons	198.4	40.0	109.7	24.9
Notothenia coriiceps	122.8	108.7	1,249.9	1,138.4

C. gunnari biomass estimates (table 2) in the Elephant Island area were higher than the previous year's estimate of 606 metric tons (MT) by Kock (1998). In the lower South Shetland Islands, there was about twice as much total biomass estimated. When the regions are combined as one system, estimates of total biomass are 8,166 MT. Here, there was a very low percentage of spawners per tow in Elephant Island region and higher proportion in the lower South Shetlands region. When the combined area model is computed, the lower proportion of spawners in the Elephant Island region tends to drive down the total estimate of spawning stock biomass for combined regions.

Biomass estimates of *G. gibberifrons* (table 2) in the Elephant Island area were almost twice as high as the previous year's estimate of 5,157 MT by Kock (1998). In the lower South Shetland Islands, there was about twice as much total biomass. When the regions are combined as one system, the estimate of total biomass is 38,709 MT. In the case of *G. gibberifrons*, spawning stock biomass is substantially higher in the combined model than the sum of both regions. This situation results from the Elephant Island region having a disproportionately higher spawning stock biomass than the lower South Shetland Islands. When this biomass is expanded across the much larger areas of seabed around the lower South Shetland Islands, the overall spawning stock biomass increases accordingly.

Estimates of *C. aceratus* biomass (table 2) in the Elephant Island region were about half of the previous year's estimate of 2,124 MT by Kock (1998). In the lower South Shetland Islands, there was about three times the biomass estimated compared to Elephant Island. When the regions are combined as one system, the estimate of total biomass is 4,440 MT, and about 40 percent of this biomass is mature.

Table 2. Estimates of biomass (in metric tons) and 95 percent confidence intervals for Elephant Island, the lower South Shetland Islands, and combined regions

Species	Area	Total biomass	Spawning stock biomass
Champsocephalus gunnari	Elephant Island	2,765 (1,088–12,471)	70 (49–143)
	South Shetland Islands	5,616 (2,280–40,410)	1,032 (578–3,105)
	Combined	8,166 (4,036–24,586)	676 (445–1,184)
Gibionotothen gibberifrons	Elephant Island	10,272 (4,205–29,306)	5,080 (1,689–15,943)
	South Shetland Islands	20,283 (6,732–136,452)	2,169 (679–7,489)
	Combined	38,709 (17,882–119,902)	12,359 (4,949–27,077)
Chaenocephalus aceratus	Elephant Island	965 (531–165,881)	487 (259–24,264)
	South Shetland Islands	3,080 (1,171–7,636)	800 (459–1,852)
	Combined	4,440 (2,782–615,956)	1,789 (1,070–91,199)
Notothenia coriiceps	Elephant Island	341 (193–1,152)	311 (157–801)
	South Shetland Islands	6,674 (2,018–81,782)	5,699 (1,943–50,501)
	Combined	3,232 (1,719–9,186)	3,177 (1,626–9,650)
Chionodraco rastrospinosus	Elephant Island	551 (254–1,887)	288 (144–785)
	South Shetland Islands	2,962 (1,541–29,302)	1,648 (986–6,571)
	Combined	3,011 (1,785–6,323)	1,598 (1,057–2,710)
Lepidonotothen squamifrons	Elephant Island	998 (233–15,189)	180 (61–794)
	South Shetland Islands	1,676 (695–7,060)	281 (153–590)
	Combined	3,068 (1,289–11,579)	513 (275–1,141)

The estimate of *N. coriiceps* biomass (table 2) in the Elephant Island region was 341 MT. Biomass levels from the 1996–1997 German survey were not available. In the lower South Shetland Islands, there was about 20 times the biomass estimated at Elephant Island. When the regions are combined, the estimate of total biomass is 3,232 MT, 98 percent being spawning biomass. Here, low catches per tow of fish at Elephant Island, combined with high catches in the lower South Shetland Islands, result in estimates of biomass converging, yielding a lower overall estimate (compared to lower South Shetland Islands) when modeled across the entire region. The decrease in combined area spawning biomass was not as great as the decrease in combined area total biomass, driving the percentage of spawners higher than estimates of either region alone. Catches consisted of mostly mature fish. This composition can be attributed to limited numbers of younger fish available to the trawl, since adult fish tend to be located mainly in deeper water, and juveniles are more likely encountered in fjords.

Biomass estimates of *C. rastrospinosus* and *L. squamifrons* (table 2) in the Elephant Island area were about 3.5 times greater than the previous year's estimates of Kock (1998). In the lower South Shetland Islands, there was about 5.4 times the biomass for *C. rastrospinosus* and 1.6 times for *L. squamifrons* compared to the Elephant Island region. When the regions are combined as one system, the estimate of total biomass is 3,011 MT (53 percent spawning biomass) for *C. rastrospinosus* and 3,068 MT (17 percent spawning biomass) for *L squamifrons*.

One must exercise caution when directly comparing estimates of biomass from this survey in the Elephant Island region to those of the 1996–1997 German survey. First, although the survey designs are quite similar, we used a slightly different allocation of hauls by strata than did the 1996–1997 survey, and there may have been a different likelihood of hitting different concentrations by stratum. In addition, there may have been different concentrations in March (this survey) than in November (1996 survey). Finally, there are gear and catchability considerations, although similarity in catch composition between the two surveys suggests differences in catchability in most species were likely small.

The differences in size and maturity stages between Elephant Island and the lower South Shetland Islands for *C. gunnari* and *G. gibberifrons* suggests that different components of the stock are using different regions of the South Shetland Islands. Whether this is persistent from year to year has not been investigated. For these and most other finfish species, the Elephant Island–lower South Shetland Islands chain probably constitutes a single stock, and the combined model likely captures the best estimate of biomass.

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The U.S. Antarctic Marine Living Resources (AMLR) program: 1998-1999 field season activities

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The U.S. Antarctic Marine Living Resources (AMLR) program conducts a research plan, which reflects the goals of the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), part of the Antarctic Treaty System. The Convention manages antarctic fisheries to conserve targeted species, while also considering the impact fishing activities might have on other organisms in the antarctic ecosystem. This unique style of management has been coined the "ecosystem approach." In keeping with CCAMLR's directive, the AMLR program seeks to elucidate the impact of the krill (*Euphausia superba*) fishery upon dependent predators.

The AMLR program monitors finfish and krill fisheries, projects sustainable yields where possible, and formulates management advice and options. In addition, the program conducts field research with the long-term objective of describing the functional relationships between krill, their predators, and their environment. The field program is based on two working hypotheses:

- Krill predators respond to changes in the availability of their food.
- The distribution of krill is affected by both physical and biological aspects of their environment.

For eight consecutive seasons, the AMLR field program included a research cruise near Elephant, Clarence, and King George Islands, which are among the South Shetland Islands at the tip of the Antarctic Peninsula. Land-based studies were conducted at a field camp on Seal Island, off the northwest coast of Elephant Island. However, because Seal Island was found to be unsafe due to landslide hazards, research at the camp was discontinued.

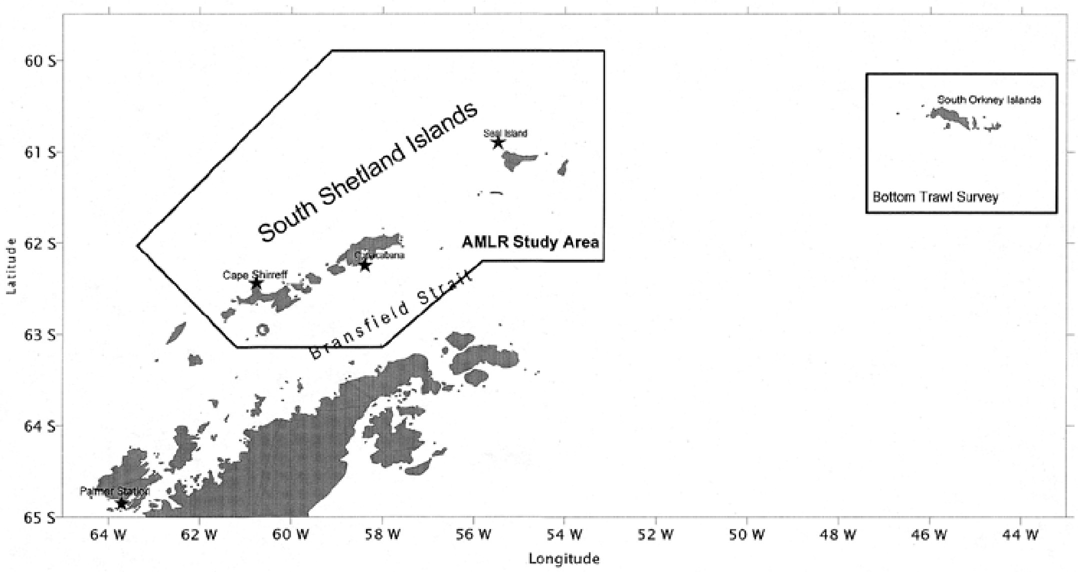

Figure 1. Locations of the U.S. AMLR field research program: AMLR study area, Cape Shirreff, Palmer Station, and the South Orkney Islands.

Beginning in the 1996-1997 season, the AMLR study area was expanded to include a larger area around the South Shetland Islands, and a new field camp was established at Cape Shirreff, Livingston Island (figure 1). The 1998-1999 season continued with descriptive surveys of the pelagic ecosystem in the expanded AMLR study area and studies on the reproductive success and feeding ecology of pinnipeds and seabirds at Cape Shirreff. In addition, a bottom trawl survey was conducted to describe the biomass of finfish in the South Orkney Islands area. As in the past, research was also conducted at Palmer Station, the U.S. station on Anvers Island further south on the Peninsula.

The specific objectives of the 1998-1999 field season were the following:

- to map the physical structure of the upper 750 meters, including the thermohaline composition, oceanic fronts, water mass boundaries, surface currents, eddies, and turbulent mixing;
- to map the distribution of phytoplankton biomass and production;
- to map the distribution of zooplankton (krill and other species), including the horizontal and vertical variations in krill density and demographic characteristics;
- to conduct bottom trawls at selected sites around the South Orkney Islands to provide baseline estimates of abundance, species size and composition, and demographic structure of fish species within the 500 meter isobath;
- to describe the reproductive success, attendance behavior, feeding ecology, and diving behavior of seabirds and pinnipeds at Cape Shirreff; and
- to describe the reproductive success, feeding ecology, and growth rates of

Adélie penguins (*Pygoscelis adeliae*) throughout the reproductive season at Palmer Station.

The cruise was conducted aboard the chartered research vessel *Yuzhmorgeologiya*. The ship departed Punta Arenas, Chile, on 10 January 1999 to begin Leg I of the cruise; the leg was completed on 2 February. Following a port call, Leg II was conducted 5 February - 1 March. After another port call, Leg III was conducted 5 - 29 March.

During Legs I and II, a large-area survey of 78 Conductivity-Temperature-Depth (CTD)/carousel and net sampling stations, separated by acoustic transects, was conducted in the expanded AMLR study area (Survey A on Leg I, Survey D on Leg II, figure 2). Acoustic data were collected at three frequencies with 38, 120, and 200 kilohertz transducers. Data for physical oceanography, primary productivity, and krill distribution and condition studies were collected during the surveys. Operations at each station included:

- recording of vertical profiles of temperature, salinity, oxygen, photosynthetically available radiation, light beam attenuation, and fluorescence;
- collection of discrete water samples at standard depths for analysis of chlorophyll-*a* content, primary production rates, inorganic nutrients, dissolved oxygen, phytoplankton cell size and species composition, and phytoplankton biomass; and
- deployment of a 1.8-meter (6-foot) Isaacs-Kidd Midwater Trawl (IKMT) to obtain samples of zooplankton and micronekton.

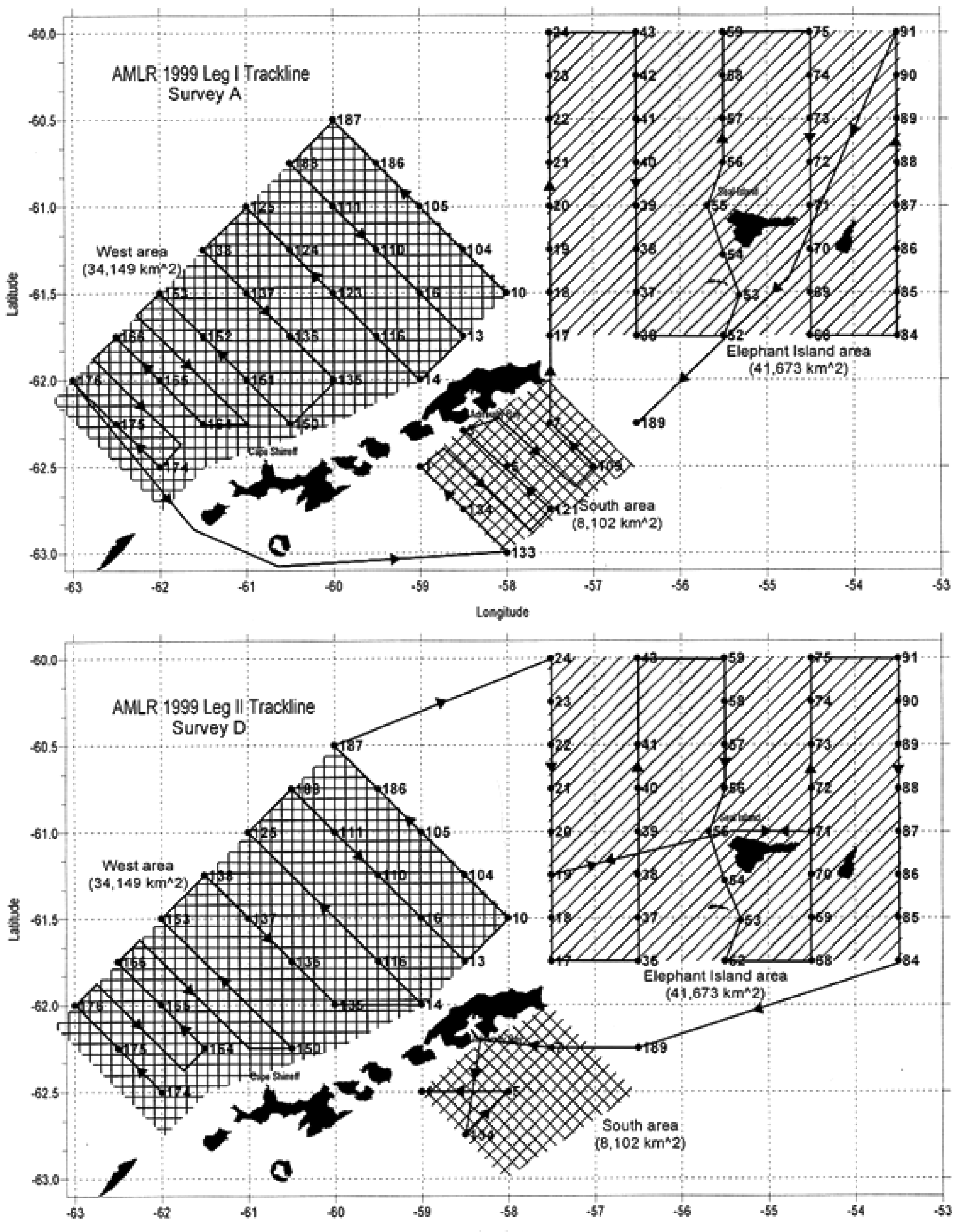

Figure 2. The large-area surveys conducted on Leg I (Survey A, Stations A001-A189) and on Leg II (Survey D, Stations D001-D189). Stations are located in three areas: stations to the west of Livingston and King George Islands are designated the "West area," those to the south of King George Island are designated the "South area," and those around Elephant Island are called the "Elephant Island area."

During Leg III, 64 bottom trawls were conducted at selected stations around the South Orkney Islands. Other operations on Leg III included acoustic data collection, underway measurements of meteorological and sea surface conditions, and CTD casts at selected sites.

The field camp at Cape Shirreff was occupied from 25 November 1998 to 26 February 1999. An emergency shelter/bird observation blind was constructed at the northern end of Cape Shirreff. Seabird research at Cape Shirreff included studies of reproductive success, breeding chronology, foraging ecology, and growth rates of chinstrap (*Pygoscelis antarctica*) and gentoo (*Pygoscelis papua*) penguins. Pinniped research included a census of antarctic fur seals (*Arctocephalus gazella*), monitoring of antarctic fur seal pup production and growth rates, observations of female fur seal attendance behavior, collections of fur seal scat and milk samples for diet studies, descriptions of fur seal foraging and diving behavior, and tagging of 500 fur seal pups for future demographic studies.

A four-person field team occupied the closed Seal Island camp from 30 January to 9 February 1999. During their stay, the team dismantled all remaining structures and retrograded building materials for the last phase of the field camp deconstruction. Field work at Palmer Station was initiated on 29 September 1998 and completed on 6 April 1999; studies on aspects of the ecology of Adélie penguins were conducted.

AMLR program: Salps and other zooplankton in the Elephant Island area during austral summer 1999

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Information on zooplankton abundance, species composition, and distribution patterns was derived from net samples taken at established stations during AMLR large-area surveys (Martin, Hewitt, and Holt, *Antarctic Journal*, in this issue). *Salpa thompsoni* receives special attention because of the hypothesized influence of this salp on the distribution, behavior, and recruitment success of krill. Results are compared to those from previous AMLR surveys to assess between-year differences in krill demography and zooplankton composition and abundance over the 1993 to 1998 period.

Net sampling specifics are presented in Loeb (*Antarctic Journal*, in this issue). Freshly collected samples were analyzed onboard. All salps were removed from samples of 2 liters or less and enumerated. For larger catches the numbers of salps in 1 to 2 liter subsamples were used to estimate abundance. For samples with fewer than 100 individuals, the two salp life stages (aggregate/sexual and solitary/asexual) were enumerated and internal body length (Foxton, 1966) was measured to the nearest millimeter (mm). Representative subsamples of at least 100 salps were analyzed in the same manner for larger catches. After removal of salps, krill, and adult fish from small samples or subsamples, the remaining zooplankton were analyzed. All larger organisms (e.g., amphipods, other euphausiids) were sorted, identified to species if possible, and enumerated. The smaller constituents in representative aliquots were then analyzed using dissecting microscopes. Density is expressed as numbers per 1,000 cubic meters (m^3) water filtered. Data are presented for the total large-area survey and a more restricted "Elephant Island Area" (figure 1A, 1B), which represents the historically sampled area used for long-term analyses of the Antarctic Peninsula marine ecosystem.

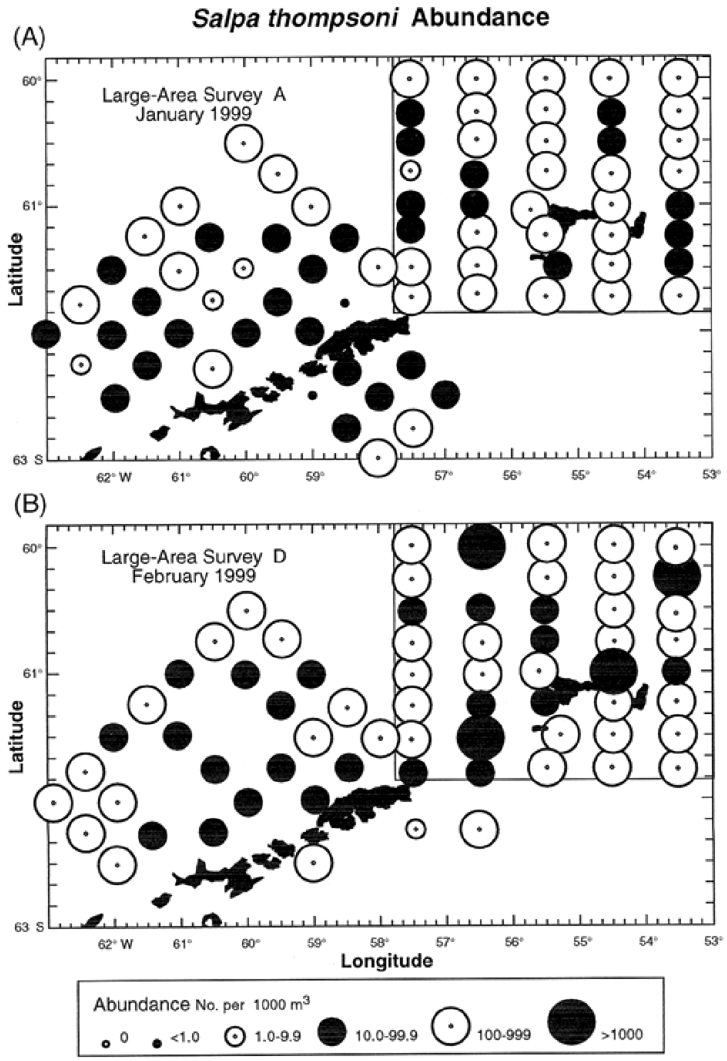

Figure 1. Distribution of* Salpa thompsoni *abundance in the Antarctic Peninsula region during (A) January 1999 (Survey A) and (B) February 1999 (Survey D).

