FIBEX–AN INTERNATIONAL SURVEY IN THE SOUTHERN OCEAN: REVIEW AND OUTLOOK

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Abstract: The first international experiment under the framework of the Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) aimed at quantitative estimates of krill (*Euphausia superba*) in four areas of the Southern Ocean: Western Atlantic Sector, Western and Eastern Indian Ocean Sectors, two transects in the Western Pacific Sector.

The method for the quantitative estimation of krill abundance by means of stratified randomized echo survey sections run by several research vessels simultaneously required a high degree of calibration and co-ordination. Catch data were needed for the interpretation of the echo signals. Environmental data were required in order to understand the distribution and abundance of krill and of its key food organisms as well as its predators.

The seagoing activities in January to March 1981 involved 12 vessels of 10 countries and produced the largest amount of data ever collected during an international co-operative study in biological oceanography.

The compilation of the data sets and their transfer into a centralized computer system was the next step, carried out during an international post-FIBEX Data Workshop in September/October 1981.

The Workshop produced the first estimates of krill abundance in four major areas of the Southern Ocean, also giving figures of variance.

Most important for the understanding of the system will be the further combination of krill data with environmental data and other biological observations.

1. Introduction

Amongst the great variety of organisms endemic in the Southern Ocean, krill (*Euphausia superba*) plays a predominant role both in nature and in marine science, being the staple food of many whales, seals, bird and fish, the target species of a growing fishing industry and the subject of an increasing number of scientific studies following the pioneering work of the DISCOVERY-expeditions in the 1920's and 1930's. The concern about possible impact of krill fisheries on the Antarctic marine ecosystem was one of the factors which led to the establishment of the international programme of BIOMASS (Biological Investigations of Marine Antarctic Systems and Stocks) in 1976 under the auspices of SCAR (Scientific Committee on Antarctic Research) and SCOR (Scientific Committee on Oceanic Research) with the assistance of FAO (UN Food and Agriculture Organization) and IABO (International Association for Biological Oceanography). The goals of BIOMASS, however, go much beyond a study of krill *per se*.

Its objectives formulated in 1976 and slightly revised in 1982 read as follows:

"To gain a deeper understanding of the structure and dynamic functioning of the Antarctic marine ecosystem as a basis for the management of actual and potential living resources BIOMASS wants to contribute to a biological understanding of the Southern Ocean and to assist in the development of an ecologically sound strategy for the exploitation of the living resources and for the conservation of Antarctic biota."

BIOMASS consists of various types of activities, including international multiship surveys. 1) Seagoing experiments on a national and international scale. 2) Routine marine programmes, *e. g.* the annual fishery studies by Japan, bird census, oceanographic surveys and recordings. 3) Shore based studies, *e. g.* ecophysiology of krill and its predators, rookery studies. 4) Modelling of certain compartments of the Antarctic ecosystem.

The need for international co-ordination and co-operation was particularly stressed in the fields of survey methodology and data handling. For this purpose as well as for evaluating the results of the various exercises, several international workshops were scheduled by the Group of Specialists.

Various kinds of publications and symposia will provide platforms for the presentation and discussion of the results.

The SCAR "Group of Specialists on the Living Resources of the Southern Ocean" planned two major international surveys, named First and Second International BIOMASS Experiment (FIBEX 1980/81 and SIBEX 1983/84—now extended to 1985). The present paper will concentrate on the concept of FIBEX as it was developed over the planning period. The paper will review some of the work carried out in February 1981, which was evaluated during an international data workshop in Hamburg, September 1981 and at the BIOMASS Colloquium, Tokyo, May 1982. The paper will look at FIBEX as an attempt to develop and test the methodology for estimating the biomass of krill in parts of the Southern Ocean together with certain environmental factors (oceanography, phytoplankton, zooplankton, fish and birds) and furthermore as the first large-scale international co-operative study in biological oceanography in the Southern Ocean.

