Palmer LTER: Overview of krill acoustic studies and results from the Antarctic Peninsula grid

CATHY M. LASCARA *and* EILEEN E. HOFMANN, *Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, Virginia 23529*
ROBIN M. ROSS *and* LANGDON B. QUETIN, *Marine Science Institute, University of California, Santa Barbara, California 93106*

Several research programs [for example, Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) and Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)] have shown that bioacoustics is an effective tool for quantitatively mapping the abundance of antarctic krill (*Euphausia superba*). The Palmer long-term ecological research (LTER) program has included acoustical measurements as part of the multidisciplinary sampling conducted at stations within the large-scale peninsula grid, which covers a coastal region [approximately 900 kilometers (km) by 200 km] west of the Antarctic Peninsula (Waters and Smith 1992). The acoustic information is used to characterize the spatial and temporal distribution of antarctic krill, which is one of the key species of the LTER program (Ross and Quetin 1992).

This overview describes the methods of collection and postprocessing of acoustical measurements and presents preliminary results from the 1993 field season. Replicate acoustic tows (two to three) are made over short distances (1–2 km) centered on each grid station and are concurrent with zooplankton or nekton net tows. This approach provides acoustic sampling that is coincident with other data collected at the stations, for example, hydrographic and primary production measurements, and allows local and regional variability in krill biomass and distribution to be correlated with other habitat characteristics.

Echo integration estimates of volume backscattering are obtained with a Biosonics echo sounder connected to a towed downward-looking 120-kilohertz (kHz) dual-beam transducer. The voltage returns are binned into 2-meter (m) intervals over a depth range of 6–190 m and are integrated over 3 pings, which gives a horizontal resolution of 2–10 m depending on ship speed. The volume-scattering data [in square meters per cubic meter (m^2 m^{-3})] are then converted to krill biomass [in grams per cubic meter (g m^{-3})] using estimates of krill target strength (TS). The following TS-weight relationship, adopted by the LTER, is based upon the empirically derived regression equation of Wiebe et al. (1990) as modified by Greene et al. (1991) for 120 kHz:

$$TS_{120} = 10 \log \sigma_{bs} = -98.64 + 10.28 \log WW \qquad (1)$$

where σ_{bs} is the weight specific backscattering cross section [in square meters per milligram (m^2 mg^{-1})], WW is krill wet weight (mg), and TS is in decibels (dB).

Because krill length-weight (L-W) relationships vary with season and year, a L-W regression is determined for each cruise. Length-frequency data from net samples are converted to a weight-frequency distribution using these L-W regressions; this conversion allows krill biomass estimates to be made from the TS-weight equation. The resultant two-dimensional maps of krill biomass are then analyzed to determine patch characteristics, to compute average krill biomass (g m^{-2}, integrated vertically from 6–190 m) for a given spatial scale, and to identify patterns of swarm distribution.

For our purposes, a patch or swarm is defined to be a contiguous group of cells in the acoustic matrix with biomass values exceeding a minimum threshold of 0.5 g m^{-3}. Patch-finding software (details presented in Nero and Magnuson 1989) is used to quantify the following internal and external parameters of each krill swarm: horizontal and vertical dimensions; cross-sectional area; middepth of swarm from sea surface; mean and peak biomass; variance and horizontal and vertical grain of biomass values; and distance and angle to nearest neighbor.

During the 1993 field season, two cruises were conducted within the Antarctic Peninsula grid. Acoustical measurements were made at 39 stations during the summer (January and February) cruise and at over 80 stations during the fall (March to May) cruise (see figures 1 and 2 in Quetin, Ross, and Baker *Antarctic Journal*, in this issue). The remainder of this article will focus on krill distributions observed acoustically during the summer cruise (transect lines 200–500).

Over 1,500 swarms were identified from 98 acoustic tows, totaling 150 linear km. The horizontal dimension of these swarms ranged from 4 m to almost 1 km with a median value of 15 m (figure 1*A*); the vertical dimension varied between 4 and 76 m, with a median value of 6 m (figure 1*B*). Over half of the swarms were positioned shallower than 40 m depth from the surface, but some swarms ranged as deep as 170 m (figure 1*D*). The areal extent (figure 1*C*) of the swarms was generally smaller than 500 m^2 but values as high as 10^4 m^2 were observed. The mean swarm biomass ranged from 1 to 635 g m^{-3} but values less than 30 g m^{-3} predominated (figure 1*E*). Multiplying the mean biomass of a swarm by its areal extent gives the total biomass of the swarm in kg m^{-1}. No assumptions were made concerning the extent of the unknown third dimension of the swarms; total biomass ranged from less than 1 to almost 300 kg m^{-1} (figure 1*F*). The range and median values of krill swarm parameters observed during this study are very similar to results obtained off the Antarctic Peninsula during the BIOMASS program (Witek, Kalinowski, and Grelowski 1988, pp. 237–244) and for recent acoustic studies conducted by the European *Polarstern* Study (EPOS) in the northern Weddell Sea (Sprong and Schalk 1992).