Sixty-three taxonomic categories were identified during Survey A (January 1999), but six taxa constituted more than 95 percent of the zooplankton. These were copepods, *S. thompsoni*, postlarvae of the euphausiid *Thysanoessa macrura*, larval *T. macrura,* larval krill (*Euphausia superba*), and chaetognaths. Copepods were by far the most abundant; they were present in all 75 samples and contributed over 54 percent of total mean zooplankton abundance (table 1). *Salpa thompsoni*, the second most abundant taxon, contributed 12 percent of the zooplankton; it was present in all samples with fairly even concentrations distributed across the survey area (figure 1A). Postlarval *T. macrura,* larval krill and larval *T. macrura* followed in mean abundance. Greatest concentrations of copepods, larval *T. macrura* and larval krill were offshore northwest of Elephant Island; postlarval *T. macrura* were most abundant north of Livingston Island and around King George Island. Chaetognaths ranked 6 in overall mean abundance.

Other relatively abundant taxa were unidentified larval euphausiids, postlarval *Euphausia frigida* and krill, and the amphipod *Vibilia antarctica. Ihlea racovitzai*, another Southern Ocean salp species, ranked 11 in mean abundance.

Over 95 percent of *S. thompsoni* individuals were the aggregate stage. These ranged in size from 5 to 70 mm, but the majority (75 percent) were between 15 and 45 mm (figure 2). The size distribution was polymodal with a primary mode of 24 to 28 mm. Based on the overall size distribution and an estimated growth rate of 14 mm per month after birth at 5 mm, budding was probably initiated in late August/early September 1998 with more or less continuous production starting in mid-September. There were no regional differences in size distribution.

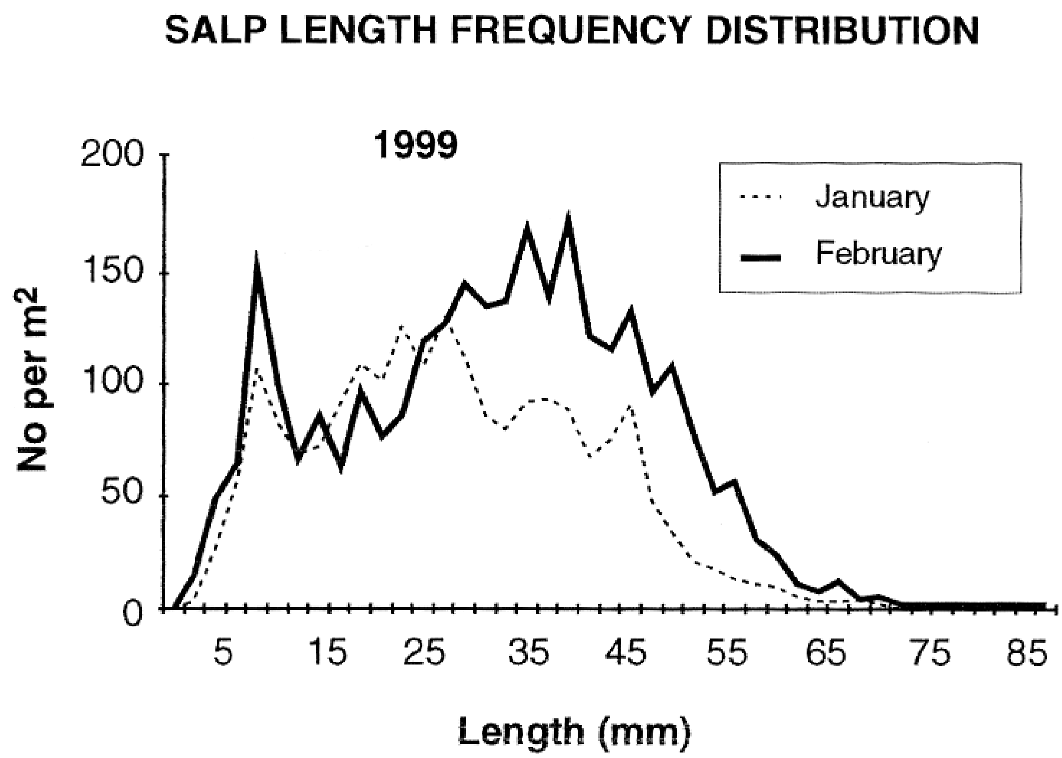

Figure 2. Length frequency distributions of **Salpa thompsoni** ***in the Antarctic Peninsula region during January and February 1999.***

Table 1. Abundance of dominant zooplankton taxa during Survey A (January 1999) and Survey D (February 1999).

Numerically dominant zooplankton taxa in the large Survey A and Survey D areas, January and February 1999. "N" is the number of samples. F(%) is the frequency of occurrence in samples for each survey. Ranks (R) provide the 10 most abundant taxa for each survey. % is the proportion of total mean zooplankton abundance contributed by each taxon. (L) indicates larval form. Asterisks denote significant between-survey abundance differences based on Percentage of Variance—P<0.001, **P<0.01, *P<0.05.***

	Large Survey Area A January 1999 (N=75)						Large Survey Area D February 1999 (N=67)					
Taxon	**F(%)**	**R**	**%**	**Mean**	**SD**	**Med**	**F(%)**	**R**	**%**	**Mean**	**SD**	**Med**
Copepods*	100.0	1	54.4	711.6	1,266.8	286.8	100.0	1	65.5	1,445.1	2,197.9	662.6
Salpa thompsoni	100.0	2	12.5	163.3	197.9	101.4	100.0	2	11.2	248.1	307.2	149.9
Chaetgnaths*	97.3	6	5.4	70.9	170.7	23.0	98.5	3	6.4	140.2	257.8	52.6
Thysanoessa macrura (L)	69.3	5	5.5	72.5	262.7	3.0	74.6	4	6.2	137.4	428.4	10.0
Thysanoessag macrura	93.3	3	10.3	135.1	587.1	36.9	98.5	5	4.2	93.1	142.9	18.0
Euphasusia superba (L)	65.3	4	7.9	103.1	587.4	2.6	80.6	6	2.3	49.8	119.3	9.0
Euphausia superba	60.0	9	.05	6.1	12.0	1.3	61.2	7	1.1	24.4	122.7	0.4
Euphausia frigida **	34.7	8	0.7	9.0	22.6	0.0	64.2	8	0.9	20.0	36.1	4.1
Ostracods***	49.3		0.2	2.8	5.6	0.0	80.6	9	0.6	14.0	28.9	6.6
Ihlea racovitzai	25.3		0.3	3.3	9.0	0.0	26.9	10	0.2	5.1	18.4	0.0
Cyllopus magellanicus ***	78.7		0.2	2.0	2.4	1.0	95.5		0.2	4.8	5.3	3.4
Vibilia antarctica	94.7	10	0.3	3.8	4.5	1.7	98.5		0.2	3.6	3.2	2.5
Suphausia spp. (L)	10.7	7	0.8	11.1	64.7	0.0	13.4		0.1	1.5	6.8	0.0
Total No. Taxa	63						59					

Fifty-nine zooplankton taxa were identified in the 67 Survey D (February 1999) samples. Copepods again dominated and, due to a significant two-fold seasonal abundance increase, comprised an even greater proportion (65 percent) of total mean zooplankton abundance than during Survey A (table 1). Abundance of *S. thompsoni* was similar to that during January and ranked second overall (11 percent of zooplankton). Due to a significant doubled seasonal abundance increase, chaetognaths became the third most abundant taxon; this was followed by mean abundance of larval and postlarval *T. macrura* and krill, respectively. Largest concentrations of copepods, larval krill and larval *T. macrura* again occurred in offshore waters; these concentrations were possibly in association with a persistent hydrographic retention zone (e.g., a front or eddy) north of King George and Elephant Islands (see Amos, *Antarctic Journal*, in this issue). Other relatively abundant taxa during February were *E. frigida, o*stracods, *I. racovitzai* and the amphipod *Cyllopus magellanicus*; all of these except *I. racovitzai* were significantly more abundant than during January (table 1).

Aggregate stage *S. thompsoni* predominated (93 percent) during February, indicating that seasonal production of the overwintering solitary form had not yet started. These ranged from newly budded 5 mm long individuals to 90 mm forms released early in the seasonal production period (figure 2). The majority were 28 to 46 mm in length with a primary mode of 35 to 40 mm. Similar salp densities (figure 1B) and size frequency distributions occurred across the survey area.

Relatively stable salp population size over the 2-month survey indicates that production of new aggregates was not much greater than loss due to mortality and advection out of the area. Length-frequency distributions from both surveys (figure 2) reflect an early initiation (late August/early September) and relatively long budding period with peak production in December. The primary length mode increase from 24 to 28 mm in January to 35 to 40 mm in February (11 to 12 mm change over a 23 day period) is consistent with an estimated 14 mm per month summer growth rate (Loeb et al. 1997). The estimated initiation time was the earliest noted in the past 6 years and was most likely related to exceptionally low sea-ice development during winter 1998.

The zooplankton community sampled during 1999 is characteristic of the Elephant Island area during austral summer; copepods, *S. thompsoni*, chaetognaths, postlarval and larval stages of *T. macrura* and krill, and postlarval *E. frigida* typically contribute more than 90 percent of mean zooplankton abundance in AMLR collections. There are, however, large between-year differences in the absolute and relative abundance of these taxa (table 2) that reflect periods when the zooplankton is clearly dominated by either copepods (1995, 1996) or salps (1993, 1998). These are separated by "transition periods" (1994, 1997) characterized by more similar copepod and salp abundance values. The abundance rankings and proportions of copepods and salps during summer 1999 most resemble those during the 1994 and 1997 transition periods, suggesting that there will be a shift to conditions favoring copepod dominance in the year 2000.

We greatly appreciate the help in sample collection and onboard processing provided by Kimberly Dietrich, Michael Force, Nancy Gong, Adam Jenkins and Darci Lombard .

Table 2. Abundance relations of dominant zooplankton taxa during January-March surveys 1993-1999.

Percent contribution and abundance rank of numerically dominant zooplankton taxa in the Elephant Island Area during January-March surveys, 1993-1999. Includes the 6 most abundant taxa each survey (L) indicates larval stages. "N.a." indicates that the taxon was not enumerated. Shaded columns are salp dominated years.

	January Elephant Island Area													
	1993		**1994**		**1995**		**1996**		**1997**		**1998**		**1999**	
Taxon	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**
Copepods	3.3	4	4.1	3	61.5	1	56.2	1	57.2	1	4.8	3	58.1	1
Salpa thompsoni	86.6	1	80.8	1	1.5	5	1.4	6	17.8	2	68.8	1	12.4	2
Euphausia superba (L)	n.a.		n.a.		12.8	2	0.2		1.5		0.1		10.9	3
Thysanoessa macrura (L)	n.a.		n.a		1.5	6	21.8	2	1.7	6	0.0		7.3	4
Chaetognaths	0.8	5	<0.1		7.8	4	0.9		2.3	5	0.9		4.0	5
Thysanoessa macrura	4.5	2	7.9	2	9.1	3	7.6	4	10.2	3	15.4	2	2.9	6
Euphausia frigida	0.3	6	0.4		0.9		0.1		1.5		0.0		1.0	
Euphausia superba	3.8	3	2.7	4	1.4		8.0	3	4.0	4	3.1	5	0.3	
Vibilia antarctica	0.1		1.2	5	<0.1		<0. 1		0.2		1.1	6	0.3	
Ihlea racovitzai	n.a.		n.a.		n.a.		n.a.		n.a.		3.5	4	0.2	
Limacina helicina	0.0		<0.1		0.2		2.4	5	0.3		0.7		0.1	
Themisto gaudichaudii	0.1		1.0	6	0.5		0.3		0.4		<0.1		<0.1	
TOTAL	99.5		98.0		97.2		98.9		96.9		98.4		97.4	

	February-March Elephant Island Area													
	1993		**1994**		**1995**		**1996**		**1997**		**1998**		**1999**	
Taxon	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**
Copepoda	0.5	4	82.2	1	40.5	2	62.1	1	44.5	1	7.4	4	62.8	1
Salpa thompsoni	89.6	1	11.8	2	0.2		1.4	6	43.6	2	65.3	1	12.5	2
Thysanoessa macrura (L)	n.a.		n.a.		3.8	3	21.4	2	0.4		0.0		7.5	3
Chaetognaths	<0.1		0.5	6	3.6	4	2.4	5	0.7		0.6		5.9	4
Thysanoessa macrura	7.3	2	1.8	3	0.9	5	4.9	4	6.4	3	9.4	3	3.8	5
Euphausia superba (L)	n.a.		n.a.		50.2	1	0.6		0.9	6	0.2		2.7	6
Euphausia superba	2.0	3	0.4		0.1		5.6	3	1.1	5	10.9	2	1.4	
Euphausia frigida	0.1		0.7	5	0.2		0.4		1.6	4	0.6		1.0	
Ostracods	n.a.		n.a.		0.4	6	0.4		0.2		0.4		0.6	
Ihlea racovitzai	n.a.		n a.		n.a.		n.a.		n.a.		2.8	5	0.3	
Vibilia antarctica	0.1		0.2		<0. 1		<0. 1		0.3		0.7	6	0.2	
Euphausia spp. larvae	n.a.		0.8	4	n.a.		n.a.		n.a.		n.a.		0.1	
Themisto gaudichaudii	*0.1*	5	0.3		<0.1		0.1		0.1		<0.1		<0.1	
Cyllopus lucasii	0.1	6	0.1		<0.1		01		0.1		0.1		<0.1	
TOTAL	99.7		98.6		99.8		99.2		99.6		98.3		98.9	

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AMLR program: Evidence for continued decline in krill biomass density from acoustic surveys conducted in the vicinity of the South Shetland Islands during the 1998-1999 austral summer.

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Since 1992, the AMLR program has conducted acoustic surveys near Elephant Island during the same portions of the austral summer, using a reasonably consistent survey design. The primary objectives of these surveys were to map the meso-scale (10's of kilometers) dispersion of krill (*Euphausia superba*), to estimate their biomass, and to determine their association with predator foraging patterns, water mass boundaries, spatial patterns of primary productivity and bathymetry. In 1998, the survey grid was expanded to include two additional areas to the northwest of the South Shetland Islands (West area) and to the south of King George Island (South area) (figure 1). In 1999, area coverage remained the same as 1998, but survey effort in the Elephant Island area was reduced by approximately 40%. This report focuses on the inter-annual variability of the 1992 through 1999 time series of krill density estimates from the Elephant Island area. Most notable is the decline in krill biomass density over the last three years. Estimates of krill biomass density in 1999 were the second lowest in the seven year time series.

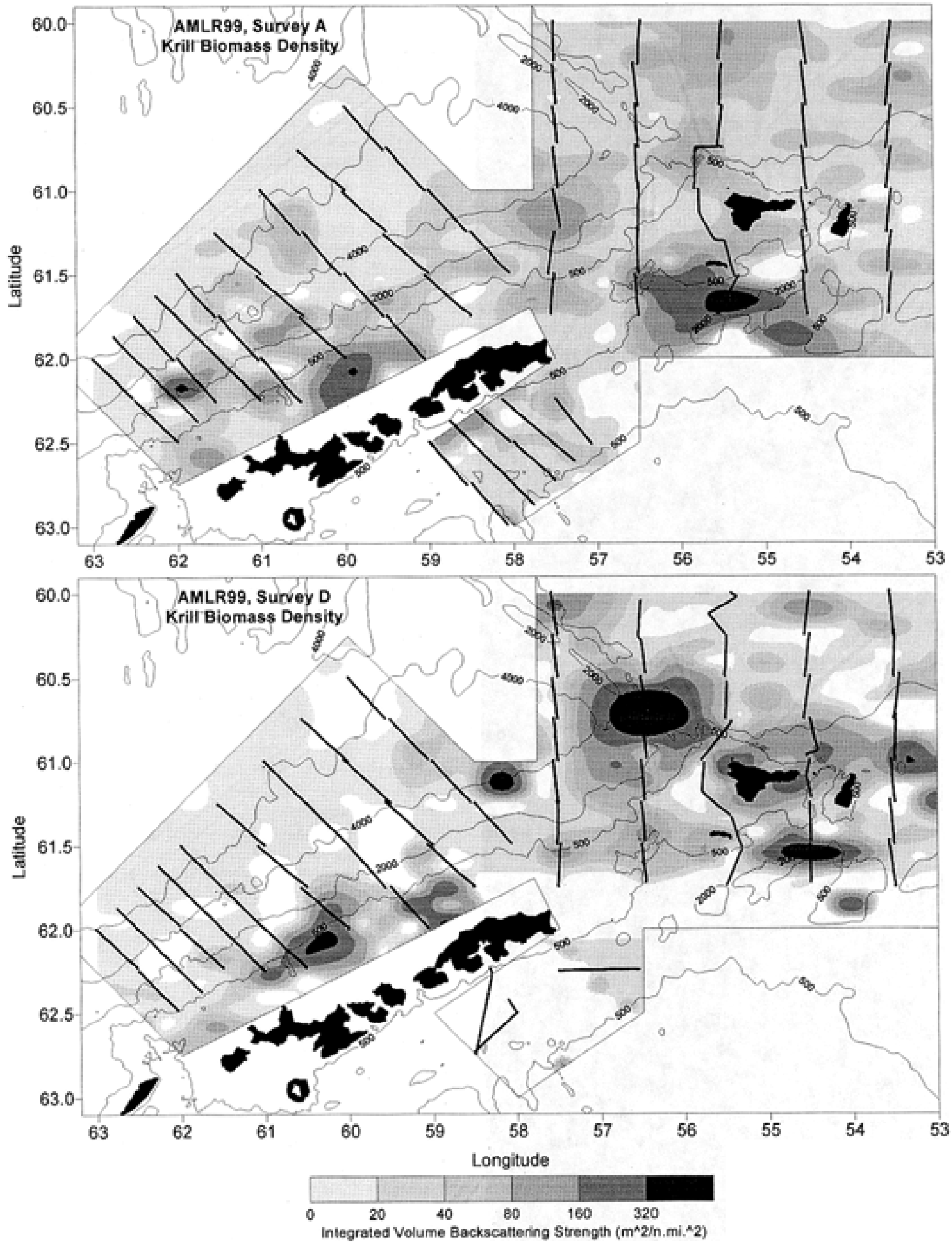

Figure 1. Krill biomass density based on visual classification of data at 120 kHz; solid lines indicate acoustic transects.

Acoustic data were collected using a multi-frequency echo sounder (Simrad EK500) configured with downlooking 38, 120, and 200 kilohertz (kHz) transducers mounted in the hull of the ship. System calibrations were conducted before and after the surveys, using standard sphere techniques while the ship was at anchor. During the surveys, pulses were transmitted every 2 seconds at 1 kilowatt for 1 milliseconds duration at 38, 120 and 200 kHz. Geographic positions were logged every 60 seconds. Ethernet communications were maintained between the EK500 and a Windows NT workstation. SonarData EchoLog and EchoView software was used for primary system control, and data logging, processing and archiving.