2. The Planning Phase

The planning of FIBEX started at the meeting of the Group of Specialists on the Living Resources of the Southern Ocean in Woods Hole, 1976, where the major objective of FIBEX was directed to the question: "how much krill is there in the Antarctic?" Furthermore, in view of the patchy distribution of krill it was also asked: "how much of the total stock of krill occurs in swarms and what is the structure of krill swarms?" The second question was of particular relevance to any census of krill by acoustic methods which only pick up krill swarms but no individual krill scattered over the water column. Therefore acoustic data will be underestimates of total stock size in cases when parts of the population are not concentrated in swarms. Target strength of krill in the echo recordings depend on the orientation of animals in the water column, moulting stage affecting carapace density, and the calibration of the echo sounder. Other sources of underestimates in acoustic surveys include the ship factor: near surface swarms are not picked up by the echo sounder if they stay shallower than the transducer and the deeper parts of very dense and thick swarms will be acoustically shadowed by the acoustic mass above.

In spite of those shortcomings the Group of Specialists recommended echo surveys as the most effective means for estimating of overall krill abundance. It was recognized during informal discussions in 1977 that the ships' time needed to cover the entire Southern Ocean would by far exceed the pool of vessels available and suitable for a FIBEX co-ordinated echo survey.

The plans for FIBEX were further developed at the meetings of the Group of Specialists in Kiel 1978 and Krakow 1979. The BIOMASS Technical Group on Programme Implementation and Co-ordination met in Buenos Aires 1979 for the planning of FIBEX. In three essays by MATHISEN, TRANTER and HEMPEL its objectives and limitations were looked at from different angles: It was agreed that the study of the abundance and distribution of krill would be the primary objective. MATHISEN felt that methodology was still not adequate to answer the central question in quantitative terms. HEMPEL pointed to the need to compare the data of krill distribution as obtained by FIBEX with the results of earlier years, particularly to work up the old DISCOVERY-data on a year to year basis. TRANTER wanted FIBEX to provide as many opportunities as possible for studying the Antarctic ecosystem, in particular the trophodynamics of krill and its position in the food web.

It was not before the second meeting of the Technical Group in Dammarie-les-Lys in June 1980, *i.e.* only 7 months prior to the expedition, that the following objectives of FIBEX were finally agreed upon:

1) To study the methodology for assessing the abundance of the total krill population. This should include quantitative echo integration and its calibration, survey design and statistical analysis.

2) To describe the distribution of krill in four selected areas (SW-Atlantic, two Indian Ocean Sectors, two meridional sections in the Pacific Ocean).

3) To measure the abundance of krill in the SW-Atlantic Sector of the Southern Ocean.

Already in Buenos Aires it had been decided that FIBEX should consist basically of two parts: 1) A krill census by echo survey plus some net hauls to be carried out simultaneously by as many vessels as possible and 2) studies of large krill swarms.

Parallel to the krill census a limited amount of environmental data, particularly on physical oceanography had to be obtained by every FIBEX vessel. In addition most scientific groups worked on supplementary programmes.

The BIOMASS Working Group on krill abundance and an ad hoc group on survey design developed criteria and plans for a 20–30 days' acoustic survey carried out on a co-ordinated base by as many vessels as possible. For the survey design conflicting views were expressed, to what extent one should concentrate on areas where krill is supposed to be abundant, *i.e.* more than 90% of the krill population might concentrate in less than 20% of the Southern Ocean. Particularly soviet scientists felt confident in their knowledge about the general distribution of krill in relation to water masses and bathymetry. Further the question on randomized cruise tracks *vs.* regularly spaced tracks was also subject of heated discussions.

Finally it was decided to work on a survey design of double stratified sampling: only those survey areas were chosen which are known for the presence of krill in great numbers. Those areas might be expanded in case much krill is found near the edge. During *phase I* the entire study area should be covered by a wide grid of echo tracks. In *phase II* the smaller area of large krill abundance area should be covered on a less extended but narrower grid. After lengthy discussions track distribution was randomized to a certain extent for statistical reasons.

