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Distribution, abundance and vertical migration pattern of krill – *Euphausia superba* Dana at fishing area 58 of the Indian Ocean sector of Southern Ocean

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The First Indian Antarctic Krill Expedition (FIKEX) was an attempt to examine and obtain first-hand information pertaining to distribution, abundance and vertical migration pattern of krill – *Euphausia superba* Dana at fishing area 58 of the Indian Ocean sector of Southern Ocean. It has been ascertained that krill migrations occur between sea surface and a depth of about 100 m. Availability of food is the key factor affecting both seasonal and annual changes, and leads to krill migration. Under good feeding conditions the amplitude is maximal, and the migration cycle approaches 24 h. Adult individuals exhibit 24 h migration, whereas juveniles show lower migration, and their submergence is shallower. Water stratification may also affect krill distribution in the water column, and in certain conditions may lead to limitation of migration range.

Keywords: Antarctic krill, FIKEX, Indian Ocean, migration, Southern Ocean.

DENSE concentration, large biomass and industrial importance of Antarctic krill, *Euphausia superba* Dana play a special role in the Antarctic ecosystem. The krill has long been regarded as a key organism in the Antarctic food chain[1–3]. High krill concentrations are found in areas of intensive circulation of water mass, such as in the West Antarctic, mainly in the vicinity of the Antarctic Peninsula; the Scotia Sea; the northern part of the Weddell Sea and also close to South Georgia[1,4–9]. It occurs around the Antarctic continent and shelf waters in the south, up to the Polar Front in the north.

Except for fragmentary information regarding harvesting of finfish in the sub-Antarctic region of Kerguelen Islands, Ob and Lena sea mounts, a detailed account of exploitable krill and other living resources of (fishing area 58 according to the CCAMLR demarcations, the proposed survey area will fall in the ENDERBY–WILKES DIVISION IV; Division 58.4.4) Indian Ocean sector of Southern Ocean is not available. The present cruise was primarily aimed at studying the distribution, abundance and migration. However, the continuous hydroacoustic records yielded a wealth of field data on distribution of *E. superba* in the preferred area and periods of time. In 1995, FIKEX (First Indian Antarctic Krill Expedition) was organized to ob-

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tain first-hand information pertaining to factors affecting viability of commercial harvest and post-harvest operations.

The scientific objectives set for the expedition and data were collected under the BIOMASS programme[10]. The expedition was set during the austral summer (December 1995 to March 1996) cruise of FORV *Sagar Sampada* to the Antarctic continent. The area covered was between lat 57°53′–61°13′S and long 31°40′–36°31′E (Figure 1).

Fishing operations were conducted using a 49.5 m experimental krill trawl of Danish origin. Krill trawling operations were conducted at the above-mentioned locations (Figure 1). SIMARD Integrated Trawl Information (ITI)