An acoustic survey of the waters surrounding the South Shetland Islands was conducted on each of the first two cruise legs (Survey A and Survey D, figure 1). The surveys were divided into three areas:

1. A 41,673 km^2 area centered on Elephant Island (Elephant Island area) was sampled with five north-south transects.
2. A 34,149 km^2 area along the north side of the southwestern portion of the South Shetland archipelago (West area) was sampled with nine transects oriented northwest-southeast.
3. A 8,102 km^2 area south of King George Island in the Bransfield Strait (South area) was sampled during the first leg with five transects oriented northwest-southeast (poor weather and scheduling conflicts during Leg II precluded complete sampling of the South area on Survey D).

Intensified sampling in the western portion of the West Area and in the South Area was intended to complement studies of krill predator foraging and reproductive performance conducted at Cape Shirreff and Admiralty Bay.

The 120 kHz echogram was scanned visually and portions attributed to krill were delineated. Visual classification was accomplished by scanning the 120 kHz echograms for scattering forms that have been attributed to krill (Kalinowski and Witek 1985) and by noting those aggregations where average volume backscattering strength at 200 kHz exceeded that at 120 kHz, which in turn exceeded that at 38 kHz. The guidelines for classifying aggregations and sound scattering layers were as follows:

1. Aggregations were classified as krill if the scatterers coalesced into a discrete, relatively dense target above 225 meters (m) in the water column.
2. Sound scattering layers were classified as krill if the edges or boundaries in the horizontal dimension were distinct (not diffuse) above 225 m in the water column.

Overall, a conservative approach was used to classify aggregations as krill and, as such, a bias may exist toward underestimation of krill biomass density based on visual classification of the data. In addition, some krill may have been dispersed in diffuse layers and were not included. Conversely, some of the aggregations may not have contained krill, which would have contributed to an overestimate of krill biomass density. On the whole, however, the visual classification of krill aggregations before integration most likely resulted in a slight to moderate underestimate of krill biomass density.

For the purposes of generating distribution maps, the volume backscattering at 120 kHz attributed to krill was integrated over 15-225 m depth and averaged over 185.2 m distance intervals. Integrated volume backscattering strength per unit of sea-surface area was scaled to estimates of krill biomass density by applying a factor equal to the quotient of the weight of an individual krill and its backscattering cross-sectional area, summed over the sampled body length frequency distribution for each survey (Hewitt and Demer 1993). A 30x20 cell grid was imposed on the survey area and integrated volume backscattering values were interpolated at grid nodes using geostatistical methods and contoured; portions of the grid outside of the survey area were masked. For each area in each survey, mean biomass density and its variance was calculated by assuming that the mean density along a single transect was an independent estimate of the mean density in the area (Jolly and Hampton 1990, Hewitt and Demer 1993).

The highest concentrations of krill during Survey A were along the shelf break north of Livingston and King George Islands and southwest of Elephant Island (figure 1). During Survey D, highest concentrations were again mapped along the shelf break north of Livingston and King George Islands; but near Elephant Island, the high concentrations were mapped to the northwest and southeast of the island (figure 1). Krill north of the islands were reproductively mature as spawning was evident throughout both surveys; this contrasts with the previous 3 years during which only limited spawning was observed (see Loeb et al., in this issue). Visual classification of krill aggregations also afforded an opportunity to examine the possible relationship between demographic parameters of krill and the shapes and positions of their aggregations. Preliminary results (five out of five cases during Survey D) suggest that gravid females may have been encountered most often in surface swarms.

Mean krill biomass density for surveys conducted from 1992 to 1999.

Coefficients of variation (CV) are calculated by the methods described in Jolly and Hampton, 1990, and describe measurement imprecision due to the survey design. Other contributions to measurement uncertainty (i.e. calibration, diel vertical migration, target strength estimation, species delineation, etc.) are not included in these values. 1993 estimates were omitted due to system calibration uncertainties; only one survey was conducted in 1997; 1999 South area values not available (NA) due to the lack of data. See Figure I for descriptions of each survey area.

Survey		Area	Mean Density (g/M2)	Area (km^2)	Biomass (103 tons)	CV
1992	A (late January)	Elephant Island Area	61.20	36,271	2,220	15.8%
	D (early March)	Elephant Island Area	29.63	36,271	1,075	9.2%
1994	A (late January)	Elephant Isand Area	9.63	41,673	401	10.7%
	D (early March)	Elephant Island Area	7.74	41,673	323	22.2%
1995	A (late January)	Elephant Island Area	27.84	41,673	1,160	12.0%
	D (late February)	Elephant Island Area	35.52	41,673	1,480	24.2%
1996	A (late January)	Elephant Island Area	80.82	41,673	3,368	11.4%
	D (early March)	Elephant Island Area	70.10	41,673	2,921	22.7%
1997	A (late January)	Elephant Island Area	100.47	41,673	4,187	21.8%
1998	A (late January)	Elephant Island Area	82.26	41,673	3,428	13.6%
		West Area	78.88	34,149	2,694	9.9%0

Survey		Area	Mean Density (g/M2)	Area (km^2)	Biomass (103 tons)	CV
	D (late February)	Elephant Island Area	47.11	41,673	1,963	14.7%
		West Area	73.32	34,149	2,504	16.6%
		South Area	47.93	8,102	388	12.2%
1999	A (late January)	Elephant Island Area	23.72	41,673	988	20.3%
		West Area	27.13	34,149	927	28.7%
		South Area	19.68	8,102	159	9.4
	D (late February)	Elephant Island Area	15.37	41,673	641	26.0%
		West-Area	11.85	34,149	405	30.0%
		South Area	N/A	N/A	N/A	N/A

Krill biomass density estimates were calculated from integrated volume backscattering visually classified as krill. The results indicate that krill biomass density near the South Shetland Islands declined for the third year in a row and is the second lowest in observed in the 7-year time series (table). The values are also consistent with those predicted from a model of the variability of acoustic estimates of krill in the Elephant Island area (figure 2, Hewitt and Demer, this issue).

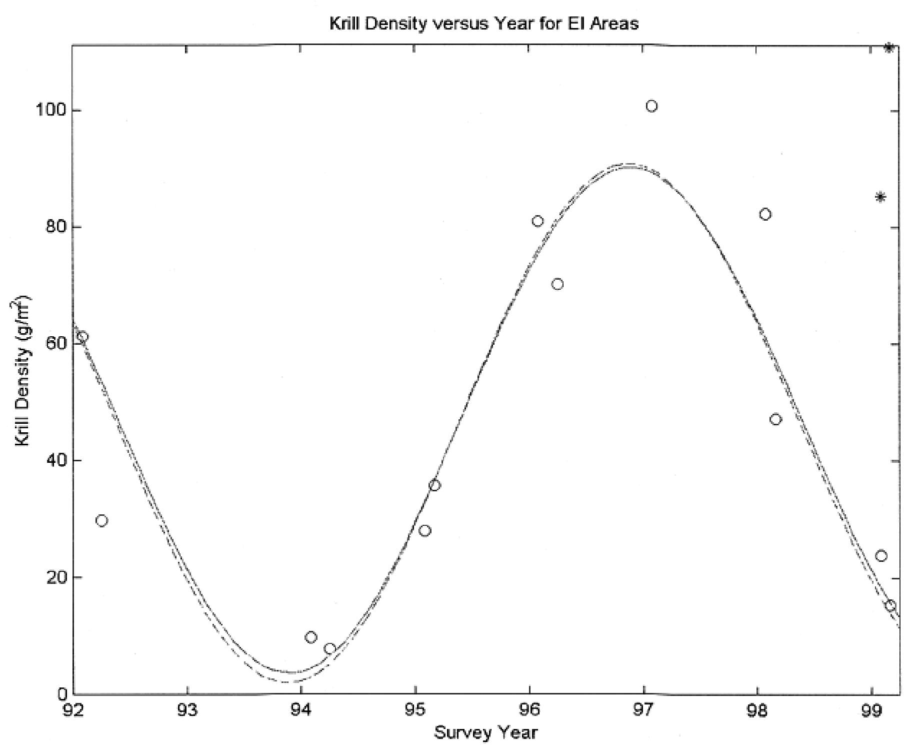

Figure 2. Time series of krill density in the Elephant Island area from austral summer 1991-1992 to 1998-1999. A simple sinusoidal cycle was fit to the data where the solid line represents the curve fitted to 1992-1998 data; the dashed lien represents the curve fitted to the 1992-1998 data. Data from 1993 were omitted due to uncertainty in the system calibration and other equipment parameters.

These results reaffirm the comments made by Hewitt and Demer (this issue) regarding the interpretation of the results of a multi-national, multi-ship survey of krill in the southwest Atlantic sector of the Southern Ocean conducted in the summer of 1999-2000 and coordinated by the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR employs a general yield model to set precautionary limits on the krill harvest in the southwest Atlantic. The model is currently scaled to a krill biomass survey conducted in 1981, a period when krill density near the South Shetland Islands was high relative to the 1990's (Siegel et al. 1997). If the density of krill in the South Shetlands continues to follow the cycle described above, and if the density in the South Shetlands is representative of the southwest Atlantic sector, then a low biomass of krill can be expected during the 1999-2000 survey. An additional complication is the suggestion by Loeb et al. (1997) that the frequency of strong krill year classes has decreased since 1981 and that a lower equilibrium level of krill may be expected. If a low biomass estimate results from the 1999-2000 survey, then CCAMLR will have difficulty in determining whether the 1981 and 2000 biomass estimates represent two extremes of a cyclically varying population abundance or a decreasing trend in the krill population in the southwest Atlantic. In this context, the annual regional surveys conducted by national programs of CCAMLR members (such as the AMLR surveys reported here) are highly valuable and their continuation should be encouraged.

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AMLR program: Standing stock biomass of eight species of finfish around the South Orkney Islands

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Commercial exploitation for finfish in the South Orkney Island chain in the Southern Scotia Arc was conducted from 1977-1978 through 1989-1990. The main reported species captured in this region during this time were *Champsocephalus gunnari*, *Gobionotothen gibberifrons* and *Notothenia rossii* (CCAMLR 1990a). The first year of fishing yielded a reported catch of almost 140,000 tonnes of *C. gunnari*, supported mainly by 1973-1974 and 1974-1975 cohorts (Kock 1991). Both cohorts were largely exhausted within 2 years, and overall catches declined by almost two orders of magnitude within a few years (figure 1). Catches increased slightly in the mid-1980's and decreased substantially thereafter. These rapid declines lead CCAMLR to impose a moratorium on all directed fishing for finfish in the South Orkney Islands in 1990-1991. This paper uses information collected during the 1999 U.S. AMLR program bottom trawl survey of the South Orkney Islands to estimate stock biomass within the 500 meter (m) isobath for eight antarctic finfish species: *Gobionotothen gibberifrons*, *Lepidonotothen squamifrons*, *Pseudochaenichthys georgianus, Champsocephalus gunnari*, *Chaenocephalus aceratus*, *Chionodraco rastrospinosus*, *Notothenia rossii* and *Lepidonotothen larseni*.

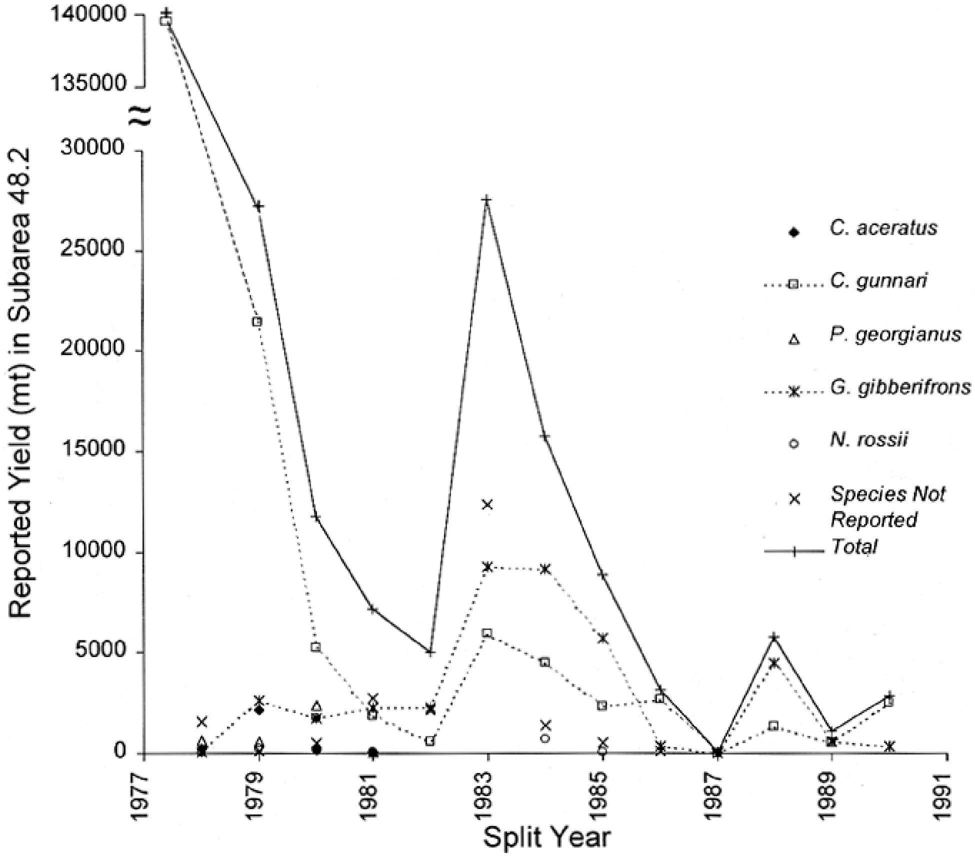

Figure 1. Nominal catches of species around the South Orkney Islands (Subarea 48.2). Catch of* G. gibberifrons *from 1980 through 1983 were adjusted according to CCAMLR (1990b).

The sampling strategy was based on a random depth stratified (50-150 m, 150-250 m, and 250-500 m) survey design. The proportion of fishing effort allocated to each stratum was proportional to the area of seabed within each strata and weighted by abundance from previous surveys. The gear type used was a "Hard Bottom Snapper Trawl" (NET Systems Inc., USA). A total of 64 hauls were taken: 7 in the 50-150 m strata, 24 in the 150-250 m strata, and 33 in the 250-500 m strata (figure 2).

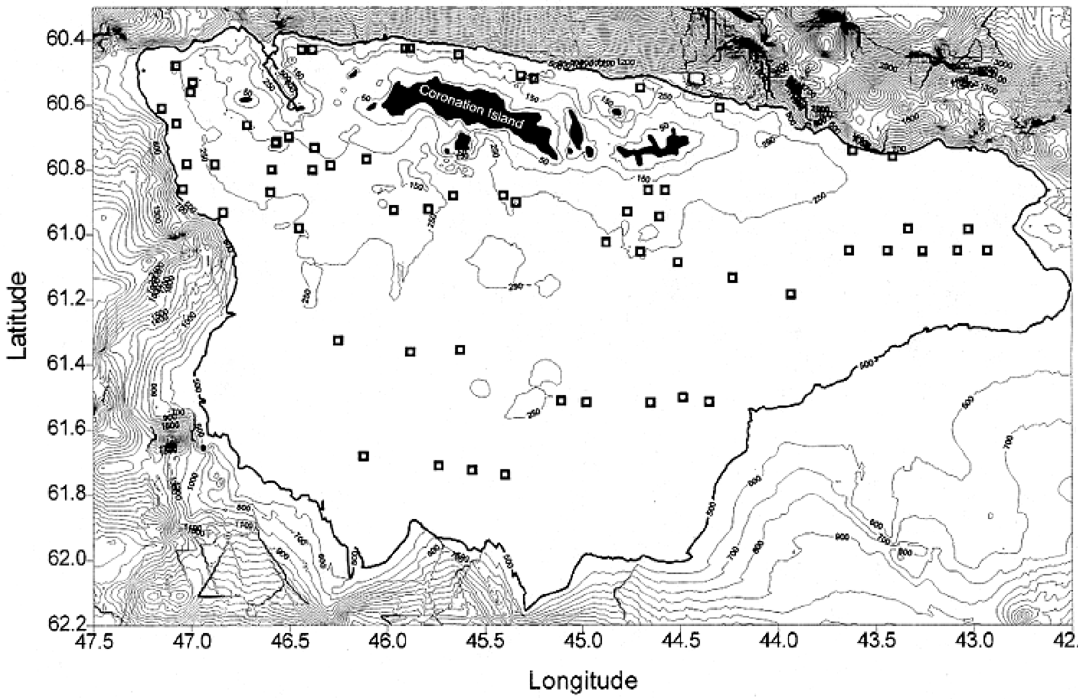

Figure 2. Map of station coordinates from the 1999 AMLR survey of the South Orkney Islands.

All hauls were conducted during daylight hours, with a target time of 30 minutes per haul. Once contact with the bottom was made, we recorded position, time, ship speed, bearing, headrope depth, bottom depth, and net mouth height and width. Recordings were made every 5 minutes, for a total of seven observations for each haul. Supplementary data collected for each haul included ship course, sea-surface temperature and salinity, bottom temperature and salinity, air temperature, wind direction and speed, weather, cloud conditions, sea state, light, and ice conditions. After a successful haul, the contents of the trawl were sorted into species, counted, weighed, maturity staged, and sexed.

For each haul, total weight of individual species captured was standardized to one square nautical mile (n.mi.^{2}) of area swept using the average trawl mouth width and bottom distance covered. Estimates of standing stock biomass were computed by stratum using the Delta-lognormal maximum likelihood estimator (Pennington 1983; de la Mare 1994) with seabed area estimates of Jones (1999).

During the survey, a total of 16,167.53 kilograms (kg) (38,356 individuals) of 42 species was captured. The eight species considered in the paper represented about 98% of the total yield (table). The highest yields were generally to the west and north of the South Orkney Island chain (figure 3) and around the Inaccessible Islands. The distribution of catches by species were also dependent on depth strata at which hauls were taken, with average yields and variability of yields per haul greatest in the 150-250 m depth strata and the lowest in the 50-150 m strata. The average standardized (kg/n.mi.^{2}) nominal catch per haul for the eight species combined was 18,173 kg/nm^2.

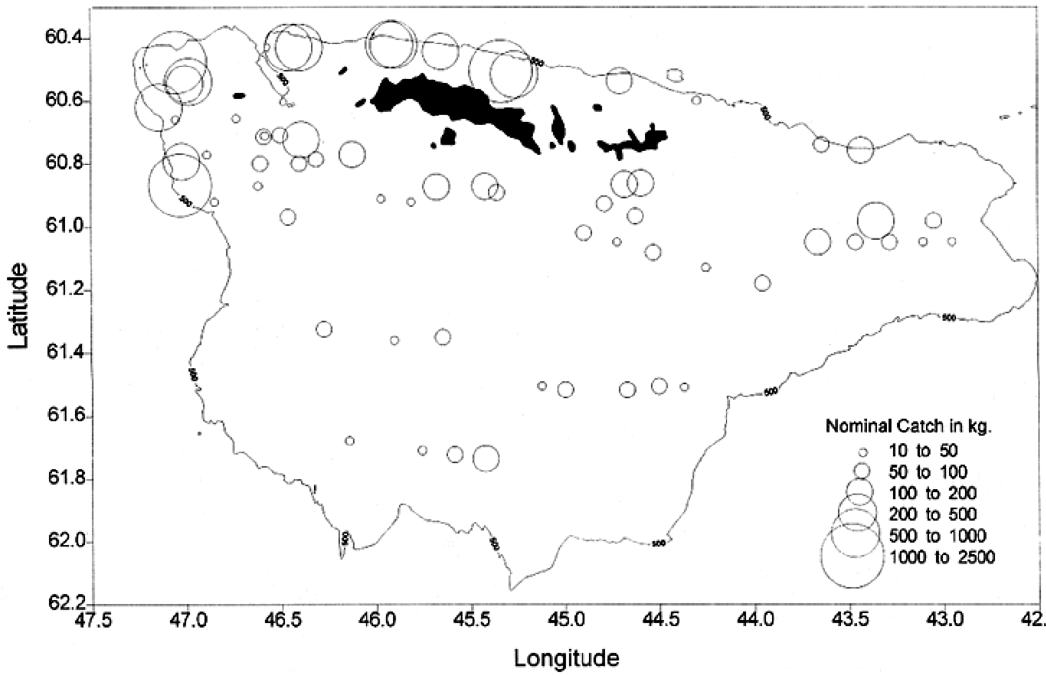

Figure 3. Map of nominal catches for all species combined from the 1999 AMLR survey of the South Orkney Islands.