In the *Western Atlantic Sector* the likely area of krill distribution was subdivided into 7 regions allocating each region to one of the participating vessels. In doing so national preferences for certain regions were taken into account, *e.g.* Britain's interest in the South Georgia region. The average spacing of the *ca.* 6 meridional tracks of phase I was *ca.* 50 miles, while it was hoped that during the second phase the tracks might be much shortened according to the actual distribution of krill. In that case number of transects could be at least doubled and hence average distance between transects be reduced to 20–25 miles. Every day each vessel should run its echo integrator over a distance of 150–180 miles at a speed of 8–10 knots.

Net sampling for krill should provide some sort of check for the echo sounding. Aimed horizontal and/or oblique tows in krill concentrations as well as blind hauls in areas of no echo traces were recommended. At least one blind haul every noon had to carried out. Those net samples would also give an indication of the zooplankton within and outside areas of major krill concentrations.

At local noon and midnight a CTD-station should be worked for temperature profiles of the upper 200–400 m taking also water samples for nutrients, chlorophyll and phytoplankton. Light penetration should be measured at the noon station. Sea bird observations were recommended according to the international observation scheme.

Originally the problem of intercalibration of echo sounding equipment had been stressed, particularly by soviet scientists. However, actual intercalibration at sea was limited to a one day exercise in Bransfield Strait carried out by the research vessels ITSUMI (Chile), ODISSEE (USSR) and WALTHER HERWIG (FRG).

For the *Indian Ocean Sector* information on krill distribution prior to FIBEX was much poorer than for the Western Atlantic Sector. Therefore it was decided to cover a wider area, in spite of the smaller number of vessels.

In contrast to the work in the Atlantic and Pacific Sector, zonal cruise tracks were planned parallel to the coast. This was done under the assumption that krill distribution follows the zonal direction of the current system and hence a vessel working in the same direction would stay longer with any krill concentration than in the case of meridional transects running normal to the currents.

In the *Pacific Sector* Japan planned to work along two meridional transects on 125°E and 160°E. The time frame of FIBEX in the Pacific and Indian Sectors was not as rigid as in the Western Atlantic Sector.

3. The Seagoing Phase of FIBEX

Brief accounts of the field phase of FIBEX were published in BIOMASS Newsletter, **3**(1). Table 1 gives a list of those vessels which worked strictly in the framework

Table 1. Research vessels participating in the FIBEX co-ordinated echo survey, 1981.

Name of vessel	Country	FIBEX period	Area
Western Atlantic Sector			
EDUARDO L. HOLMBERG	Argentina	Jan. 19–26, Feb. 7–16	South Orkney Isl.
ITSUMI	Chile	Jan. 21–March 2	Bransfield Str., Drake Passage
WALTHER HERWIG	Fed. Rep. Germany	Jan. 20–March 4	Central Scotia Sea
PROFESSOR SIEDLECKI	Poland	Feb. 15–March 2	Bransfield Str., eastern Bellingshausen Sea
ODISSEE	USSR	Feb. 2–early March	Eastern Scotia Sea
Indian Ocean Sector			
NELLA DAN	Australia	Jan. 20–March 13	South of 60°S. 60°–88°E
MARION-DUFRESNE	France	Feb. 12–24	South of 60°S, 30°–50°E
KAIYO MARU	Japan	Dec. 11–26, Jan. 16–30	South of 60°S, 30°–90°E
AGULHAS	South Africa	Feb. 10–March 20	South of 60°S, 15°–30°E
Pacific Sector			
UMITAKA MARU	Japan	Dec. 22–Jan. 14	63°–65°S, 125°E
		Jan. 24–Feb. 2	60°–66°S, 160°E

of the FIBEX co-ordinated echo survey. Further vessels engaged in the FIBEX-related studies were R.V. MELVILLE (USA) and R.V. METEOR (FRG). Both vessels were primarily used for work on general biological and physical oceanography but made continuous acoustic observations for collection of krill distribution data. Furthermore both vessels studied in great detail krill concentrations off Elephant Island. On the other hand, the British research vessel JOHN BISCOE which had been scheduled for a grid around South Georgia was not able to participate in FIBEX for technical reasons.