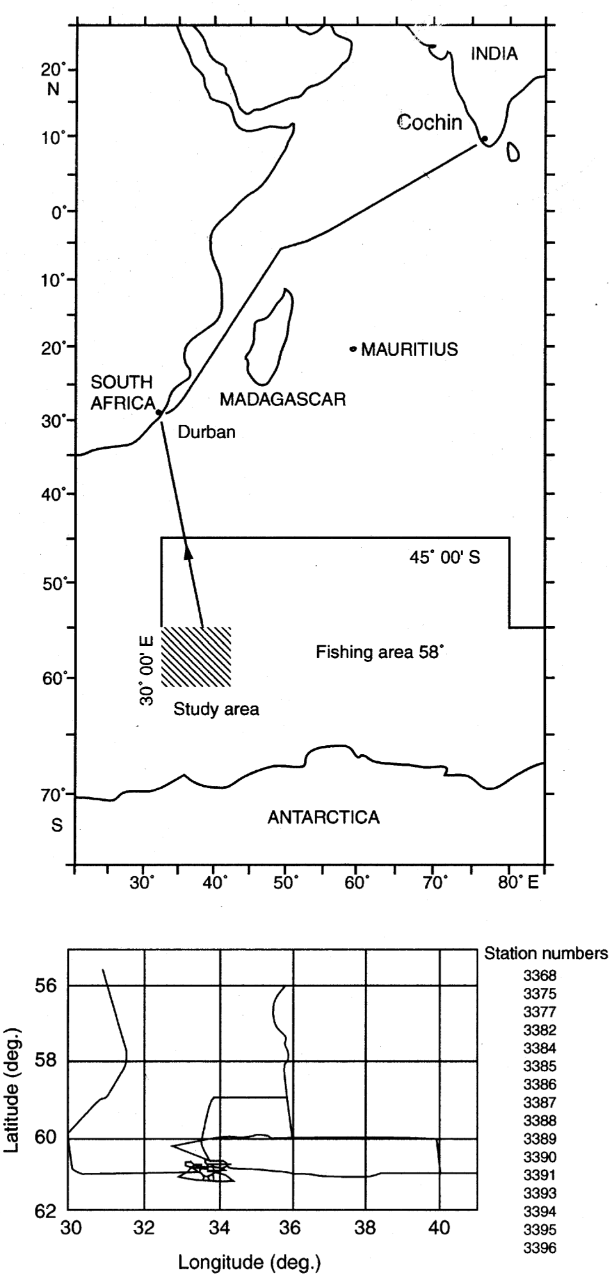

Figure 1. FIKEX cruise study area, cruise track and sampling stations.

system was used for calibration of the trawl and aimed trawling after location of krill swarms by echosounding. A typical echogram representing krill swarm is given in Figure 2.

The four equal panel, two-bridle krill trawl of 49.5 m headline (Cosmos Trawl, Hirtshals, Denmark) was of lighter construction with outer netting and nylon inner lining, having a cod end mesh size of 10 mm stretched. The gear was rigged with 40 floats of 270 mm size along the headline and about 80 kg of link chain along the foot rope. Double sweeps of 98 m, 350 kg bunched chain depressors and 5 m^2 suberkrub otter boards were used for the operations. Evaluation of operational performance using ITI system at a towing speed of 2 knots and warp of 300 m showed a vertical opening of 19 m (38%), distance between otter boards of 32 m with an estimated wing-end spread of 46% and depth of operation of 108 m. This krill midwater trawl was operated at all 16 stations.

Acoustic equipment, such as sound transmitters and receivers are some of the major tools in underwater studies. Echosounding provides a more accurate and effective research tool for studying migrations than trawl net-based assessments. The important advantage is that acoustic measurements are performed continuously along the track of the vessel and enable to cover large areas within comparatively short periods of time (a 10 knots speed during measurements is commonly accepted), while net measurements are done at spatially dispersed points, which reduces the probability of detecting krill swarms distributed in patches.

SIMRAD 100 (49 kHz) with colour display CF 100 and EK 400 (120 kHz) echosounders was used for echolocation of krill swarms. Krill concentration and resource assessments were performed using standard echo integrator method. The calibrated SIMRAD EK 400 echosounder working at a frequency of 120 kHz and connected to QD echo integrator was used. The echo signal was integrated in 1 n mile intervals within the integration depth range from 5 to 125 m in eight layers, each of 15 m thick. The echosounder was operated with the basic scale range of 200 m (ping rate: 61–63 pings per minute). The integrated echo signal was corrected for spreading and attenuation losses at depths above the echo-sounder TVG range, i.e. from 107 to 125 m. The upper 5–9 m was removed to avoid summation of echoes from subsurface bubble layer.

Additional envelopes of echo signal were collected using an analogue digital converter (ADC) system, visualized on a colour monitor for on-line identification purposes and fed into a computer. The data acquisition system chosen for this project is based on the ADC with a dynamic range 12 bits comparable with the QD system. The amplitude of the echo-sequences of the signal envelope was recorded with a sampling rate of 3.3–3.5 kHz, which enables 0.25 m vertical resolution.

Transect of the acoustical observations and area of the cruise from 25 January to 14 February 1996 are given in