Total nominal yield in weight (kg) and estimates of biomass (MT) with 95% confidence intervals by stratum for the South Orkney Islands from the 1999 AMLR bottom trawl survey.

Species	Strata	Nominal Yield (Kg)	Computed Biomass (MT)
G. gibberiftons	50-150 in	1084.10	6248 (2304-49329)
	150-250 in	2438.06	10173 (5960-22700)
	250-500 m	1539.41	22479 (12840-50640)
	Total	5061.57	38900 (26091-82780)
L. squamifrons	150-250 in	65.45	875 (160-22497)
	250-500 in	4957.84	50059 (14345-372432)
	Total	5023.29	50934 (15129-373309)
C gunnari	50-150 in	76.92	501 (320-1002)
	150-250 in	341.39	1249 (757-2591)
	250-500 in	84.11	1267 (551-4280)
	Total	502.42	3016 (2027-6073)
C. aceratus	50-150 in	353.83	1859 (887-7594)
	150-250 in	896.46	5962 (2994-17599)
	250-500 in	203.87	2610 (1344-7012)
	Total	1454.16	10431 (6628-22220)
C rastrospinosits	50-150 in	23.43	153 (73-623)
	150-250 in	85.57	399 (282-640)

Species	Strata	Nominal Yield (Kg)	Computed Biomass (MT)
	250-500 in	814.92	12881 (7373-29114)
	Total	923.92	13434 (7921-28796)
P. georgianus	50-150 in	26.65	167 (48-1425)
	150-250 in	2397.43	6504 (2350-35071)
	250-500 in	159.32	2057 (910-6836)
	Total	2583.40	8728 (4138-36461)
N. rossii	50-150 in	8.17	58(14-532)
	150-250 in	14.01	61(25-126)
	250-500 in	251.12	3160 (675-61159)
	Total	273.30	3278 (790-60672)
L. larseni	50-150 in	6.71	45(14-474)
	150-250 in	15.56	91(47-249)
	250-500 in	10.89	151 (105-241)
	Total	33.15	288 (205-718)
	Total	15899.56	129009

The most abundant species both in terms of weight and numbers was *G. gibberifrons*. This species was found in all regions with concentrations in the western and northern sectors of the island chain. Catches throughout the rest of the island chain and offshore were relatively consistent. The second most abundant in terms of catch was *L. squamifrons*, though distribution was the most patchy. Large yields of *L. squamifrons*, as well as *P. georgianus*, were the product of encountering very dense aggregations in limited areas to the north and west of the islands. Point estimates of total standing stock biomass estimates (table) for *L. squamifrons* were the highest of any species during the 1999 survey. However, due to the skewed distribution of catches, the uncertainty of biomass levels was greatest as well, particularly in the 250 to 500 m strata.

A remarkably low number of *C. gunnari* were encountered during the survey relative to other species encountered. With the exception of the small nototheniid *L. larseni*, this was the least abundant of the eight species captured. The lack of *C. gunnari* encountered during the 1999 survey is disturbing, as this species once drove the commercial fishery in the 1970’s-early 1980’s. Given the current biomass levels, even the upper 95% confidence limit is roughly at 4% of pre-exploitation levels (Kock et al. 1985) around the South Orkney Islands.

There appears to be little shift in overall (combined) estimates of biomass of the eight species from this survey and a similar survey conducted in 1991 by Spain (Balguerías, 1991). However, in both of these surveys, there is a substantial increase in biomass compared to a survey conducted by Germany in 1985 (Kock, 1986). The 1985 survey followed 3 - 4 years of the highest directed effort toward finfishing in the region; limited fishing was conducted during 1985. The apparent biomass increase between 1985 and 1991 may have been the result of low effort directed at finfish in the region after 1982-1983 and the final closure of the area for finfishing after 1989-1990. The fishery shifted again from the South Orkney Islands back to South Georgia where concentrations of *C. gunnari* were exploited in the 1980s. The similarity of estimates in

1991 and 1999 indicate the stocks had largely recovered by then and little change in the stocks has taken place since the beginning of the 1990s. Given estimates from the 1999 survey, most fish stocks are probably not in a state that could withstand even limited exploitation at this time.

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AMLR program: Krill abundance and population structure in the Elephant Island area, January and February 1999

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Krill (*Euphausia superba*) is the keystone prey species in the antarctic seasonal sea-ice zone. Information on krill length, maturity stage composition, and reproductive condition is essential to assess between-year differences in spawning success and recruitment (i.e., the supply of juveniles spawned the previous summer). This has relevance to the population size and availability of krill to their predators, which include penguins, other seabirds, and seals monitored by the Antarctic Marine Living Resources (AMLR) program.

Krill were obtained from a 1.8-meter (6-foot) Isaacs-Kidd Midwater Trawl (IKMT), fitted with a 505-micrometer mesh plankton net, and fished obliquely from 0-170 meters (m) or from 10 m above the bottom in shallower water. Samples were collected at AMLR large-area survey stations (Martin, Hewitt, and Holt, *Antarctic Journal*, in this issue) during 15-28 January (Survey A) and 10-26 February (Survey D). Demographic analyses were made using fresh or freshly frozen specimens. All krill from samples with less than 150 individuals were analyzed. For larger samples, 100 to 200 individuals were measured, sexed, and staged. Measurements were made of total length [millimeters (mm)]; maturity stages were based on the classification scheme of Makarov and Denys (1981).

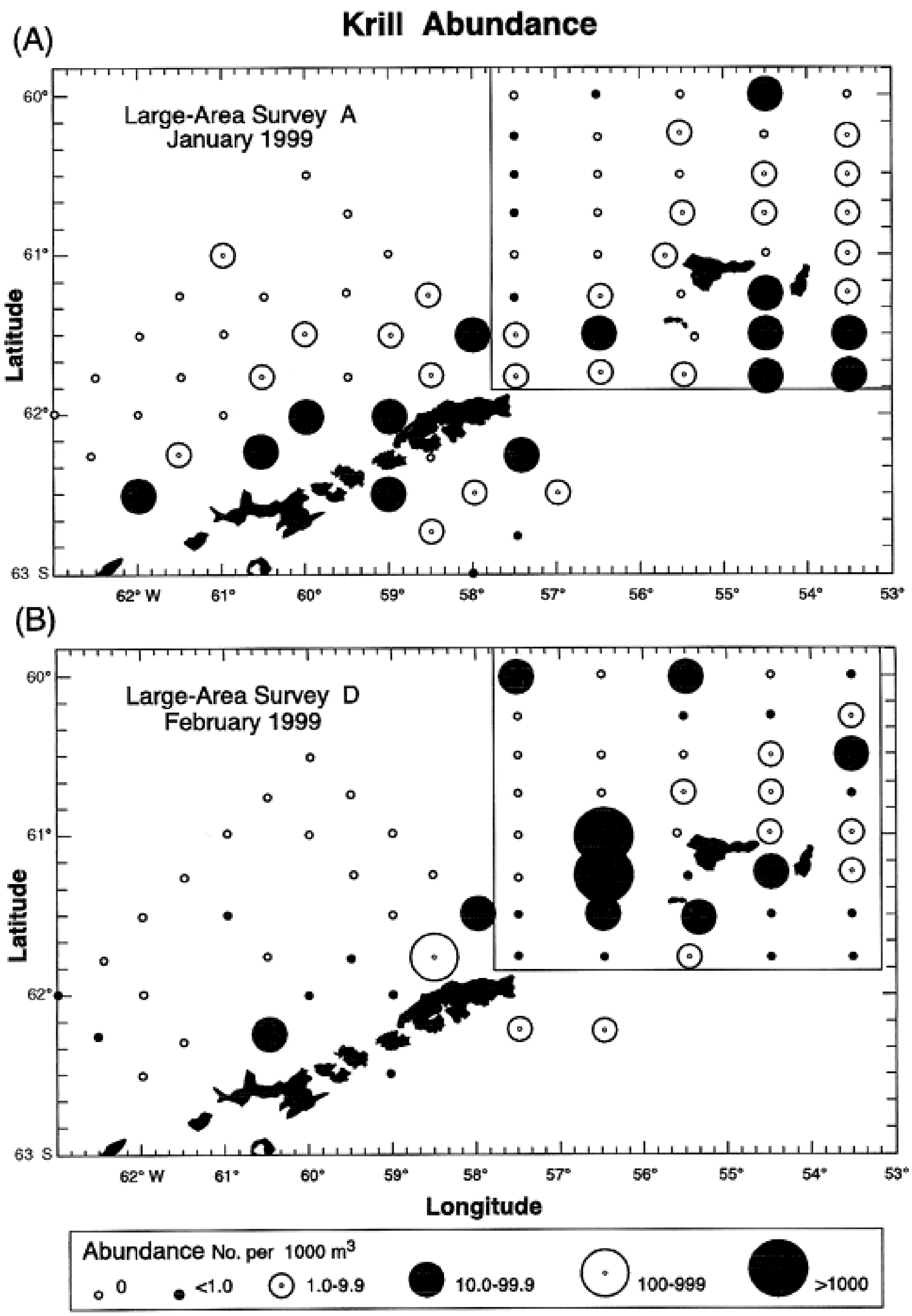

Figure 1. Krill abundance in IKMT tows collected during (A) Survey A, January 1999 and (B) Survey D, February 1999.

Primarily small numbers of postlarval krill were represented in the January samples. A total of 1,657 individuals were collected by 44 of 75 Survey A tows (59%) with mean and median abundance of 6.1 and 1.3 per 1,000 cubic meters (m^3) water filtered, respectively (table). Most krill were obtained over, or immediately adjacent to, island shelf regions (figure 1A). The largest catch (291 individuals, 80 per 1,000 m^3) occurred in Bransfield Strait adjacent to Robert and Nelson Islands. Virtually all of the krill were longer than 35 mm and distinct length modes of 36 to 39 mm and 41 to 45 mm (figure 2A) represented mixtures of 2 and 3 year old individuals (the 1996/97 and 1995/96 year classes; Siegel, 1987). Greatest numbers of krill 50 mm and longer (remnants of the highly successful 1994/95 year class) occurred in the Elephant Island area. Juveniles comprised only 3% of the catch, while mature stages contributed 67% and immature stages 30%. Overall, 61% of the mature females were in advanced reproductive stages (3c, with developing ovaries; 3d, gravid; 3e, spent). The frequent presence (65% of samples) and relatively high abundance of early stage calyptopis larvae (stage 1 and 2, mean abundance 103 per 1,000 m^3) indicated that active spawning was initiated between mid-December and early January (Quetin and Ross, 1984). Largest larval krill concentrations (200 to 5,100 per 1,000 m^3) were in the Drake Passage north of Elephant Island.

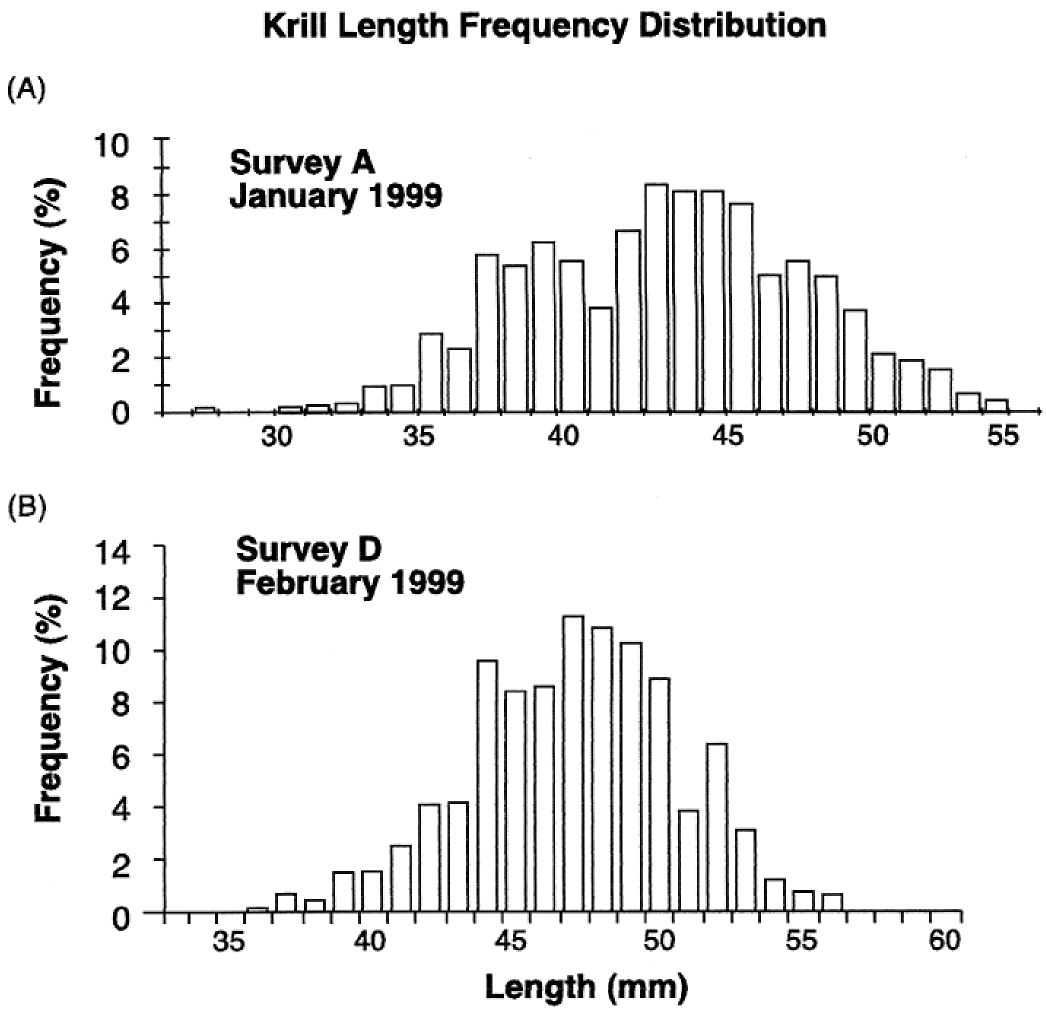

Figure 2. Overall length frequency distribution of krill collected during (A) Survey A (January 1999) and (B) Survey D (February 1999).

Abundance and maturity stage composition of krill in the AMLR survey area during January and February, 1999. Abundance estimates are numbers per 1,000 m^3. Advanced female stages are proportions of mature females that are 3c, 3d and 3e in January and 3d and 3e in February.

	Survey A January	Survey D February
No. Tows	75	66
No. Krill	1657	7,359
Mean (No. per 1000 m3)	6.1	24.4
S.D.	12.0	122.7
Median	1.3	0.4
Maturity Stage	%	%
Juveniles	3.1	0.0
Immature	30.1	5.2
Mature	66.8	94.8
Females:		
F2	10.4	0.7
F3a	12.7	1.1
F3b	3.0	0.2
F3c	8.5	9.6
F3d	12.8	40.6
F3e	3.9	12.2
Advanced Stages	61.5	82.9
Males:		
M2a	9.1	0.0
M2b	7.3	2.5
M2c	3.3	1.9
M3a	2.0	2.9
M3b	24.0	28.2

Substantially more krill (7,359) were collected during February (Survey D), but most of these (63%) were represented by just one of the 67 samples. Estimated density of this catch was 979 krill per 1,000 m^3. This and two other relatively large catches (159 to 233 krill per 1,000 m^3) occurred west and northwest of Elephant Island (figure 1B). Due to increased patchiness and general paucity of krill across the survey area, the mean abundance value (24.4 per 1,000 m^3) was four times higher and median value (0.4 per

1,000 m^3) 70% lower than in January (table). Predominantly large krill were again collected; lengths ranged from 35 to 58 mm and centered around a 47 mm mode (figure 2B). Overall, krill size was significantly larger than during January (Kolmogorov-Smirnov test, $P<0.01$); krill smaller than 40 mm comprised less than 5% of the total catch, while sizes of 50 mm and larger (1995/96 and 1994/95 year classes) represented 25%. Total absence of juvenile and decreased abundance of immature stages (5%) were associated with this size change. The majority of individuals were mature females (64%), most of which were gravid or spent (3d and 3e, 83%). Most of the males were reproductive. Widespread occurrence of stage 1 and 2 calyptopis larvae (81% of samples) indicated that spawning had occurred over the past month. Median larval krill abundance (9 per 1,000 m^3) was three times larger than in January. Largest krill densities again occurred offshore north of King George Island.

Changes in krill distribution and demography between Surveys A and D reflect seasonal southward migration of age/maturity classes (Siegel 1988) with the smaller, immature (i.e., 2 year old) krill moving into higher latitudes and larger mature krill (i.e., 3 years and older) entering the area from offshore. Increased patchiness with the advancing season may be associated with reproduction (Siegel and Kalinowski, 1994). Although the presence of krill larvae in January indicated that spawning was probably initiated in mid- to late-December, there were no substantial increases in either larval abundance (table) or development past calyptopis stage 2 over the two-month period. These observations suggest that there may have been low larval survivorship and/or larval retention within the survey area during summer 1999.

Mean and median abundance of postlarval krill during 1999 were among the lowest monitored in the past eight years. These minima continue a trend of decreasing abundance since 1996 and result from a succession of years of poor recruitment over the past three years (i.e., after the 1994/95 year class). The overall size/maturity composition reflects this history (figure 2; table). Dwindling numbers of the 1994-1995 year class, now represented by lengths of 50 mm and longer, comprised 11 to 25% of the krill collected during 1999; the remainder consisted of three-year-old (1995-1996 year class) and two-year-old (1996-1997 year class) individuals (figure 2). The virtual absence of smaller, juvenile krill is testament to failure of the 1997-1998 year class.

The large proportion of females in advanced maturity stages (82 to 93%) during summer 1999 represents "normal" (i.e., December to March) spawning seasonality and contrasts markedly with 1993 and 1998 when fewer than 20% of mature females were in advanced stages. Normal spawning seasonality is believed to be important for krill year class success (Siegel and Loeb 1995; Loeb et al. 1997). However, the relatively modest larval krill abundance values (comparable to those in 1996 and 1997) and absence of advanced larval stages call for guarded optimism about recruitment success of the 1998-1999 year class. Theoretically, this will depend on the extent of sea ice development and associated larval feeding and overwintering conditions during 1999 (Siegel and Loeb 1995; Loeb et al. 1997).

I greatly appreciate the help in sample collection and onboard processing provided by Wesley Armstrong, Kimberly Dietrich, Michael Force, Nancy Gong, Adam Jenkins, and Darci Lombard .