Accounts of certain aspects of FIBEX and its data were presented at the BIOMASS Colloquium, Tokyo 1982 by HAMPTON (acoustic methods and results), KOMAKI, SEGAWA and KATO (krill distribution in relation to oceanographical conditions in the Indian Sector), NAST (krill distribution based on net sampling in Western Atlantic).

4. FIBEX in the Western Atlantic

The major FIBEX activities in the Western Atlantic started on 26 January with a meeting of the research vessels WALTHER HERWIG, ITSUMI, ODISSEE and METEOR in Admiralty Bay of King George Island to confirm cruise tracks etc. and make arrangements for radio communication and for oceanographic data exchange. By that time R.V. EDUARDO L. HOLMBERG and R.V. ITSUMI had already completed their first surveys in the eastern Scotia Sea and in Drake Passage respectively. In early 1981, ice was distributed rather far north in the northern Weddell Sea, blocking the southern part of the intended study area. None of the vessels were sufficiently ice-strengthened to work in pack ice. On the other hand krill was fairly abundant at the northern edge of the study area which therefore had to be extended northward into the open Scotia Sea. The area around and south of South Georgia had to be covered partly by R.V. ODISSEE and R.V. MELVILLE because of the technical failure of R.V. JOHN BISCOE.

All vessels worked their grids during phase I according to the scheme developed by the ad hoc group for survey design, except for R.V. PROFESSOR SIEDLECKI which came so late that it immediately went into phase II. In most areas krill proofed to be so widely distributed that the areas to be covered by phase II were not much smaller than those of phase I. There was a daily radio communication between most of the vessels, R.V. WALTHER HERWIG working as focal point for information on hydrography and krill in the various parts of the study area. On the basis of the data submitted every day, Mr. STEIN on R.V. WALTHER HERWIG compiled data lists and produced charts of surface temperature which were ready for distribution by the end of the co-operative exercise.

Some of the achievements of the survey may be summarized as follows:

R.V. ITSUMI covered *ca.* 900 miles in Bransfield Strait. The chilean vessel detected large concentrations of adult krill south of Elephant Island entering Bransfield Strait along the continental shelf contours. The vessel also worked the continental shelf break at the northern side of South Shetland Islands but did not report much krill in that area. Chilean scientists collected phyto- and zooplankton including larval krill and worked 35 hydrographic stations and in addition XBT's. Data on krill abundance were compared with those of abiotic and biotic parameters including primary production and bird and mammal concentrations.

The Polish research vessel PROFESSOR SIEDLECKI encountered heavy krill concentrations in the western approaches of Bransfield Strait. The scientists on the vessel immediately produced maps of the various data sets of oceanography and plankton including krill and krill larvae.

R.V. WALTHER HERWIG started its survey off Elephant Island where high concentrations of krill were found particularly over the northern shelf of the island. Juvenile krill concentrated along the edge of the Weddell Sea pack ice off and east of the tip of Antarctic Peninsula. Otherwise, the Weddell-Scotia Confluence and the contours of the Scotian Arch seem to play a major role in the distribution of krill and of its larvae. But over 5200 miles of echo survey krill concentrations were rarely very dense and large.

For the Argentinean R.V. EDUARDO L. HOLMBERG the study area was divided by South Orkney Islands into a northern and southern part. Because of the risk of hitting ice, the southern part was not covered to a wide extent. A very large krill swarm was detected in late January southwest of South Orkney Islands.

One of the most significant findings of FIBEX in the Western Atlantic Sector was the extremely high abundance of krill larvae throughout the area of the Scotian Arch from South Shetland Islands to South Orkney Islands. The abundance was highest at the shelf break, exceeding figures of previous years by at least 3 orders of magnitude. According to layered hauls by MOCNESS gear on R.V. MELVILLE the larvae were mainly concentrated in a thin near surface layer. In late January calyptopis stage 1 predominated which had reached calyptopis stage 3 in mid February and furcilia stage in March.