Krill biomass was vertically integrated (from 6–190 m) for each record (3 pings) in an acoustic profile, and records from replicate acoustic tows were pooled to compute the mean krill biomass (g m^{-2}) for each station (figure 2). In general, krill were found throughout the entire region (except stations 600.200 and 600.100) with mean station biomass values ranging from 0 to 460 g m^{-2}. Except for the 500 line, several of the inner stations along each transect line were observed to have biomass values higher than 100 g m^{-2}. Biomass exceeding 300 g m^{-2} was observed for two stations: 200.040 and 400.080. For both of these stations, large, dense aggregations were found extending over hundreds of meters horizontally and 50 m vertically.

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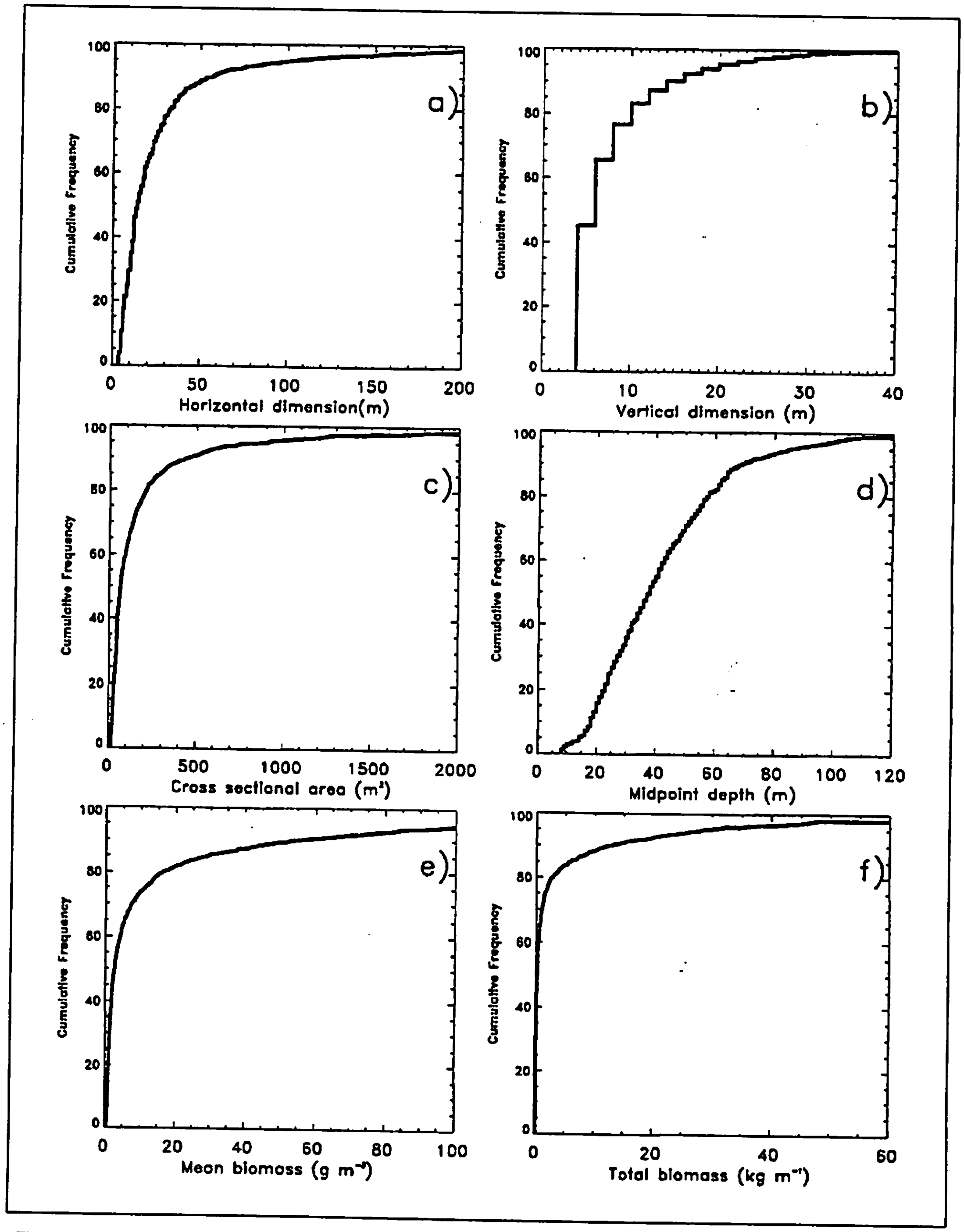