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AMLR program: Foraging range and daily traveling distance of antarctic fur seals, Cape Shirreff, Livingston Island, Antarctica

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The U.S. Antarctic Marine Living Resources (AMLR) program conducts pinniped studies at Cape Shirreff, Livingston Island, Antarctica (62°47'S, 60°77'W). Our research at this site began in 1997-1998 and focuses on antarctic fur seal foraging ecology and population dynamics. All other pinnipeds are monitored for trends in abundance and distribution. Research activities are coordinated with Chilean colleagues who operate a small summer camp at Cape Shirreff as well. Studies of fur seal foraging ecology are conducted in collaboration with University of California, Santa Cruz (UCSC). In 1998-1999 the joint AMLR-UCSC field team conducted their studies from 25 November 1998 through 26 February 1999. The major research objectives for the 1998-1999 field season were to:

- Monitor antarctic fur seal female attendance behavior (the time at sea foraging and time ashore attending a pup).
- Assist Chilean researchers in collecting pup length, girth, and mass for 100 pups every 2 weeks throughout the season.
- Document fur seal pup production at U.S. AMLR study rookeries on Cape Shirreff and assist Chilean colleagues in censuses of fur seal pups for the entire Cape and the nearby San Telmo Islands.
- Collect 20 fur seal scats (10 from each sex) every 2 weeks for diet studies.
- Collect a milk sample at each antarctic fur seal female capture for fatty acid signature analysis and diet studies.
- Deploy time-depth recorders on female fur seals for diving studies
- Record at-sea foraging locations for female fur seals using ARGOS satellite-linked transmitters (PTT).
- Measure at-sea metabolic rates and foraging energetics of 20 lactating female fur seals using doubly labeled water. Deployments coincide with the U.S. AMLR large-area survey cruises (10 during Leg I in January, 10 during Leg II in February).
- Measure milk intake using deuterated water (HDO) on the pups of foraging energetics study females.
- Measure milk intake and energetics for 20 Antarctic fur seal pups using doubly labeled water.
- Tag 500 fur seal pups for future demographic studies. Annual fur seal pup

production at Cape Shirreff is approximately 5,500 (Hucke-Gaete pers. comm.).

- Measure total blood volume for adult female and juvenile Antarctic fur seals.
- Measure metabolic rates (oxygen consumption) and thermo-neutral zones of pups and juvenile antarctic fur seals using a metabolic chamber.
- Deploy a weather station for continuous recording of wind speed, wind direction, ambient temperature, humidity, and barometric pressure during the study period.

One of the goals for our studies of fur seal foraging locations was to document the maximum range of foraging and the mean daily traveling distance for females rearing pups at Cape Shirreff. Knowledge of an animal's distribution within in its habitat is a fundamental component of its ecology and biology. Habitat preferences for many large terrestrial carnivores are well understood, but our knowledge of the habitat characteristics and preferences of marine carnivores is comparatively small. During their breeding season, late-November through April, female antarctic fur seals are central-place foragers; that is, they forage from a central place, the rookery, to a feeding area hours to days away offshore and periodically return to land to suckle their pup. Little is known about how far female fur seals must travel to acquire enough food to meet their energy demands as well as their pups. We do know, however, that female trip duration in the South Shetlands varies from overnight to 9 days (Martin, 1998). Presumably, females foraging overnight travel much shorter distances than females foraging for 9 days and acquire all their energy needs closer to their pupping sites.

Previous studies of fur seal foraging locations off Cape Shirreff showed the continental shelf break to be an important foraging area (Goebel et al. in press). The continental shelf off Cape Shirreff is approximately 30 kilometers (km) wide and calculations of mean swimming rate gives an indication of how accessible the shelf break area is to fur seals breeding at Cape Shirreff.

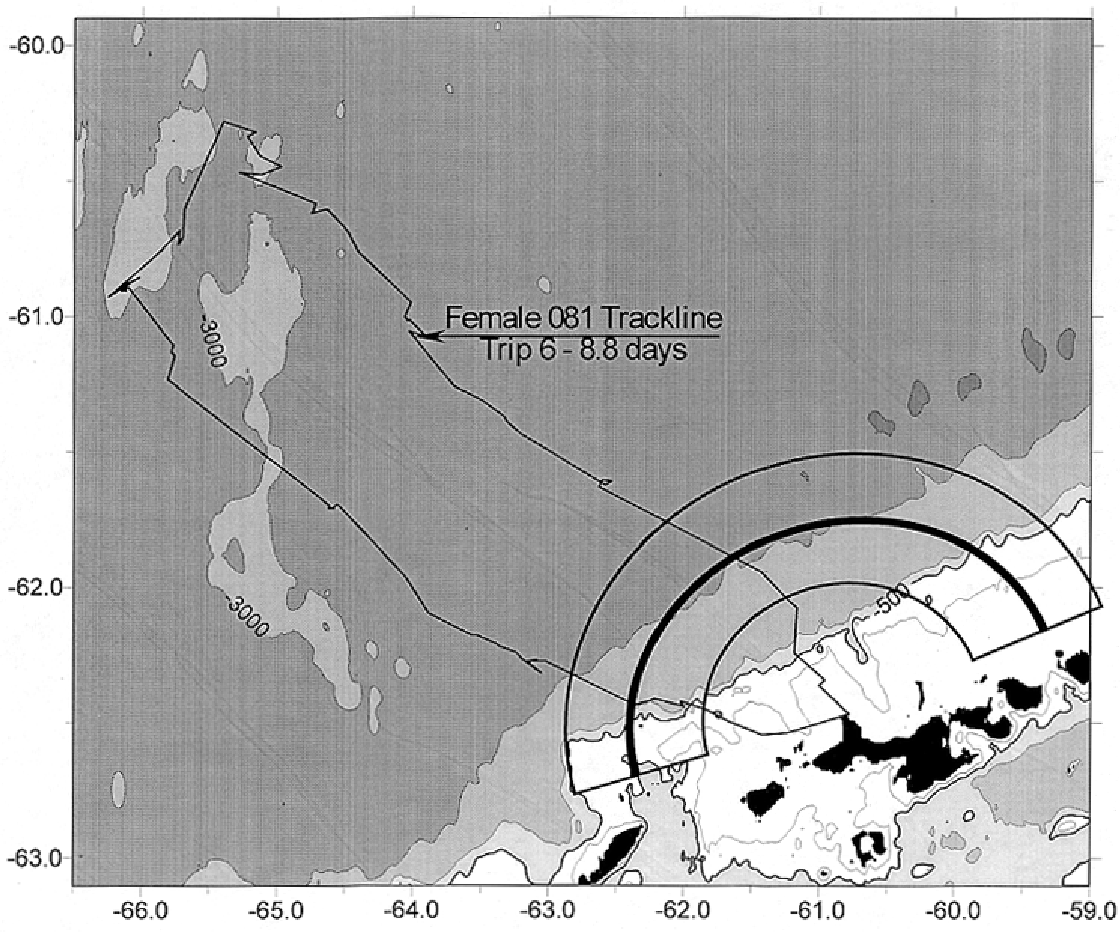
Estimates of travel rate for fur seals also helps to interpret diet data collected on land. For instance, measures of diet based on scats collected on land are limited to spatial-temporal scales constrained by the physiology of digestion, meal size, and prey type.

All the females in our foraging locations study were from 23-67 days post-partum. Each female and her pup were captured with a hoop net on the second day of a visit to shore. Length, girth, and mass were recorded and an ARGOS-linked PTT, time-depth recorder (Wildlife Computers Mark 7), and a VHF radio transmitter were attached mid-back with 5-minute Devcon Epoxy (mixed 60:40 epoxy to hardener). The pup's mass, length, and girth were recorded before being bleach-marked and released with the mother. Females were subsequently re-captured with their pups on their next visit to shore. The PTT and time-depth recorder were removed and the mother and pup were released together after recording mass, length, and girth.

Each PTT had a unique ID code and a transmission repetition rate of 34 seconds while the seal was at the surface. ARGOS provides a Location Quality (LQ) code for each location fix that depends primarily on the number of up-links received. They range from 0-3 with an ARGOS predicted accuracy of <150 meters (m) to 1km+. Two other LQ codes, "A" and "B, " are assigned to poorer quality fixes. We filtered location fixes to eliminate positions that required an animal to travel at speeds greater than 4m per second and used only locations with LQ's of 0-3 for our plots and dive analysis.

A total of 3,721 location fixes were obtained from land (589) and sea (3,132) for 29 females making 39 trips to sea. After the at-sea data were filtered, we had 2,796 locations, of which 1,435 had LQ's of 0-3 (LQ 0=997, 1=373, 2=54, 3=11).

The mean furthest distance traveled offshore was 98.2 km ± 58.8 (n=39). The furthest distance traveled offshore was 345.6 km by female 081 making 8.83-day trip (figure). The total distance female 081 traveled was 959 km. The mean total distance for all females was 361.2 km (± 202.7, n=39), and the mean trip duration was 4.5 days (± 1.7, n=39). The mean daily distance traveled was 80.7 km (± 25.3, n=39)



Female antarctic fur seal mean daily traveling distance, 80.7 km (± 25.3, n=39), plotted as an arc around Cape Shirreff, Livingston Island, South Shetland Islands, Antarctica (62°47'S, 60°77'W). A track-line for female 081 showing the maximum distance traveled for a single foraging trip in 1998/99. Female 081 began her sixth foraging trip postpartum on 15 January 1999 and returned 8.8 days later. The track-line shown is based on 183 at sea foraging locations.

Our results show that the continental shelf break area off Cape Shirreff is well within the range of mean daily traveling distances of female fur seals. The total distance traveled on a foraging trip, however, is variable and may be largely influenced by prey encounter rates and predictability of prey in time and space.

Pinniped research at Cape Shirreff, Livingston Island, is supported by the U.S. AMLR program. Studies of antarctic fur seal foraging ecology are also supported by the National Science Foundation grant OPP 97-26567 to Daniel P. Costa and Michael E. Goebel. We are grateful to our Chilean colleagues, Daniel Torres, Veronica Vallejos, Olivia Blank, Rogrigo Hucke-Gaete, Jorge Acevedo, Juan Bravo, and Juan Carlos Quezada for their assistance in the field, good humor and for sharing with us, their considerable knowledge and experience of Cape Shirreff. We are also grateful to Wayne Trivelpiece and Terence Carten for their considerable help on pinniped studies. We thank AMLR personnel and the crew of the research ship *Yuzhmorgeologiya* for their support and assistance to the land-based AMLR and UCSC personnel.

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AMLR program: Temporal aspects of phytoplankton distribution and abundance in waters around Elephant Island, Antarctica, summer 1999

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One of the major objectives of the phytoplankton component of the Antarctic Marine Living Resources (AMLR) program is to improve our understanding of the factors that influence the distribution and concentration of phytoplankton throughout the study area. The AMLR survey grid around Elephant Island (78 stations; see Martin, Hewitt, and Holt *Antarctic Journal*, in this issue) is particularly interesting and challenging in this regard because it includes diverse water types and associated frontal mixing zones, in addition to both relatively shallow coastal and deep pelagic waters.

The biomass of phytoplankton was estimated on the basis of cellular concentrations of chlorophyll-*a* (chl-*a*). Water samples for measurement of chl-*a* were obtained at 10 standard depths (0 to 200 meters) at every Conductivity-Temperature-Depth (CTD)/carousel station. Concentrations of chl-a were determined by filtering the phytoplankton onto GF/F glass fiber filters, extracting the photosynthetic pigments in absolute methanol, and measurement of fluorescence (Holm-Hansen and Riemann 1978).

During Leg I (January 10 through February 2, 1999), phytoplankton biomass at 5 m depth was lowest (< 0.2 milligrams chl-a per cubic meter) in the pelagic waters to the northwest of the South Shetland Islands and Elephant Island and highest (>1.0 milligrams chl-*a* per cubic meter) in the coastal waters north of Livingston Island and Elephant Island and in pelagic waters northeast of Elephant Island. During Leg II (February 5 through March 1, 1999), chl-*a* concentrations increased to over 2.0 milligrams per cubic meter in Bransfield Strait waters. The mean chl-*a* concentrations at 5 m depth during Legs I and II were 0.63 and 1.30 milligrams per cubic meter , respectively.

The patterns of integrated chl-a values in the upper water column during both legs (figure 1) were similar to the patterns of chl-*a* concentrations at 5 m. At the low chl-*a* stations the integrated values for chl-*a* were generally <20 milligrams per square meter (0 to 100 m), as compared to the chl-a rich stations where the values exceeded 200 milligrams chl-a per square meter. The most dramatic changes in integrated chl-a values from Leg I to Leg II were in Bransfield Strait waters (compare figure 1A with 1B). The mean integrated values for chl-*a* during Legs I and II were 44.5 and 83.1 milligrams per square meter, respectively.

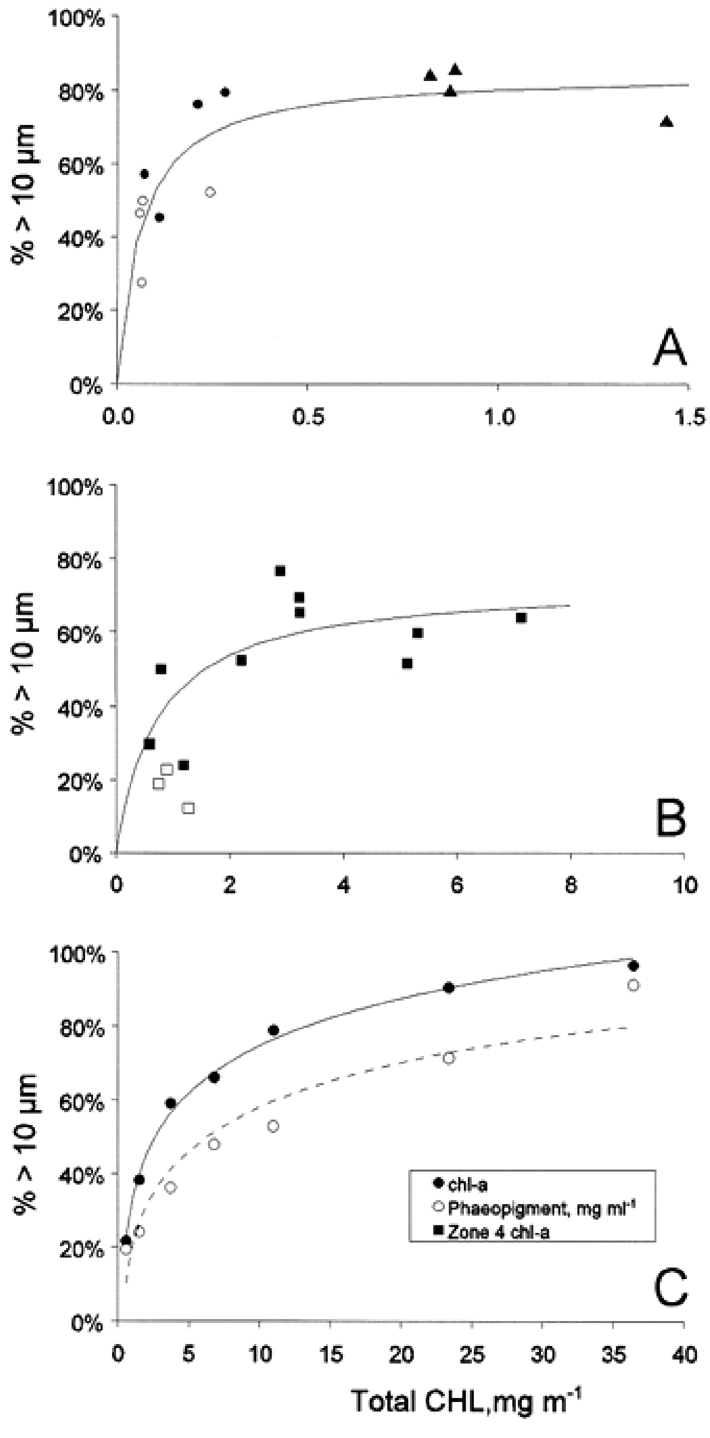

Figure 1. Integrated chlorophyll-a values (milligrams chl-a per square meter, 0 to 100 meters) throughout the AMLR survey grid. (A) Leg I; (B) Leg II. Cross-hatched areas indicate depths less than 500 meters. Depth contours (meters) are also indicated by the thin irregular lines.

Profiles of chl-*a* concentrations in the upper water column differed markedly in various regions of the survey grid. Stations with the lowest chl-*a* concentrations in surface waters generally have a deep chl-*a* maximum at approximately 80 m depth and are found in Drake Passage waters (Water Zone I, as described by Holm-Hansen et al. 1997). Stations in the other four water zones generally have higher chl-a values in the upper 20-30 m of the water column, and no deep chl-*a* maximum. At some of the stations in Water Zone I, there were elevated chl-*a* concentrations in the upper 20-30 m of the water column in addition to the characteristic deep chl-*a* maximum. In past years such stations have shown higher than usual concentrations of silicic acid in the upper mixed layer, suggesting some input of nutrients from contiguous water masses. The number of such stations this year was higher than in recent years.

The most striking observation regarding chl-*a* concentrations in 1999 was the development of a massive phytoplankton bloom in the Bransfield Strait during the 35 days that elapsed between Legs I and II (figure 2). This bloom extended from south of Admiralty Bay (Station 134) to northeast of Elephant Island (Station 084) (figure 2B). During Leg I these stations in Bransfield Strait had moderate chl-*a* concentrations (<1.0 milligram chl-*a* per cubic meter), but by Leg II the values had increased up to 2-8 milligram chl-*a* per cubic meter. The greatest concentrations of chl-*a* were found at Station D005, which had fairly uniform concentrations of chl-*a* (7-8 milligrams chl-*a* per cubic meter) down to ~60 m. Integrated chl-a at this station was 460 milligrams chl-*a* per square meter (0 to 100m) . This is the highest integrated chl-*a* value that we have measured during the 10 years of the AMLR survey. The only other year that showed near-comparable concentrations of chl-a in Bransfield Strait was in February of 1994. The development of such a rich phytoplankton bloom in February is surprising in that solar irradiance had declined considerably since the summer solstice in late December, and there is no evidence of any nutrient limitation for phytoplankton growth in the Bransfield Strait at any time of the year.

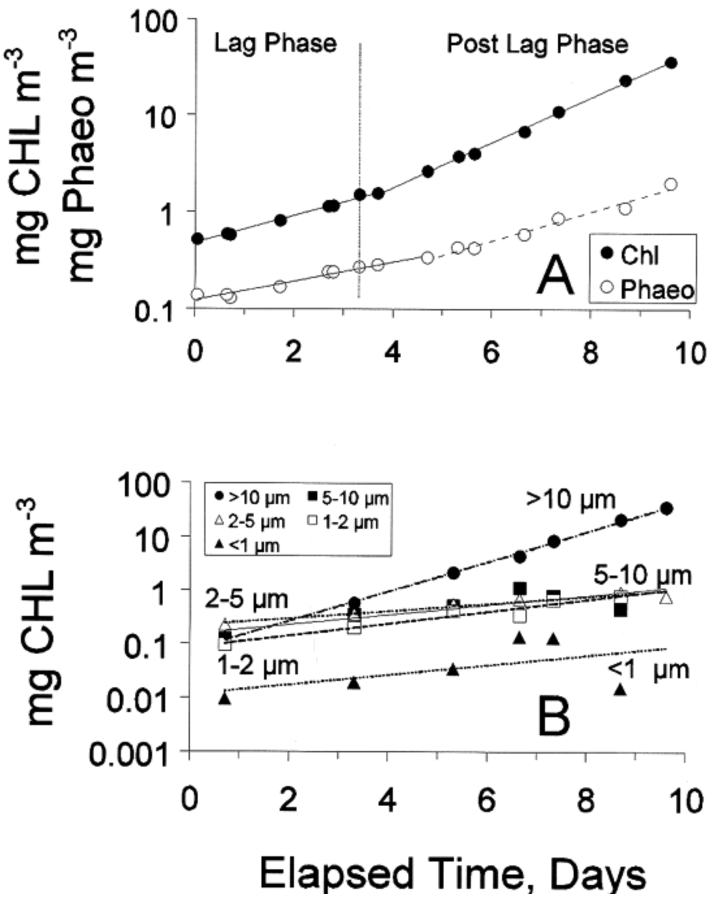

Figure 2. Profile sections of chlorophyll concentrations in Bransfield Strait showing the development of a rich bloom in the 35 days between sampling during Leg I (figure 2A) and Leg II (figure 2B). Isolines and values are in milligrams chlorophyll-a per cubic meter; dots represent depths from which samples were taken.

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Martin J.E., R.P. Hewitt, and R.S. Holt. 1999. The U.S. Antarctic Marine Living Resources (AMLR) program: 1998-1999 field season activities. *Antarctic Journal of the U.S.*, this issue.

AMLR program: Inorganic nutrient concentrations in the Elephant Island area in relation to different water zones.