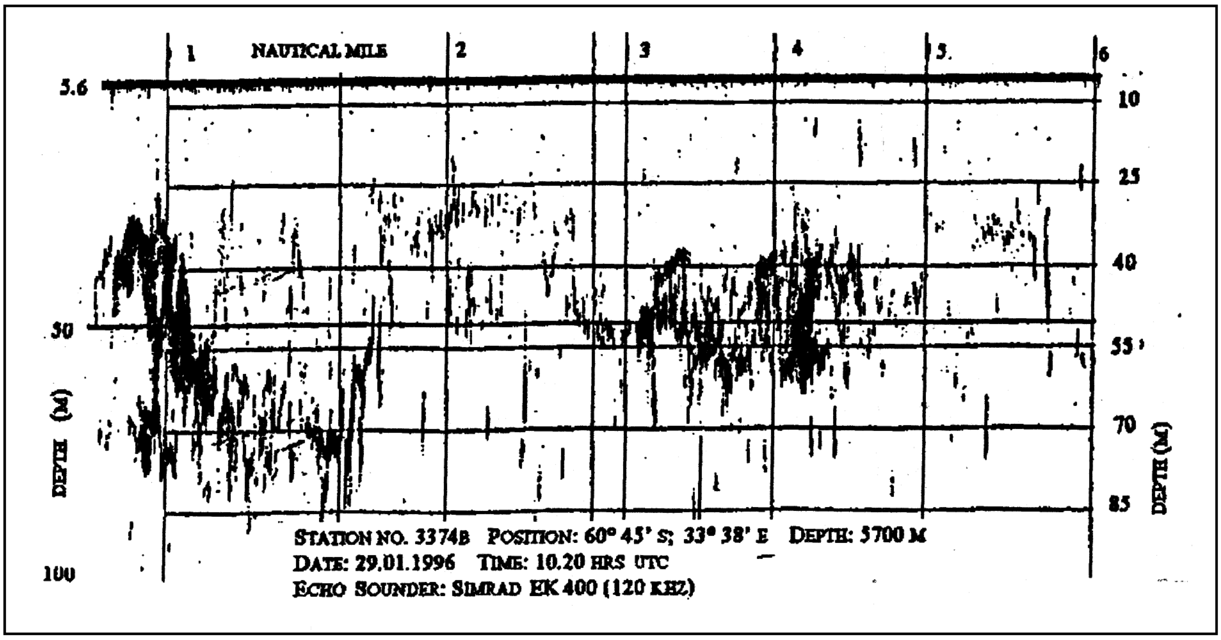

Figure 2. Echogram representing krill swarm.

Figure 1. The coordinates of the starting point of observations (echogram records only) were 55°37′S lat and 31°31′E long. Acoustical observations were concluded at 54°37′S lat and 34°59′E long.

The process of echo integration began on 27 January 1996 at 07.35 h UTC and at the position 60°58′S lat and 32°20′E long. It concluded on 13 February 1996 at 17.50 h UTC at 56°32′S lat and 35°37′E long, with gaps caused by non-availability of computer and drifting of the vessel. Total length of the echo integrator track was 1097 n mile and total duration of registration was 225 h.

The mean target strength (TS) of krill in the area was calculated using data from krill samples taken by IKMT or Krill Midwater Trawl on the basis of a new formula[11]:

$$TS = 34.85 \log I - 127.45 \text{ [dB]}, \quad (1)$$

where I is the mean weighted length of krill in mm for all areas.

The relation between the mean backscattering strength obtained from QD (SV), TS and number of krill in unit volume (n) is of the form

$$SV = 10 \log (n) + TS. \quad (2)$$

Equations used in analysis in the simplest form when krill are homogenous are as follows:

$$\bar{\rho} - 10^{0.1[SV - TS + 10 \log (\ddot{A}R)]}, \quad (3)$$

where $\bar{\rho}$ is the density of krill, i.e. number of individuals in the investigated water column under surface of 1 m^2 and ÄR the thickness of water column under acoustical investigation taken as the range of echointegrator.

From the density in terms of numbers thus estimated (eq. (3)), mean biomass per 1 nm track and biomass density B in g m^{-2} or t km^{-2} were estimated on the basis of the relationship:

$$w - 0.0018.1^{3.38},$$

where w is the wet weight of individuals in mg.

Numerical programs were developed for post-processing of the EK-400 echosounder data, and densities of biomass of krill for layers and in the entire water columns along the transect were calculated. Data from a rectangle where substantial catches were possible, were extracted for independent processing.

The mean density of krill averaged along the 1 nm interval, for the hydroacoustic transect along 60 and 61° parallels and along 40° meridian was 0.58 t km^{-2} in 'optimistic' variant (all recognizable aggregations are summed) and 0.44 t km^{-2} (only data when krill biomass density exceed 0.64 g m^{-2} are taken into account) in 'pessimistic' variant. The value of about 0.64 t km^{-2} is the lowest density observed in currently exploited areas (for a comparable area in the region of Elephant Island the registered mean density of krill is 19 t km^{-2}, ranging from 0.46 to 36.5 t km^{-2}). The maximum value of the mean density of krill biomass over a distance of 1 nm was equal to 16.9 t km^{-2}. Average of absolute deviations of krill biomass densities from the mean value along the above-mentioned transects was 0.64, which indicates a high degree of patchiness in distribution. The patchiness in distribution of biomass is evident from Figure 3 *a*.