Figure 1. Cumulative frequency distributions of *A* horizontal dimension (m), *B* vertical dimension (m), *C* area (m^2), *D* midpoint of depth from surface (m), *E* mean biomass (g m^{-3}), and *F* total biomass (kg m^{-1}) of swarms (n=1,508) observed acoustically during austral summer 1993 off the Antarctic Peninsula.

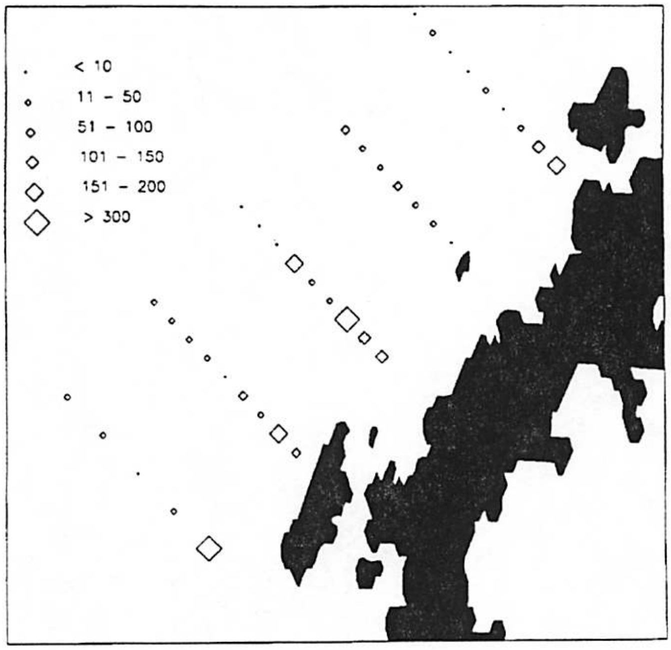

Figure 2. Mean krill biomass (g m-2) detected acoustically at stations located 20 km apart along transect lines (100 km spacing) off the Antarctic Peninsula during austral summer 1993.

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Palmer LTER: Krill distribution and biomass within coastal waters near Palmer Station

CATHY M. LASCARA, *Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, Virginia 23529*
LANGDON B. QUETIN *and* ROBIN M. ROSS, *Marine Science Institute, University of California, Santa Barbara, California 93106*

The annual Palmer long-term ecological research (LTER) cruise comprised three phases in 1993 (Quetin, Ross, and Baker, *Antarctic Journal*, in this issue). Phase II (18–25 January) was an intensive multidisciplinary sampling effort designed to characterize hydrographic and bio-optical properties and the distributions of phytoplankton, antarctic krill (*Euphausia superba*), antarctic silverfish (*Pleuragramma antarcticum*), and seabirds within coastal waters south of Anvers Island. These waters encompass the summer foraging grounds for Adélie penguins (*Pygoscelis adeliae*) and south polar skuas (*Catharacta maccormicki*) found nesting near Palmer Station. The objectives of phase II were to establish biological and physical linkages within the ecosystem and to investigate the trophodynamic relationships of representative species selected by the Palmer LTER (Ross and Quetin 1992). The sampling scale was established to complement both the fine-resolution sampling conducted within the Zodiac boating limits of Palmer Station and the coarser resolution sampling conducted further offshore and along the Antarctic Peninsula.

A small-scale subgrid was defined within the LTER peninsula grid system (Waters and Smith 1992) with transect lines spaced 10 kilometers (km) apart and extending about 60 km offshore from Palmer Basin (figure 1). Sampling along this grid was implemented twice within a 1-week period in two different modes. First, to provide a nearly synoptic view of the region, the grid was traveled at a constant ship speed of 6 knots. Along-track sampling included continuous surface conductivity-temperature-depth (CTD) measurements, expendable bathythermograph (XBT) drops every 10 km, and surface chlorophyll and nutrient samples every 5 km. In addition, a 6-km acoustic tow centered within each 10-km segment of the transect grid was made, coincident with an along-track census of all seabirds. This first survey will be referred to as the fast survey because all sampling was conducted underway and the entire grid (280 linear km) was completed in 30 hours.

To allow for more detailed studies of several biological and physical processes the grid was surveyed a second time over a $3\frac{1}{2}$-day period, during which the ship occupied select-