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The phytoplankton component of the Antarctic Marine Living Resources (AMLR) program is concerned with the distribution and abundance of phytoplankton in the waters around Elephant Island and the environmental factors that influence the dynamics of phytoplankton growth. Concentrations of the three major inorganic macronutrients that are often limiting phytoplankton biomass in marine waters (nitrate, phosphate, and silicic acid) are routinely measured in the AMLR program as they are informative in regard to problems relating to (1) possible limitation of phytoplankton growth when these major essential nutrients get depleted to very low concentrations, (2) rates of regeneration of nutrients in the upper mixed layer of the water column, (3) integrated net productivity over time periods of weeks or months, and (4) rates of physical mixing processes throughout the depth of the upper mixed layer.

Water samples for nutrient analyses were obtained from 10-liter Niskin bottles attached to the Conductivity-Temperature-Depth (CTD)/carousel unit which recorded the physical, optical, and biological characteristics from the surface to 750 meter (m) depth, or to within 10 m of the bottom at the stations located in continental shelf waters. For a description of the cruise track and survey grid, which consisted of 78 CTD/carousel stations, see Martin, Hewitt, and Holt (*Antarctic Journal*, in this issue). A water sample was taken at 5 m depth at every station, and at depths of 5, 10, 15, 20, 30, 40, 50, 75, and 100 m at selected stations. Acid-cleaned high-density polyethylene bottles of 50 milliliters (ml) capacity were rinsed 4-5 times with water directly out of the Niskin bottle before filling with approximately 35 ml. The sample bottles were then frozen in an upright position and maintained at -20^{o}C or lower until time of analysis. The samples were analyzed at the Universidad Católica de Valparaiso with an auto-analyzer following the techniques described by Atlas et al. (1971). Nitrate and nitrite were not determined separately, so that the term “nitrate” refers to the sum of nitrate + nitrite.

During survey A of Leg I (15-28 January 1999), the concentrations of nitrate, phosphate, and silicic acid were always relatively high and far in excess of concentrations that might limit phytoplankton growth rates or biomass. The concentration ranges were 21.7 to 32.3 micromolar (µM) for nitrate, 1.51 to 2.26 µM for phosphate, and 21 to 84 µM for silicic acid. The concentrations of nitrate and silicic acid at 5 m depth throughout the 78 station survey grid are shown in figure 1. Phosphate concentrations are not shown, as previous studies (Holm-Hansen et al. 1997) have shown a good correlation between concentrations of nitrate and phosphate. The distributional pattern of phosphate is thus similar to that of nitrate as shown in figure 1B.

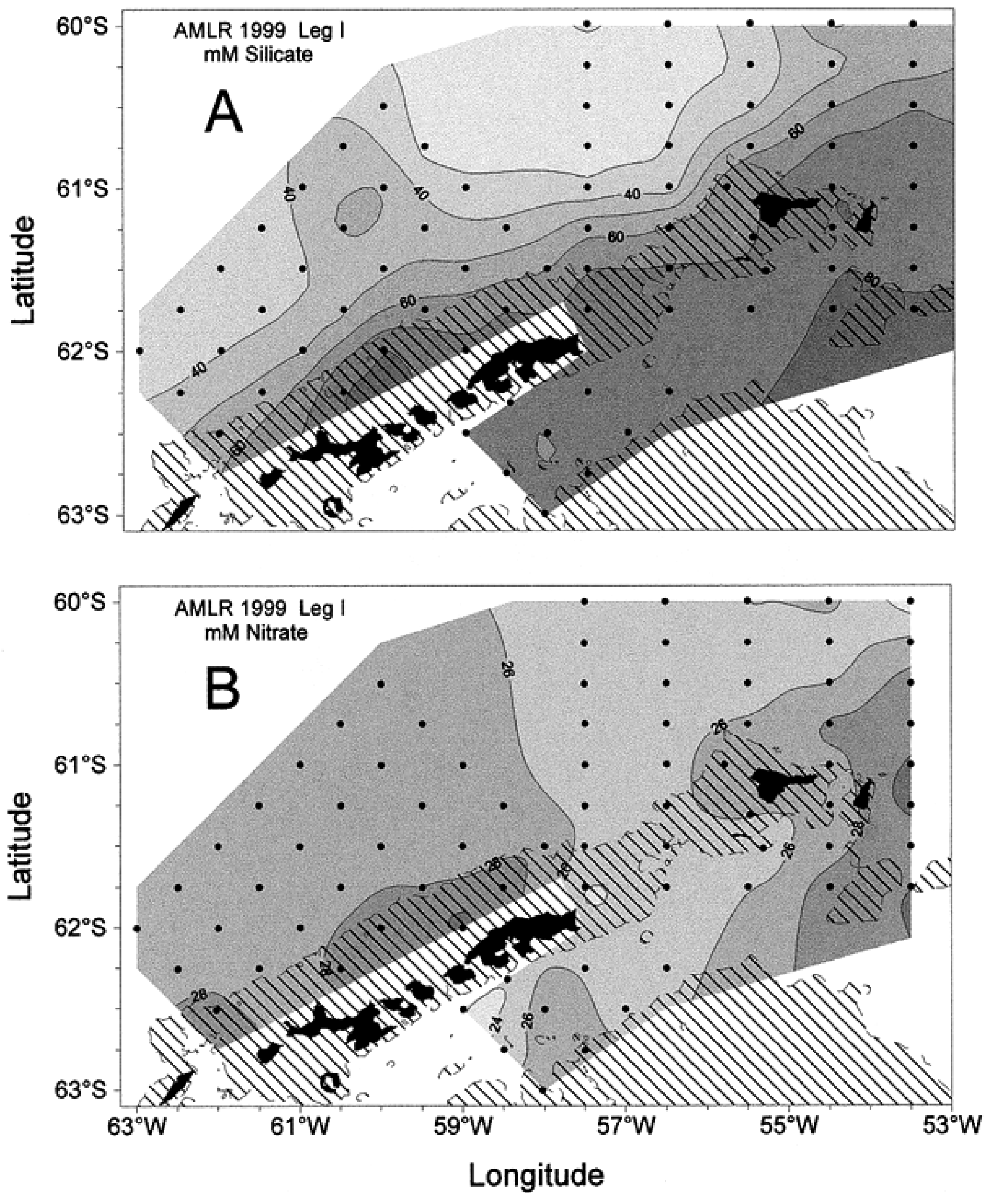

Figure 1. Micromolar (μM) inorganic nutrient concentrations at 5-meter depth throughout the AMLR survey grid during Leg I. (A) silicic acid; (B) nitrate. The cross-hatched areas show continental shelf regions with depths of less than 500 meters.

Silicic acid concentrations are highest in Weddell Sea waters (> 70 μM), decrease progressively toward the northwest, and reach their lowest concentrations (< 30 μM) in

Drake Passage waters, which historically have very low concentrations of silicic acid. In the AMLR study area, these waters are referred to as Water Zone I (see Holm-Hansen et al., 1997). It was surprising to see the elevated silicic acid concentrations (>50 µM) at stations to the northwest of King George Island as these stations are also located in Water Zone I, which are characterized not only by low concentrations of silicic acid, but also by low chlorophyll-a (chl-*a*) concentrations. As the concentrations of chl-*a* at these stations were also fairly high (> 0.5 milligram chl-a per cubic meter), it appears that there has been mixing at these stations of Drake Passage waters with nutrient-rich waters originating from the Bellingshausen Sea.

The pattern of nitrate concentrations in surface waters (figure 1B) also shows highest concentrations in Weddell Sea waters and lowest concentrations in the northern region of the survey grid. This is in agreement with data from previous AMLR cruises. It is, however, unusual to see the relatively low concentrations in Bransfield Strait waters. The likely causes for these low nitrate concentrations in Bransfield Strait include (1) advection of low-nitrate waters from the southwest and (2) in situ nutrient uptake by phytoplankton prior to our sampling during Survey A. Our data do not permit us to differentiate between these two alternative explanations.

The relationship between nitrate and silicic acid concentrations at all stations in the AMLR survey grid is shown in figure 2. The lowest silicic acid concentrations are found at stations located in Drake Passage waters (Water Zone I), but these stations can be further differentiated into Water Zone IA stations (lowest silicic acid concentrations and also very low chl-*a* concentrations in the upper mixed layer) and Water Zone IB stations (higher silicic acid concentrations and also higher chl-*a* concentrations in the upper mixed layer). Waters at the IB stations apparently have been enriched in nutrients by mixing of Drake Passage waters with the nutrient richer waters (which do not show any deep chl-*a* maximum) overlying the continental shelf regions. The two stations in figure 2 (marked with arrows), which show unusually low concentrations of nitrate and silicic acid, also had relatively high chl-a concentrations (>1.0 milligram chl-*a* per cubic meter). The low nutrient concentrations at these two stations apparently are due to nutrient uptake by phytoplankton.

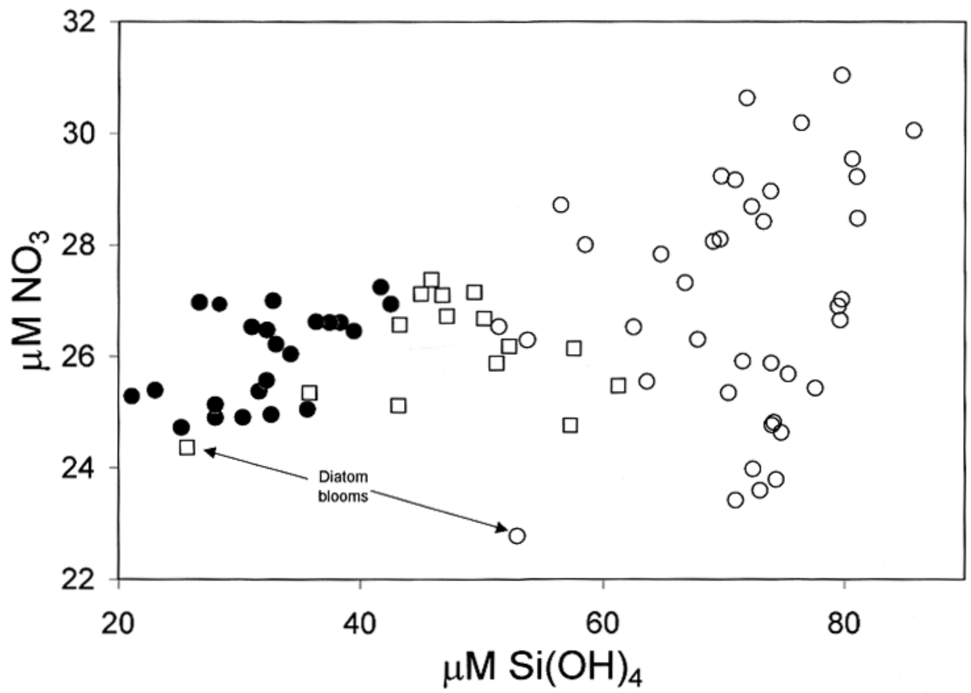

Figure 2. Plot showing the relationship of nitrate and silicic acid concentrations (micromolar) throughout the AMLR survey grid during Leg I. Solid circles indicate stations located in Water Zone IA; empty squares indicate stations located in Water Zone IB; empty circles indicate stations located in water zones II through V. For details on water zone characteristics, see Holm-Hansen et al., 1997.

This research was supported by National Oceanic and Atmospheric Administration (NOAA) Contract 50ABNF600013.

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AMLR program: Primary production and photophysiological state of the phytoplankton, summer 1999

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The overall objective of our research project was to assess the distribution and concentration of food reservoirs available to the herbivorous zooplankton populations throughout the Antarctic Marine Living Resources (AMLR) program study area during the austral summer. Specific objectives of our work included here were to determine the rate of daily primary production throughout the euphotic zone, and to determine the photosynthetic response of phytoplankton assemblages from various depths in the water column to solar irradiances ranging from 0.5% to 95% of full sunlight.

Rates of primary production were measured daily during Leg I whenever there was a CTD/carousel station between 0700 and 1000, which permitted incubation of our samples for at least eight daylight hours. Water samples from eight depths [from 5 to 75 meters (m)] were poured into 50 milliliter (ml) clear polycarbonate screw-cap tubes and inoculated with 5.0 microcuries of ^{14}C-sodium bicarbonate. Duplicate tubes were used for each depth, in addition to one tube from 5 m and one from 75 m, which were kept in the dark and used for estimation of the rate of dark-fixation of CO_2. The tubes were attached to a Plexiglas frame with sections of neutral density screening to simulate the irradiance at the depths from which the phytoplankton had been sampled. The frame with the tubes was placed in a wooden incubator with pumped surface sea water (which just covered the tubes) for temperature control. The incubator was in a relatively shade-free area on the ship's upper deck. The irradiance incident upon the samples ranged from 95% of incident radiation for the 5 m sample to 0.5% for the sample from 75 m. At the end of the incubation period (8-10 hours), the samples were filtered through GF/F glass fiber filters (25 millimeter). The filters were placed in 7 ml glass scintillation vials and any inorganic ^{14}C eliminated by fuming with HCl fumes for at least 10 hours. The filters and vials were dried at 35°C and then sealed and stored until analysis. Fixed radioactivity in the samples was determined by conventional liquid scintillation techniques, using a Wallac 1215 liquid scintillation counter in J.L. Iriarte's laboratory at the Universidad De Magallanes, Punta Arenas.

Simultaneous with the primary production measurements, water samples from high-light (5 m) and low-light conditions (between 50 to 100 m) were treated in a similar fashion except that replicate water samples from each of the above depths were exposed to the eight different irradiances (95 to 0.5% of incident solar radiation). Solar irradiance was recorded continuously (every minute) for Photosynthetically Available Radiation

(PAR; 400 to 700 nanometers) using a 2-pi sensor (model #QSR-240, Biospherical Instruments, Inc.), which was mounted in a shade-free location close to the primary production incubators.

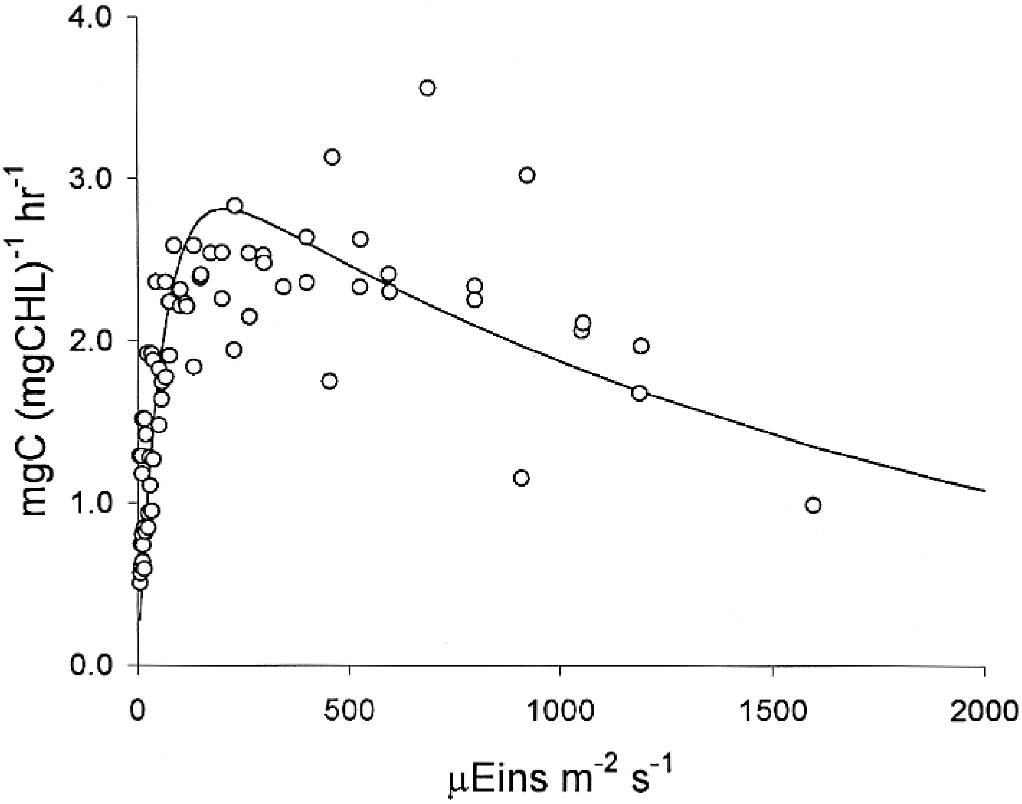

Figure 1. Rate of primary production (mg carbon fixed per mg chl-a per hour) as a function of the mean solar irradiance (microEinsteins per square meter per second) to which the samples were exposed during the on-deck incubation. The line represents the best fit of the experimental points assuming a photoinhibition effect. The photosynthetic parameters calculated from these data are listed in table 1.

Data from the primary productivity incubations (figure 1) show that the phytoplankton are very efficient at fixing carbon dioxide at low light levels (at approximately 1% of surface irradiance the assimilation numbers were consistently >0.5 milligrams (mg) carbon fixed per mg chlorophyll-*a* per hour), reach maximal photosynthetic rates at relatively low irradiances, and show considerable photoinhibition of photosynthesis with increasing irradiance. There were no obvious differences in the photosynthetic parameters for the phytoplankton from Water Zone I as compared to samples from the other water zones. The photosynthetic parameters derived from the data in figure 1 are shown in table.

Photosynthetic vs. Irradiance curve parameters of the photosynthetic response curve to light intensity incorporating photoinhibition (Platt et al. 1980), where α is the positive and β the negative rates of response to light, P_s^B is the theoretical maximal response, P_{max}^B is the maximal production rate obtained at light intensity I_m, I_k is the conventional index of light adaptation, and I_s is an analogous parameter when the photoinhibition model is used.

Parameter	Value
A	0.055 mg C (mg CHL)$^{-1}$ hr^{-1} (µEins m^{-2} s^{-1})$^{-1}$
β	0.00179 mg C (mg CHL)$^{-1}$ hr^{-1} (µEins m^{-2} s^{-1})$^{-1}$
P_S^B	3.25 mg C (mg CHL)$^{-1}$ hr^{-1}
P_{max}^B	2.82 mg C (mg CHL)$^{-1}$ hr^{-1}
I_k	51 µEins m^{-2} s^{-1}
I_s	59 µEins m^{-2} s^{-1}
I_m	210 µEins m^{-2} s^{-1}

Additional productivity vs. irradiance experiments were also performed using replicate water samples from 5 m and from 50-100 m depths and subjecting them to the eight different irradiances ranging from 0.5% to 100% of incident radiation (figure 2). The marked inhibition of photosynthetic rate at high light levels seen in these experiments, coupled with the data in figure 1, indicate that the phytoplankton throughout the AMLR survey grid have characteristics of dark adapted cells. Phytoplankton sampled from depths of 50-100 m show much more inhibition of photosynthesis at high irradiances as compared to samples from 5 m, indicating that the rate of mixing of water in the upper 100 m of the water column is relatively slow.