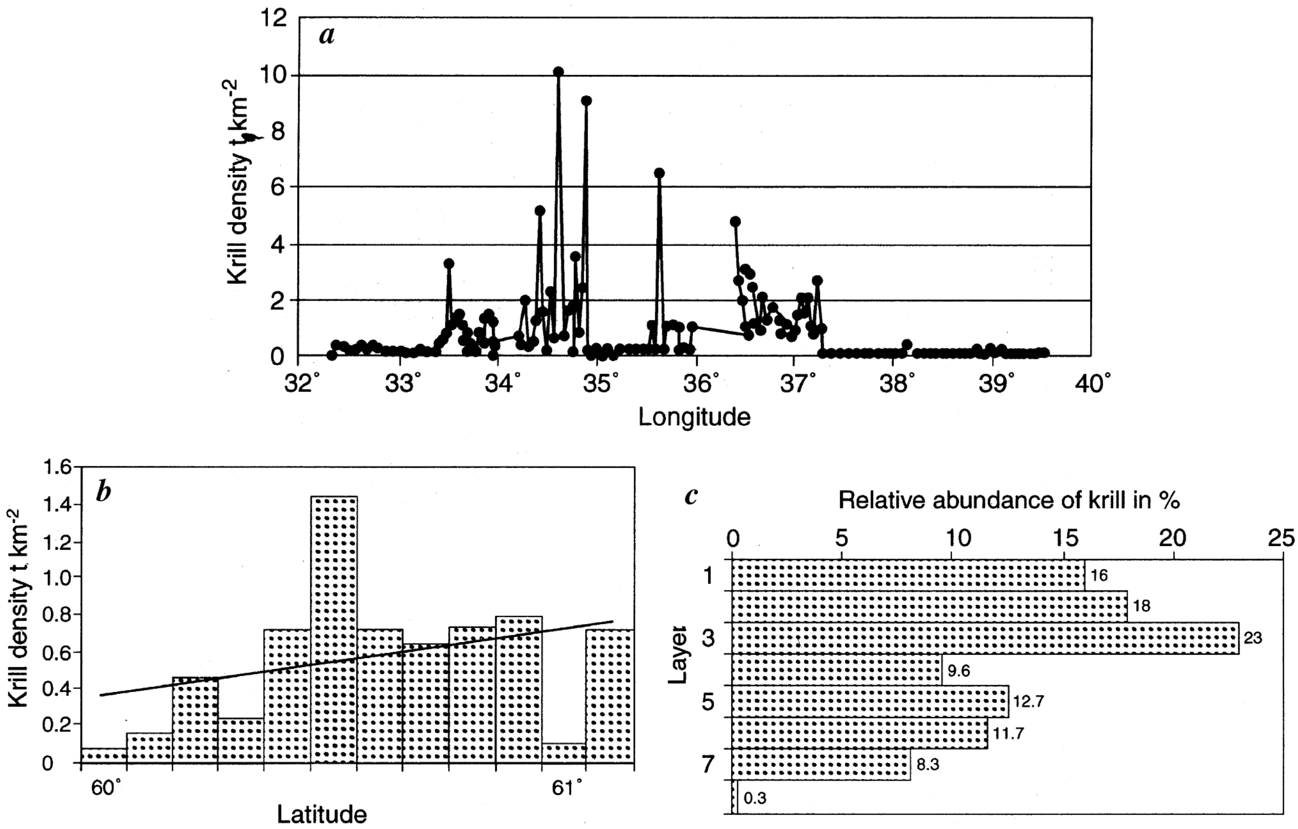

Figure 3. ***a***, Krill biomass density distribution along 61°S lat. ***b***, Trends in krill density distribution in sub-area between lat 60°00′ and 61°15′S lat. ***c***, Relative vertical distribution of krill biomass in sub-area between lat 60°00′ and 61°15′S (layer thickness = 15 m).

Preliminary acoustic survey suggested that the krill were more concentrated in one particular area and distribution in the rest of the areas under investigation was less amenable to commercial exploitation. The total krill biomass estimated for this rectangular area of 11,500 km^2, defined by the co-ordinates 60°00′S lat; 32°65′E long and 61°15′S lat; 34°23′E long, was equal to 10,050 t. In this particular area, the mean density was equal to 0.56 t km^{-2}. The krill density distribution tended to increase from 60°S parallel southwards (Figure 3 *b*). Krill biomass was maximum in the depth layer 35–50 m in this area. Relative biomass density vs depth is represented in Figure 3 *c*. The relative biomass density percentage values were calculated using the formula

$$\frac{m_i}{\sum_i m_i} 100,$$

where m_i is the total mass of krill in the sub-area in the *i*th layer (Figure 3 *c*).