All vessels working in the Western Atlantic Sector were also engaged in studies of krill swarms and their biotic and abiotic environment. In late February/early March four research vessels (WALTHER HERWIG, METEOR, MELVILLE, PROFESSOR SIEDLECKI) operated north of Elephant Island in an area of very high krill concentrations which was fished by a soviet fleet. The structure of the aggregations varied much in the course of the day and particular in relation to weather conditions. At one time the aggregations concentrated into one compact superswarm more than 100 m thick which was measured and sampled by R.V. MELVILLE. Early figures of 5–10 million tons were widely published by the press. They are now considered overestimates by the factor 2 or more. The krill patch found by R.V. EDUARDO L. HOLMBERG was 7 miles by 7.5 miles but much thinner than the Elephant Island patch.

ITSUMI did extensive photographic studies of krill swarms in Bransfield Strait, where also R.V. PROFESSOR SIEDLECKI continued its patch studies. Between Elephant Island and Clarence Island R.V. ODISSEE carried out studies in krill concentrations in relation to the hydrographic regime.

5. FIBEX in the Indian Ocean and Pacific

The reports from the Indian Ocean Sector were partly summarized by I. HAMPTON at the Tokyo Colloquium in the framework of an overall presentation of acoustic work carried out in FIBEX. A much larger area was covered and the exercise run over a longer period. Two vessels of South Africa and France surveyed the western Indian Ocean while two vessels of Australia and Japan were active in the eastern Indian Ocean.

R.V. AGULHAS worked the westernmost sector between 15° and 30°E. Nine EW lines 50–60 miles apart were situated between 60°S and the ice edge. Krill was found in patches all over the area. But only in the Antarctic divergence gravid and spent females were found as well as some krill larvae.

Due to technical difficulties the work of R.V. MARION-DUFRESNE was shortened to 14 days working between 60° to 64°S, 30° and 50°E. In this area krill abundance was rather poor except for some concentrations at 63° to 64°S, 30° to 40°E.

R.V. NELLA DAN operated its echo survey between 60°S and the Antarctic Continent, 60° and 88°E. The vessel found the highest concentrations in the area north of Prydz Bay, where krill swarms were abundant over a large area.

KAIYO MARU covered two areas in the Indian Ocean, in co-operation with other three countries. One leg was operated in the sector between 57° and 90°E, 60° and 67° S, in the earlier season. Second leg was operated in the sector between 30° and 70°E, 61° and 68°S. The heavy biomass of krill detected by the integrator was observed in the southern parts of areas surveyed.

In the Pacific the FIBEX activities were limited to two meridional lines on 125°E (leg 1) and 160°E (leg 2) operated by UMITAKA MARU. The echo survey of leg 1 was between 63° and 65°S and of leg 2 between 60° and 66°S.

The concentration of krill biomass detected by acoustic survey in the Pacific Sector is small. However, the area surveyed was good krill fishing ground through Japanese krill exploitation before. This suggests significant variation of abundance of krill, the reason of which will be studied in SIBEX.

Each of the vessels employed different types of nets to back up the findings of the acoustic estimates of krill abundance. Compared to the work in the western Atlantic krill patches were less intensively studied in the Indian Ocean and along the Pacific sections. However, the South African group did much work on the diurnal variations and migrations of krill swarms. All vessels completed a large programme of environmental studies on plankton, hydrography and bird observations.

6. FIBEX Data Handling

In the programme of FIBEX particular emphasis was given to the need of a coordinated international compilation and analysis of all data obtained by the various vessels during the field phase of FIBEX. A post-FIBEX Data Workshop was scheduled for September/October 1981 at the Computer Science Department of the University of Hamburg (FRG). Preparations of the workshop were in the hands of Dr. D. CRAM who had worked for several years on an experimental fisheries data base. He had produced and circulated within the BIOMASS Handbook Series (No. 16) a guide on the "Transmission of Data to the post-FIBEX Workshop".