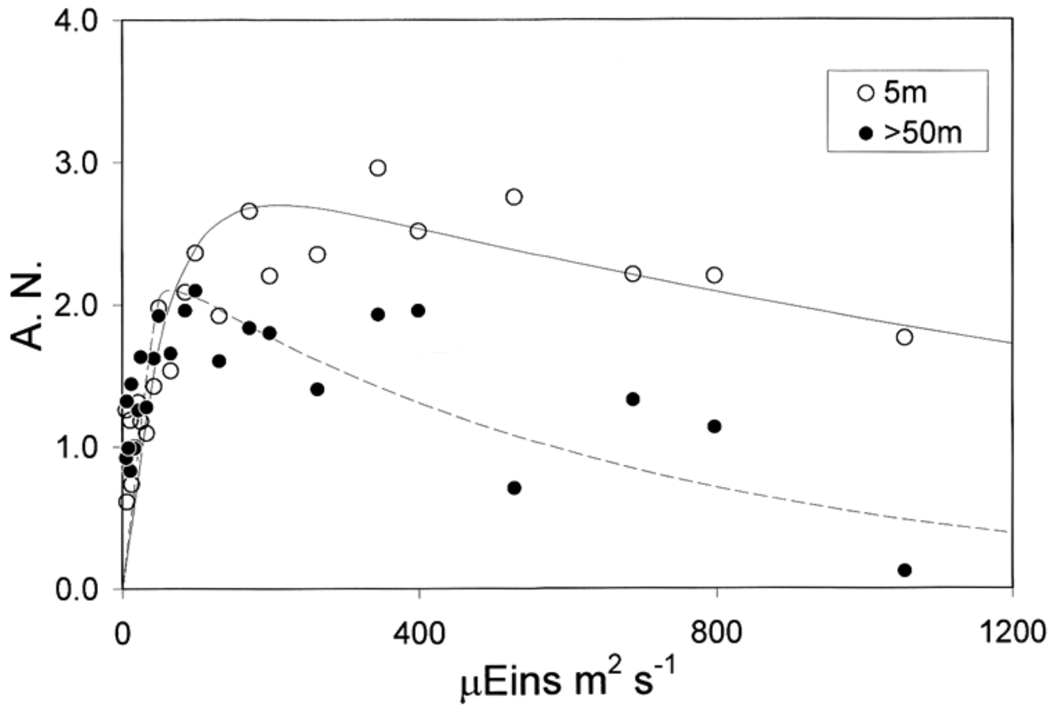

Figure 2. Photosynthetic response of phytoplankton sampled from high light conditions (5 m) and from low light conditions (50-100 m) to solar irradiances ranging from 0.5% to 95% of full sunlight. Units for the Assimilation Numbers (A.N.) are mg carbon fixed per mg chlorophyll-a per hour, and units for irradiance are shown as microEinsteins per square meter per second. Lines are best fit using the equation of Platt et al. (1980).

Profiles of the rate of primary production with depth in the water column differed appreciably, depending upon the incident solar irradiance and the distribution of phytoplankton with depth (figure 3). When the phytoplankton were predominantly in the upper mixed layer, the profiles for rate of production were fairly similar to the profiles of chl-a concentrations, except for the photoinhibition of photosynthesis noted in the upper 20 m (figures 3A and 3B). The mean irradiance for the samples in figure 3A was very high (>1600 microEinsteins per square meter per second), resulting in a marked decrease in photosynthetic rate for the samples from 5 and 10 m depths. The data in figure 3C are from a typical Water Zone I station. The mean irradiance for the samples during this incubation was low (700 microEinsteins per square meter per second), and hence no photoinhibition was noted. The decrease in rate of production from 5 m down to 40 m was due to light limitation as solar radiation is attenuated with depth. The increases in production at 50 and 75 m were due to the increasing biomass at these depths as they lie within the sub-surface chl-a maximum, which characterizes Water Zone I stations. Station A136 (figure 3D) was classified as being in Water Zone I, but it was one of those aberrant Zone I stations which show relatively high phytoplankton biomass in the upper water column in addition to having enhanced chl-a values at 75 m depth. The integrated primary production at such stations was high due to the substantial phytoplankton biomass throughout the upper 75 m of the water column. The light level was high during this incubation (1190 microEinsteins per square meter per second), which resulted in some inhibition of photosynthesis in the upper 10 m.

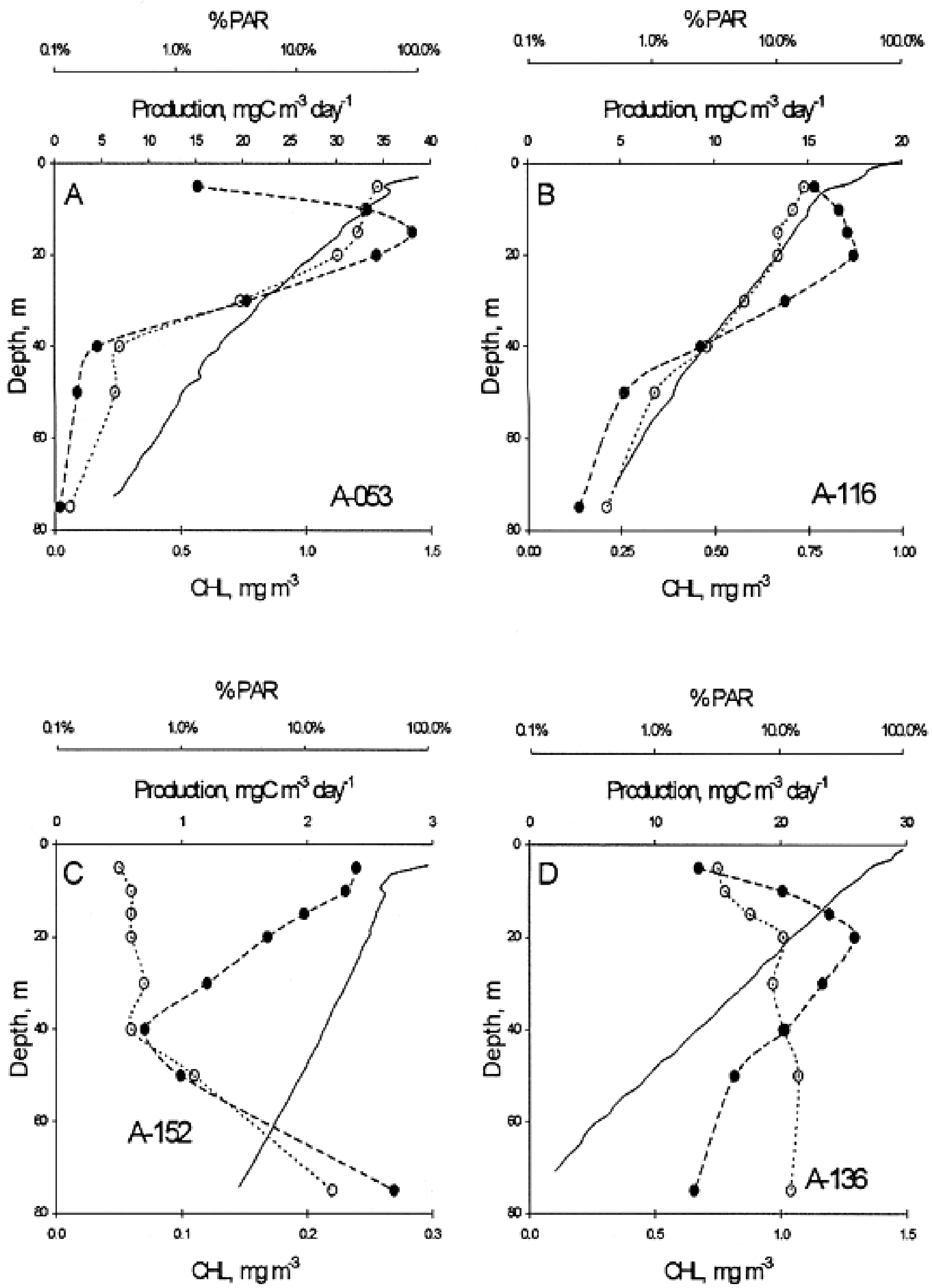

Figure 3. Profiles of rates of primary production and rates of attenuation of sunlight in the upper water column (5 to 75 m) at four stations in relation to chlorophyll-a (chl-a) concentrations. Photosynthetically available radiation (PAR) has been set to 100% at the surface to facilitate visualizing the depth of the euphotic zone, which is assumed to be where the irradiance was 1% of incident PAR. Rates of primary production (in mg carbon fixed per cubic meter per day) are shown as solid circles. Chl-a concentrations are shown as empty circles. Note change of scales for Chl-a concentrations and Productivity. (A) Station A053, Water Zone IV. (B) Station A116, Water Zone II. (C) Station A152, Water Zone I. (D) Station A136, Water Zone I. The mean incident solar irradiances for the samples shown in A, B, C, and D were 1612, 1050, 700, and 1190 microEinsteins per square meter per second, respectively.

This research was supported by National Oceanic and Atmospheric Administration (NOAA) contract number 50ABNF600013.

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AMLR program: Phytoplankton size class distributions and their relationship to different water zones, January to February 1999

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One objective of the Antarctic Marine Living Resources (AMLR) program is to describe the size distribution of the phytoplankton community, which is important to zooplankton grazing preferences. The AMLR large-area survey grid around Elephant Island (see Martin, Hewitt, and Holt in this issue) is particularly interesting and challenging in this respect because it includes diverse water masses and associated frontal mixing zones, besides both relatively shallow coastal and deep pelagic waters. These various water types generally yield different phytoplankton assemblages with different cell size spectra, which may influence the nature of the grazing community (e.g., salps vs. krill).

Size spectra of the phytoplankton assemblages were obtained by passing water samples through Nitex mesh or polycarbonate membrane filters having a range of pore sizes [1-10 micrometer (µm)] and by measuring the concentration of chlorophyll-*a* (chl-*a*) in the filtrate (for methods, refer to Hewes et al., in this issue). Gravity filtration, as compared to a partial vacuum, was used because it yields a more realistic separation of small nanoplankton and picoplankton (Holm-Hansen and Hewes 1999).

During both cruise legs, most of the phytoplankton biomass was contained in the nanoplankton (<20 µm) rather than the microplankton (>20 µm) size fraction (table 1). During Leg I, the 2-5 µm size class contained the greatest fraction of total chl-*a*, with the 1-2 µm size class having the next highest percentage. Total chl-*a* concentrations increased in the AMLR survey area between Legs I and II, reflecting the seasonal increase during February as commonly noted in previous years. For the size fractions, the greatest increase in phytoplankton biomass between January and February occurred for the microplankton (128%) and 10-20 µm (47%) size classes, while the picoplankton (1-2 µm) size class showed a decrease. For convenience in the experimental data discussed below, we group the microplankton and 10-20 µm size classes into the >10 µm category.

Table 1. Summary of results for size classed chlorophyll concentrations in water samples from 5 m during Legs I and II. Leg I and Leg II. Average percentage and chl-a concentrations, the seasonal difference (from Leg I to Leg II) and percent change from Leg I, are listed for the various size categories (see text for details)

Size Fraction	CHL Leg I % Total	CHL Leg II % Total	Average $mgCHLm^{-3}$ Leg I	Average $mgCHLm^{-3}$ Leg II	Seasonal Change $mgCHLm^{-3}$	Seasonal Change % Leg I Total
n =	12	21	12	21		
Total			0.63	2.02	1.39	221
>20 µm	19	46	0.07	0.87	0.81	128
10-20 µm	7	13	0.04	0.34	0.29	47
5-10 µm	18	14	0.13	0.37	0.24	38
2-5 µm	32	16	0.23	0.31	0.08	13
1-2 µm	21	7	0.14	0.09	-0.05	-8
<1 µm	3	2	0.01	0.04	0.03	5

In general for the Antarctic, nanoplankton are considered to dominate low biomass containing waters, and microplankton dominate phytoplankton blooms. Our data (table 1) support this idea as the high chl-*a* waters during Leg II were dominated by cells > 10 µm, in contrast to the dominance by small cells (< 2.0 µm) in the low chl-*a* waters during Leg I. This indicates that a kinetic-like relationship occurs between the relative contribution of large-sized phytoplankton and the concentration of chlorophyll. The data in figure 1 suggest that the relationship between cell size distribution and total chl-*a* concentration may depend upon the chemical and physical conditions in the upper water column. In Drake Passage waters (Water Zone I), cell dominance by cells >10 µm occurred when concentrations approached 0.4 milligrams chl-a per cubic meter (mg chl-a m^{-3}) (figure 1A), whereas in Bransfield Strait waters (Water Zone IV), >10 µm cell dominance maximized at approximately 3.0 mg chl-a m^{-3} (figure 1B). In a culture allowed to grow for 10 days, dominance by cells >10 µm was also reached at approximately 3.0 mg chl-a m^{-3}, but the proportion of larger cells continued to increase until day 10 when the cells >10 µm accounted for 97% of the phytoplankton biomass.

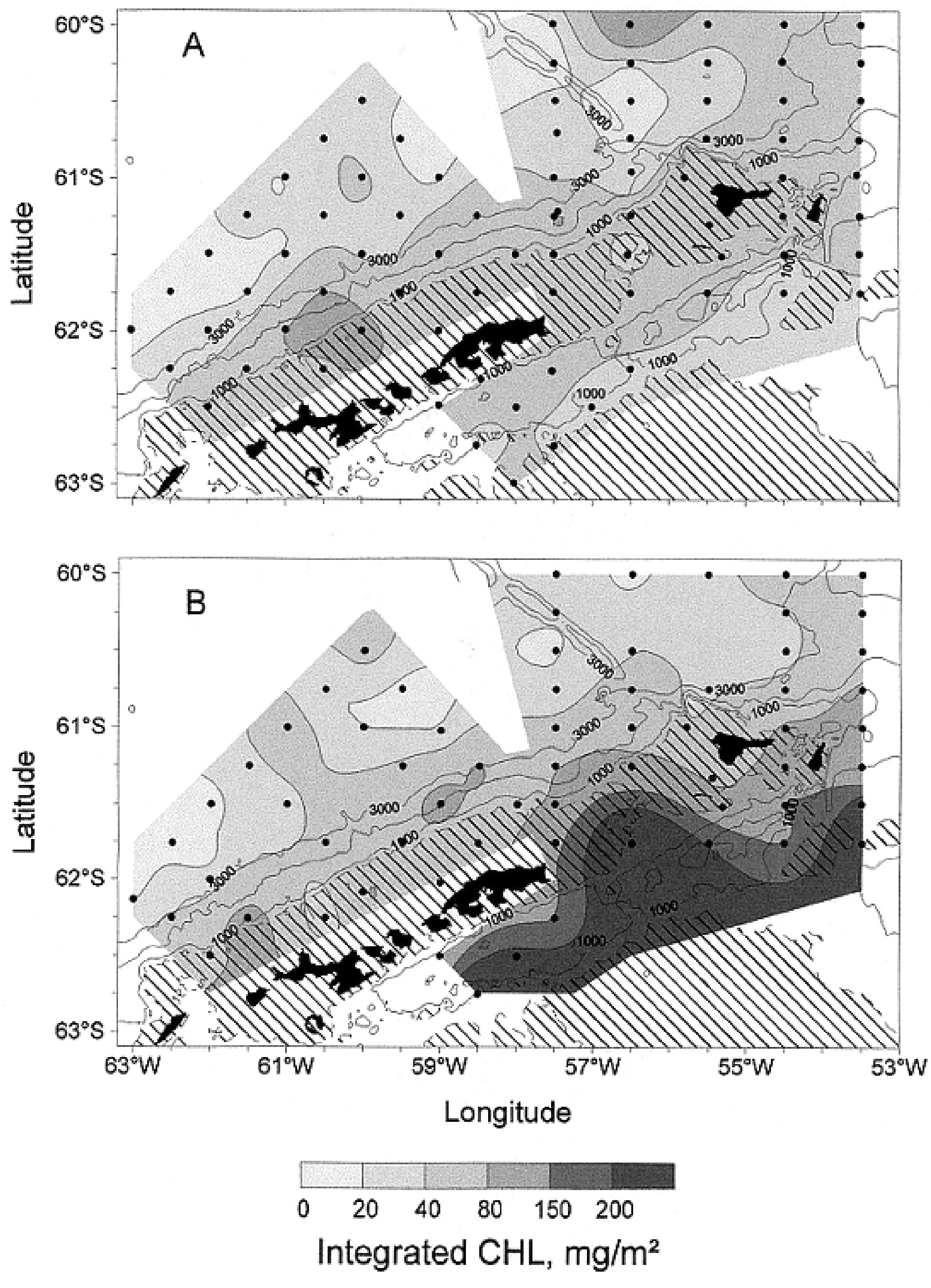

Figure 1. Relationship between percentage of chlorophyll contained in the >10 µm size class and the total chl-a concentration. (A) Drake Passage waters, with stations in Water Zone IA shown as circles and stations in Water Zone IB by triangles. (B) Bransfield Strait waters (Water Zone IV). For both A and B, open symbols denote Leg I and filled symbols denote Leg II. (C) A natural culture inoculated from Bransfield Strait waters during Leg I and allowed to grow for 10 days. Note that the units on the abscissas in A, B and C are different.

The reason that the size spectrum of phytoplankton changes between low and high chl-*a* concentrations is believed to be a function of protozoan grazing. This was demonstrated indirectly by our long-term natural culture experiment (figure 2). After a lag phase of 3-4 days with 0.46 doublings day^{-1}, total chl-*a* concentrations increased exponentially with 0.78 doublings day^{-1} (table 2), reaching a total concentration of 36 mg chl-a m^{-3} after 10 days (figure 2A). It should be noted that this concentration of phytoplankton grown from unenriched natural seawater is higher by a factor of 4-5 than rich blooms usually found in the Bransfield Strait (see figure 2 in Hewes et al., in this issue). These differences are believed to be due to our exclusion of larger zooplankton grazers in our experimental cultures. Total phaeopigments (a degradation product of chlorophyll) also increased from 0.32 doublings day^{-1} during the lag phase to 0.49 doublings day^{-1} in the post lag phase (figure 2A, table 2)

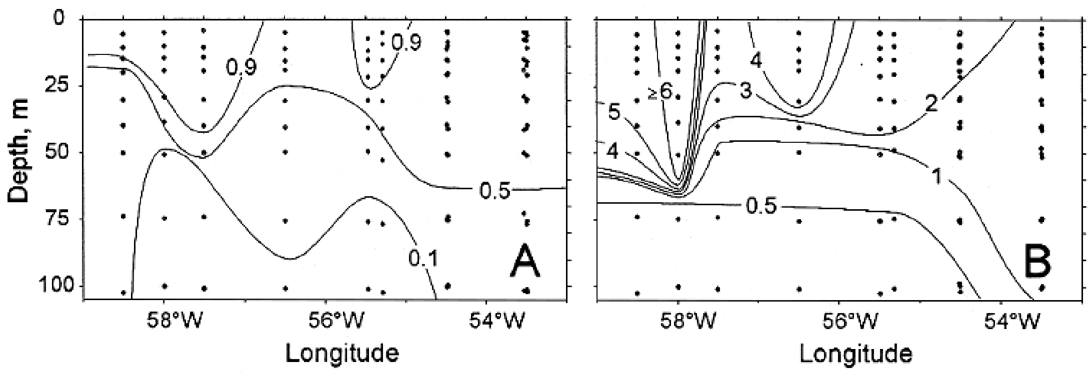

Figure 2. Growth characteristics of a natural culture grown during Leg I showing the progressive change toward larger cells as chlorophyll-a (chl-a) concentrations increased during the 10-day growth period. (A) change in concentrations of chl-a and phaeophytin with time. (B) change in various size classes of chlorophyll containing particulates. Lines represent exponential regressions with slope and statistical significance for each line found in table 2. The culture was initiated from 5-meter water obtained by Niskin Bottle at Station A121.

Table 2. Growth rate data (in specific growth and doublings day-1) and significance of exponential regressions (see figure 2) for total and size classed pigments measured during the course of a natural culture.

Size Class	Specific Growth, d^{-1}	Doublings per day	r^2
Total (lag)	0.32	0.46	0.998
Total (post lag)	0.54	0.78	0.990
>10 μm	0.71	1.02	0.998
5-10 μm	0.21	0.30	0.634
2-5 μm	0.16	0.23	0.945

Size Class	Specific Growth, d^{-1}	Doublings per day	r^2
1-2 µm	0.26	0.38	0.942
<1 µm	0.21	0.30	0.293
Total Phaeopigment (lag)	0.223	0.32	0.963
Total Phaeopigment (post lag)	0.343	0.49	0.976

Size fraction data revealed that the lag phase for total chlorophyll concentration was actually a phenomenon of changing cell size distributions of the culture as it developed (figure 2B), since most size classes >1 µm increased exponentially, but at different rates (table 2). At the start of the culture, the >10 µm size fraction comprised only 22% of the total chl-*a*, while it contained 97% on day 10. Carbon fixation was measured for the culture on day 7. The results indicated that the nanoplankton fraction had Assimilation Numbers about 60% [1.3 mg C $(mg\ chl)^{-1}\ h^{-1}$] that of the total [2.1 mg C $(mg\ chl)^{-1}\ h^{-1}$]. The reason for these differences between nanoplankton and microplankton rates was probably protozoan grazing upon nanoplankton, and thereby controlling the increase of nanoplankton biomass. There is little microbial grazing control of microplankton biomass in our culture, as this size class is thought to be controlled via macrozooplankton grazing. The shift from "lag phase" to exponential growth for total chl-*a* (figure 2A) therefore occurred when the >10 µm size classes contributed >50% of the total biomass (between days 3 and 4). The rate of increase in phaeopigments (table 2) probably reflects the rate of increase in protozoan biomass, since most protozoan fecal matter cannot be retained by the filters used. The change in the size-class distribution for phaeopigments over time was similar to that for chl-a (figure 1C). The change in size-class distribution relative to chlorophyll concentration for the culture initiated from Bransfield Strait waters had a hyperbolic relationship (figure 1C) that closely resembled the distribution found for samples from Bransfield Strait waters (figure 1B).