The presence of krill was observed from the upper limit of the echo-sounding depth to 190 m. The major proportion of krill was concentrated up to 70 m.

All forms of krill aggregations were registered: 'super-swams', dense regular swarms, loosely defined layers, very small patches and thin layers probably mixed with salps. In contrast to earlier reports[2,12] of dispersal of swarms during night hours, well-defined regular swarms were detected during night.

Due to strong currents in the investigated region and the tendency of krill to move at about the same speed, the abundance of krill in this particular area tended to vary on a day-to-day, if not hour-by-hour basis.

A total catch of 12,470 kg was landed during the trawling operations. The catch comprised of (in kg) Antarctic krill (*Euphausia superba*) 5637, krill juveniles 12, salps 6738, jellyfish 35, lanternfish 2.2, squid 5.7 and other fishes 2.7. Krill constituted 46% of the total catch while salps constituted 54%. Average catch, for krill worked out to be 354.6 kg haul^{-1}. A good catch (>1000 kg haul^{-1}) was obtained between lat 60°40′–61°13′S and long 33°34′–34°14′E.

Our analyses show that vertical krill migrations are a common phenomenon, although the amplitude of migration is relatively small. Depth distributions of krill aggregated in swarms were analysed for the sub-area. The relative abundance of biomass for the open sea area is 57% at 0–30 m and 43% above 30 m. Major proportion of krill was concentrated up to 70 m. The mean depth of krill swarm results is closer to those reported by Daly and Macaulay[12], and Godlewska *et al.*[13] and did not differ significantly.

The spatial distribution of krill and its abundance along the ship track were highly variable. Various types of aggregation were present in large, dense concentrations called superswarms – in zone 58 of the Southern Indian Ocean at few stations during the present observation. The same trend has been observed in the region of Elephant Island; compact swarms, tens to hundreds metres long – mainly close to the South Orkneys; irregular forms, loosely defined layers and small swarms were frequently present[14].

Maximal surface density of 2400 kg was recorded at station 3394. The major proportion of krill concentration was up to 70 m layers. This indicates preferably a good feeding ground[15]. At good feeding condition the amplitude is maximal, and the migration cycle approaches 24 h. When feed is scarce, the migration cycle is shortened to 12 h, and amplitude decreases[16]. The same trend has been observed in the present study. The maximum value of mean density of krill biomass on a distance of 1 nm was equal to 16.9 $t\,km^{-2}$. A value of about 0.64 $t\,km^{-2}$ is the lowest density observed in currently exploited areas and is comparable to the area in the region of Elephant Island the registered mean density of 19 $t\,km^{-2}$, ranging from 0.46 to 36.5 $t\,km^{-2}$. Average of absolute deviations of krill biomass densities from the mean value along the above-mentioned transects was equal to 0.64 $t\,km^{-2}$, which indicates a high degree of patchiness in distribution.

To examine the influence on krill distribution with a degree-wise distance from 60 to 61°, the values of volume backscattering strength were regressed against the distance along all the straight segments of the track from ice edge to open water. The demarcated line shows (Figure 3 *b*) a clear trend of increment of abundance with distance. These results are in accordance with earlier findings[12] that the acoustic biomass distribution generally had lowest abundance in pack ice and highest in open water of Antarctica. In 1988, Siegel[17] observed that usual conditions of krill abundance increase after retreat of the pack ice and the krill move to open waters in spring. These seasonal migrations of krill may lead to the observed trend in abundance distribution as well as to the separation of large and small krill (the bigger ones may swim much faster and cover longer distance), which was observed in the present study; the results are in agreement with previous reports[7,8,18,19]. However, migration alone does not explain increase in biomass. At any given point of time, the presence of krill at any given depth is a result of the action of various forces, such as passive movement with water current, eddies or internal waves, and active locomotion of individuals. An assumption is made that the location of krill at any given moment does not depend on its origin. The location is rather determined by environmental conditions such as light, food availability, water column stratification, and also by krill characteristics at the individual level, i.e. stage of development, sex and physiological conditions. The open circulation of water may develop and cause large concentrations of krill. Our understanding of these factors is still insufficient, and many problems await solutions.

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