A report of the workshop was published in the BIOMASS Report Series. CRAM also gave a further account of the problems and achievements of the Workshop in Reports on Polar Research, No. 8 (1982), published by the Alfred Wegener Institute for Polar Research in Bremerhaven, FRG which also carried most of the costs of the workshop and its preparation.

The data collected during FIBEX fall into the following categories:

1) Acoustic data

a) Echo integrator readings along transects, in terms of mean volume back-scattering strength per distance or time interval.

b) Acoustically derived measurements of the dimensions of individual krill aggregations.

2) Oceanographic data

Vertical and horizontal profiles of temperature and salinity. In some cases also light intensity, dissolved oxygen, nutrients and plant pigments.

3) Biological data

a) Quantities of krill per net haul, depth layer and volume filtered. Length distributions of juvenile and adult *Euphausia superba*, sometimes divided by sex and maturity stage.

b) Quantities of various stages of krill larvae.

c) Zooplankton and phytoplankton samples.

d) Bird and whale counts.

The chief scientists of all vessels participating in FIBEX had agreed to provide their data sets on tape in advance to the workshop. However, only *ca.* 10% of the data arrived in time, most of the rest came at the beginning or during the workshop. Finally the number of national data sets were available at the Hamburg data base (Table 2).

Much time went into coding and validating of the data sets and for the production of "national" data bases for the compilation and analysis in the integrated international system. The oceanographic data were relatively easy to handle, considerable

Table 2. The number of national data sets.

Data type	No. of sets
Echo integrator readings	11 (±10000 readings)
Krill aggregations	4 (8029 swarms)
Oceanographic	9
Krill length distributions	9
Net haul details	9
Bird observations	14 (3099 records)

difficulties arose from the acoustics data, which were not always readily compatible. Even worse were the net haul data. Therefore the workshop concentrated mainly on the oceanographic and acoustic data.

The mere data handling took most of the three weeks of the workshop and little time was left for analysis and particularly synthesis of different data sets.

The central question of FIBEX "how much krill is in the Antarctic" required great uniformity in all sampling methods employed. This was achieved mostly in physical oceanography and to a certain extent in the acoustic methods, although the latter varied considerably from vessel to vessel. POMMERANZ *et al.* (1981) had provided guidelines also for the net sampling based on the experimental field tests of various krill nets as carried out by the SCAR/SCOR Working Group on micronecton abundance in a norwegian fjord, using the nordic krill *Meganyctiphanes norvegica* as test organism. For various reasons, partly financial partly tradition, not all vessels used the same sampling gear. Length measurements and particularly the staging of krill maturity (MAKAROV and DENYS, 1981) were described, but not all participants adhered completely to those rules, if they were conflicting with earlier practice.

Uniformity in data formats was a further requirement for easy and meaningful work in FIBEX data. There again some countries found it difficult to adhere to the rules set out by the organizers of FIBEX and its workshop. One or two countries provided just raw data or punched cards.

Presence of the national scientists who were responsible for obtaining the data, and assistance by good students to run the workshop were further requirements. They were largely achieved. Financial assistance from various sources including SCAR helped in this respect.

A further problem was that the programming language PASCAL in its new version of the relational data base language PASCAL/R was chosen for scientific and practical reasons. This language, adjusted to the time-shared DEC-IO system of Hamburg University is not easily convertible into other systems.

When planning the workshop everyone underrated those problems and particularly the difficulty in getting the data sets in an adequate format. Nevertheless the workshop can be seen as the introduction of modern computer techniques into co-ordinated international marine ecosystem studies in the Southern Ocean.

A major part of the FIBEX data is now available in a standardized format ready for different kinds of processing. A special group under the BIOMASS umbrella reviewed the achievements of the post-FIBEX Workshop and recommended further processing of those data by future workshops. The group felt that the PASCAL/R system should be retained, augmented and adapted for use by computers other than DC-IO.