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AMLR program: Physical oceanography of the northern South Shetland Island and Bransfield Strait area, summer 1999

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The physical oceanography group of the Antarctic Marine Living Resources (AMLR) program surveyed the South Shetland Island waters from Elephant to Livingston Islands, parts of the Drake Passage, and the Bransfield Strait for the tenth field season during the 1999 austral summer (Martin, Hewitt, and Holt, *Antarctic Journal*, in this issue). The aim is to study the relationship between physical and biological processes and the variability on interannual and seasonal scales. AMLR 1999 was the fourth annual cruise to be conducted aboard the research ship *Yuzhmorgeologiya*. The total number of stations was reduced on AMLR 1999 compared to previous AMLR cruises. Several original stations were cut from the Elephant Island area to accommodate a shift of interest to the west following the closure of the Seal Island field camp. The Cape Shirreff field camp on Livingston Island became fully operational this year. The stations were located in three areas: the Elephant Island area, the West area off Livingston and King George Islands, and the South area in the Bransfield Strait. Due to rough weather encountered on Leg II, several planned stations could not be occupied.

The Conductivity-Temperature-Depth (CTD)/carousel instrument included fluorometer, transmissometer, and PAR sensors. CTD/carousel casts were limited to 750 meters (m) depth (or to within a few meters of the ocean floor when the depth was 750m, or less). Forty-nine days of continuously acquired weather, sea temperature, salinity, water clarity, chlorophyll, and solar radiation data were collected to provide complete coverage of surface environmental conditions encountered throughout the AMLR study area.

As in Holm-Hansen et al (1997), we classify and group stations with similar vertical temperature/salinity (T/S) characteristics and have identified six water zones, designated I through VI. The zones are based on the T/S curves from the surface to 750 m (or to the bottom in water shallower than 750 m). Water Zone I is based on these multiple characteristics: warm, low salinity surface water; strong sub-surface temperature minimum (called “Winter Water” or WW, at approximately -1°C and salinity of 34.0 ppt.); and a distinct T/S maximum near 400 m (called “Upper Circumpolar Deep Water” or UCDW). Water Zone I is the oceanic water of the Drake Passage. In the Bransfield Strait and south of Elephant Island, Water Zone IV dominates. Here bottom waters are around -1°C and the subsurface extremes are far less prominent, although there is evidence of a modified form of Circumpolar Deep Water in the Bransfield. In between, there are transition zones where adjacent water zones mix.

During AMLR 1999, we made extensive use of Ocean Data View 40 (ODV4.0) software, developed at the Alfred Wegener Institut (AWI) by Dr. Reiner Schlitzer. This software is freely available from AWI via the Internet (http://www.awi-bremerhaven/GPH/ODV). Its strength is in the ease and rapidity by which one can visualize vertical oceanographic sections and horizontal surfaces in color on a PC and produce color copy using today's inexpensive printers. Special conditions or outliers can instantly be pinpointed using the mouse and groups of stations can be isolated by time, depth, location, or parameter range.

Two sections are presented here using ODV40: a meridional section along 57.5°W (figure 1) and a longitudinal section covering the oceanic waters from Livingston to Elephant Islands (figure 2). These sections were made during Leg I of the cruise in January 1999. During January, it appeared that 1999 would be a "cold year", with surface temperatures not reaching 3°C. The sea surface warmed up in February/March with Water Zone I measuring above 3.5°C. Figure 1 is a typical section extending from the oceanic water of the Drake passage in the north to the Bransfield Strait in the south. Reproduction is less satisfactory here in grey scale than in the color of the original, but features of the frontal boundaries are clear. Waters generally <0°C fill the Bransfield Strait. Potential temperature in the Drake Passage shows the WW minimum near 100 m, and the CDW maximum >2°C near 400 m with the associated salinity maximum and oxygen minimum. The shelf slope front is delineated at the surface and subsurface by temperature, salinity, density (Sigma-0), and dissolved oxygen gradients. Longitudinally (figure 2), the depth of the winter water temperature minimum is around 75 m in the oceanic waters off Livingston Island, forming a strong shallow thermocline. The core of the winter water warms and dips to around 100 m near Elephant Island. At the eastern extreme of the AMLR study area, the boundary of the Weddell-Scotia Confluence is encountered, and the temperature minimum disappears. In fact, there is no water <0°C at our survey depths shallower than 750 m.

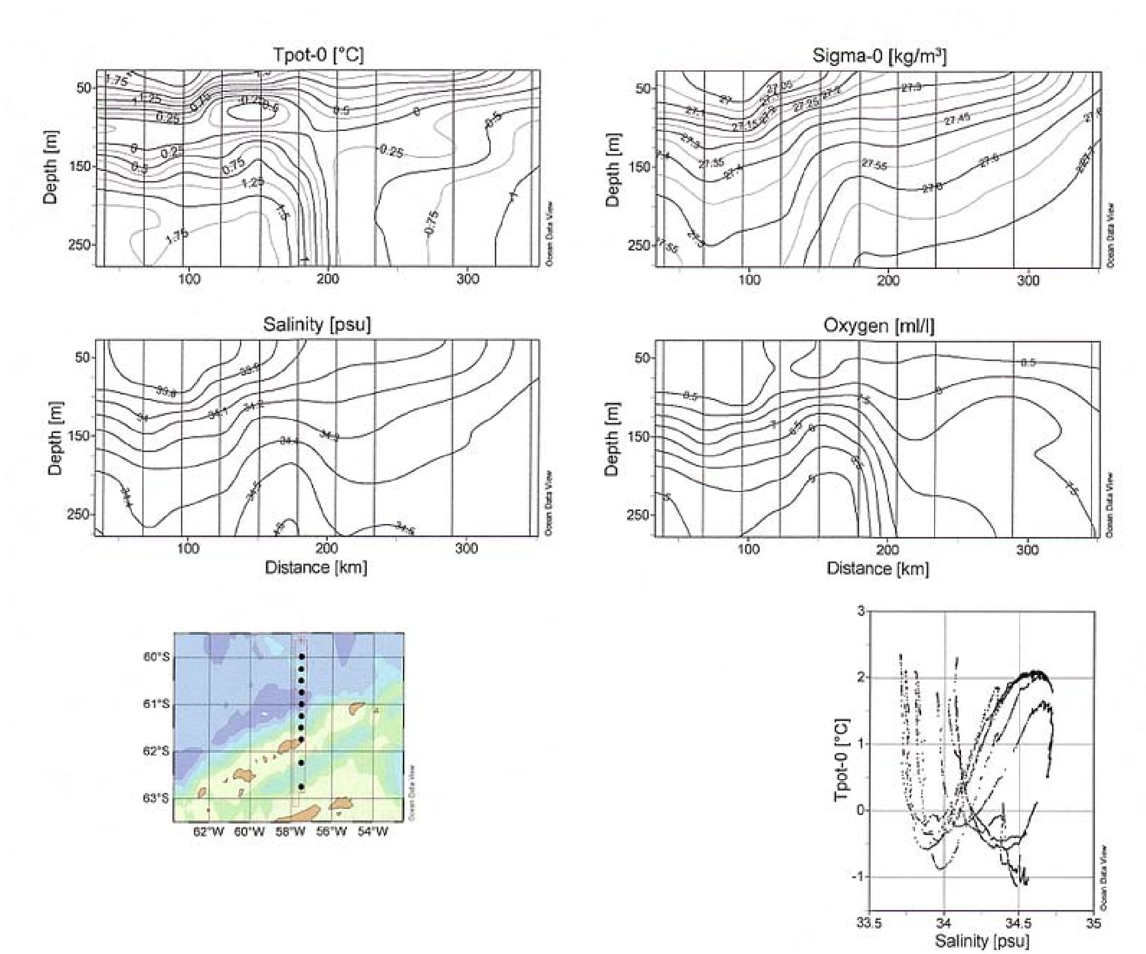

Figure 1. Potential temperature, salinity, dissolved oxygen, and density (Sigma-0) along a section to 250 m over the deep oceanic waters of the AMLR study area. West is to the left of each section panel. Station locations shown in the map, lower right. The T/S curves for stations used in the sections shown in lower right panel. Diagram produced with ODV4.0 software (see text).

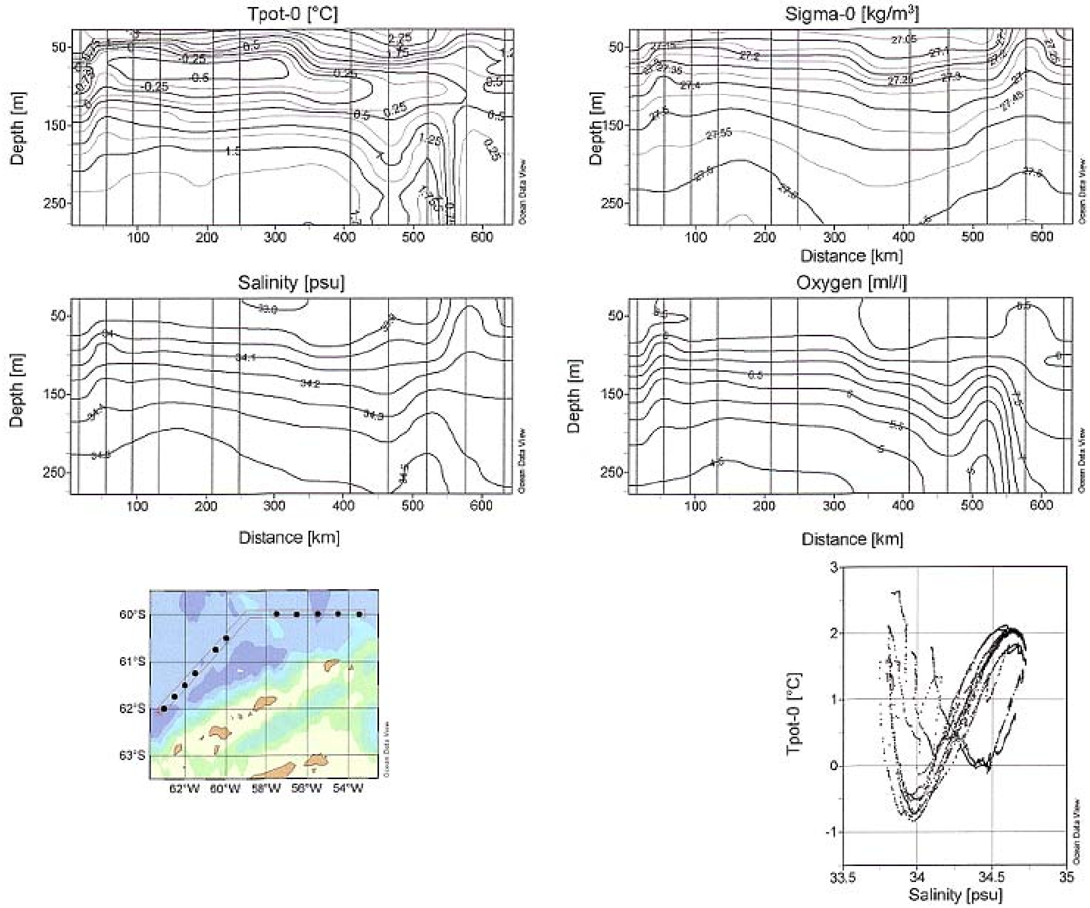

Figure 2. Potential temperature, dissolved oxygen, salinity, and density (Sigma-0) sections along the 57.5°W meridian. North is to the left of each section panel.

We know that certain aspects of the physical oceanography correlate with the biology of the AMLR study area, such as the phytoplankton and nutrient distribution. The hydrography as related to the distribution of other, more mobile organisms, such as krill and other zooplankters, remains more elusive. Loeb et al (1997) demonstrate the importance of sea ice variability to dominance of krill or salp, and during AMLR cruises, we often see a correspondence between the pycnocline and *Myctophid* fish abundance (for example) as revealed in the acoustic profile (Roger Hewitt, personal communication). The general hydrographic characteristics of the upper waters in the AMLR region are similar from year to year. Our investigations target the changes in the surface conditions and subsurface layers of potential importance to the biological regime. Organisms descending vertically in the stably stratified upper 200 m of the water column may experience temperature changes from 4°C to -1.5°C and back to nearly 2°C. This is the layer sampled by the net sampling program (Loeb, in this issue). January 1999 saw cold surface waters and an extensive WW layer. By February and early March, surface waters warmed to typical late summer values of 3.5°C in the Drake Passage while the

WW warmed and eroded, but remained distinct. We are investigating the relationship between the winter sea surface temperatures from satellite observations, and the following summer's WW layer as measured during AMLR cruises.

This work was accomplished under NOAA Contract 50ABNF600015 to the University of Texas at Austin. Chuck Rowe and Andi Wickham-Rowe of the University of Texas Marine Science Institute participated in the cruises and assisted with the data reduction. We are most grateful to Captain Igor Zhelyabovskiy and the crew of *Yuzhmorgeologiya* for their handling of the ship in the difficult fog and ice conditions this year. Valeriy Kazachenok and Andrey Mikhaylov ably assisted the physical oceanography group.

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AMLR program: Seabird research at Cape Shirreff, Livingston Island, Antarctica, 1998-1999

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The second full season of land-based predator studies was conducted by the U.S. Antarctic Marine Living Resources (AMLR) program at its field camp on Cape Shirreff, Livingston Island, Antarctica (62°28'07"S, 60°46'10"W) during the 1998-1999 austral summer. Cape Shirreff is the third site on the Antarctic Peninsula where long-term monitoring of predator populations is being undertaken in support of U.S. participation in the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR). Four scientists were put ashore by the expedition cruise ship *Explorer* on 25 November 1998 with research continuing until camp closure on 26 February 1999. Logistical support and transit back to Punta Arenas, Chile at the end of the season was provided by the AMLR program's chartered research vessel *Yuzhmorgeologiya*. The objectives of the seabird research for the 1998-1999 season were to collect the following predator-monitoring data:

- To estimate chinstrap and gentoo penguin breeding population size (Standard Method A3);
- To band 1000 chinstrap and 200 gentoo penguin chicks for future demography studies (Standard Method A4);
- To determine chinstrap penguin foraging trip durations during the chick rearing stage of the reproductive cycle (Standard Method A5);
- To determine chinstrap and gentoo penguin breeding success (Standard Methods 6a, 6b and 6c);
- To determine chinstrap and gentoo penguin chick weights at fledging (Standard Method 7c);
- To determine chinstrap and gentoo penguin diet composition, meal size, and krill length/frequency distributions via stomach lavage (Standard Methods 8a, 8b and 8c); and
- To determine chinstrap and gentoo penguin breeding chronologies (Standard Method 9).

The Cape Shirreff penguin rookery consists of 30 breeding colonies of penguins: 19 chinstrap penguin (*Pygoscelis antarctica)* colonies, six gentoo penguin (*P. papua)* colonies, and five colonies with both species. Chinstrap and gentoo penguin breeding populations were censused on 30 November 1998, approximately one week following the peak of clutch initiation in both species. All colonies were counted in their entirety according to CCAMLR Standard Methods. The breeding populations in the 1998-1999 season were determined to be 7,581 chinstrap penguin pairs and 830 gentoo penguin pairs. This represents a slight change from the 1997-1998 season when there were 7,617 chinstrap penguin and 810 gentoo penguin breeding pairs, respectively.

Reproductive success was determined by following a sample of 100 banded chinstrap penguin pairs and 60 gentoo pairs from egg laying to crèche formation. Chinstrap penguins hatched 1.54 and fledged 1.27 chicks/pair and had 82% of all hatched chicks survive to fledging. Gentoo penguins had slightly lower reproductive success hatching 1.52 and fledging 1.15 chicks/pair, while 76% of all hatched chicks survived to fledging. Reproductive success of chinstrap penguins was higher and gentoo penguins lower in the 1998-1999 season than in 1997-1998, the first year data were collected at Cape Shirreff. We banded a sample of 1,000 chinstrap and 200 gentoo chicks for future demographic studies. Birds that survive and return to the rookery will be followed throughout their reproductive lives during future seasons.

Chinstrap chick fledging weights were collected between 17 and 24 February 1999 according to Standard Method 7c. The mean fledging weight of 217 chicks captured on the rookery beaches as they were about to depart to sea was 3200 grams (g), compared with mean fledging weights of 3,180g for the 1997-1998 cohort and 3,270g in 1996-1997. "Fledging" weights were also collected for gentoo chicks. Gentoo chicks do not fledge in the classic sense, returning after their first trips to sea to be fed by their parents. Weights were collected at a set date of 85 days past mean clutch initiation for inter-annual comparisons. Assuming a 36-day incubation period, the gentoo chicks were approximately 7 weeks old at the time of weighing, the age at which other *Pygoscelid* penguins fledge. Two hundred chicks were captured and weighed on 14 February 1999 with a mean weight of 4,450g, an increase of 250g from the 1997-1998 season.

Diet samples of chinstrap and gentoo penguins during the chick-rearing phase were initiated on 4 January and continued through 11 February 1999. This study was conducted concurrently with the AMLR program's shipboard survey in January-February 1999. Forty chinstrap and 20 gentoo adults returning from foraging trips to sea were captured at their nest sites and their stomach contents were removed by lavaging before feeding their chicks. We noted the sex of the returning adult, the number of chicks present at the nest, and their approximate ages. Krill (*Euphausia superba*) was present as a prey species in 100% of the samples from both species, while evidence of fish was noted in 18% of chinstrap and 70% of gentoo samples. Most of the fish observed in the chinstrap diets was from otolith evidence, as little fresh fish was found in the stomach contents. Gentoo penguins frequently had fresh fish in their stomachs. We also found semi-digested octopii, squid, and crustaceans (unidentified crab species) in the samples. As in the 1997-1998 season, the length frequency distribution of krill in the penguin's diets during 1998-1999 was dominated by three CCAMLR size classes, which accounted for 95% of all krill in the samples. The strong 3-4 year age class of krill represented in 1997-1998 by size classes between 31 and 45 millimeters (mm) was predominant again in the 1998-1999 season, with the majority of krill shifting up into the 36-40, 41-45 and 46-50mm CCAMLR categories.

We attached 24 radio transmitters to adult chinstrap penguins feeding 2-3 week old chicks on 11 and 12 January and started following their foraging trips on 15 January after the arrival of our remote receiver and data logger from the AMLR research vessel. Data on foraging trip length and frequency were collected through mid-February. As in the 1997-1998 season foraging trips exhibited a bimodal distribution. The two main peaks for trip duration, however, were shorter during the 1998-1999 season with a major peak around 8 hours and a second peak near 14 hours in duration. Generally, the shorter trips began between dawn and noon, with the longer trips beginning in the late afternoon and evening. The majority of the longer (>13 hours) foraging trips included the overnight period. Otolith evidence in the chinstrap diets follows our suggestion from the 1997-1998 season that fish presence may be from the nocturnal foragers and is an important component of adult chinstrap penguin diets. In addition to the radio transmitters, we deployed 7 satellite-linked transmitters (PTT tags) on chinstrap adults during the chick-rearing phase to determine foraging location. Instruments were epoxied on the penguins and remained on for 7-10 days and then retrieved and re-deployed on other adults. Preliminary analysis from 10 deployments revealed that most chinstrap penguin adults are foraging over the continental shelf within 20 kilometers of Cape Shirreff.

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