7. Further Steps of FIBEX Evaluation

The data base which consists of national packets of FIBEX data sets is presently in custody of the Alfred Wegener Institute for Polar Research. Further analysis of the data and particularly the combination of various sets are planned for future international workshops.

7.1. Oceanographic data

Full use had been made of advanced on-line data processing during the cruise by daily transmission to R.V. WALTHER HERWIG of surface and subsurface temperature. The charts and profiles produced at sea were complemented by further analysis during the Hamburg Workshop and in a bilateral Polish/German exercise which was to be continued later in 1982, aiming at the identification and delineation of water masses in the hydrographically complex areas of Bransfield Strait and Weddell-Scotia Confluence. While analysis of oceanographic data *per se* is well advanced, their combination with biological data is still on an episodal stage. Particularly the combination of t/s parameters of water masses with indices of light penetration, nutrients, phytoplankton and heterotrophic microorganisms would be desirable as well as their synthesis with abundance data of krill and zooplankton.

7.2. Krill abundance data and krill distribution

FIBEX aimed at global estimates of krill in its circumpolar distribution. Before FIBEX total figures of krill abundance in the Southern Ocean were very unreliable. They were based either on estimates of the key consumers of krill and their annual consumption or on krill production estimated from primary production and the ratio between potential grazing between krill and other herbivores. FIBEX did produce some new information on those parameters by bird censuses, primary production figures and zooplankton sampling over large areas. Most of those data have not been properly evaluated. A first major step is planned through a workshop on bird abundance. SIEGFRIED already figured that annual krill consumption might be of the order of 5% of the total krill stock. These figures are subject to much doubt as long as the estimates of krill biomass are very uncertain.

Most important is the contribution by FIBEX to direct estimates of krill abundance. The total survey area of 1.3×10^6 miles^2 contained 78×10^6 t $\pm$ 19.5×10^6 t krill with an average density of 17.5 g m^{-2}. HAMPTON tried two approaches extrapolating the acoustic data over the entire Southern Ocean with an average abundance of 17 g m^{-2} or dividing it into two zones of high and low krill abundance, similar to LUBIMOVA's areas of different natural regimes. This gave an overall standing stock of 200×10^6 t. The author would guess annual krill production to be of the same order. These global figures are based on the biomass estimates made by the Hamburg Workshop for each of the national blocs. Using YUDANOV's calibration for target strength, HAMPTON (1983) integrated over parts of each transect and over all transects of each national bloc and made special efforts in the estimation of variance. For the Tokyo Colloquium, he compiled those figures together with their variances into a table which for the moment should be considered the best set of abundance estimates of krill for two large parts of the Southern Ocean (Table 3).

Table 3. Biomass, variance and density data for all sectors (after HAMPTON, 1983).

Sector	Area (km×10^6)	Biomass (t×10^6)	Variance (t^2×10^{12})	Standard deviation (t×10^6)	Coefficient of variation	Mean density (g/m^2)*
Atlantic	1.03	11.33	1.34	1.15	0.10	11.0
Indian A	1.89	11.77	5.11	2.26	0.19	6.2
Indian B	0.89	54.12	374.35	19.35	0.35	60.8
Pacific A	0.34	0.12	0.0025	0.05	0.42	0.4
Pacific B	0.41	0.25	0.0025	0.05	0.20	0.6
All sectors	4.56	77.59	380.8	19.51	0.25	17.0

* 1 $g/m^2 \doteq 3.3$ t/n. $mile^2$

For further analysis of FIBEX acoustic data and for the design of future surveys some questions on methodology in relation to krill biology have to be studied, *e.g.* the variance in relation to number and spacing of transects. Tests by deleting certain transects from the data sets as well as simulation models may indicate how many transects are needed to obtain acceptable variances at a minimum of survey time.

The transformation of the integrator readings of 120 kHz echo sounder into figures of krill biomass had been based on various tank and cage experiments *e.g.* by YUDANOV measuring the target strength of a known number of krill. During FIBEX, GUZMAN added a further piece of calibration by photographing dense krill swarms *in situ* which at the same time were picked up by the echo sounder and later on sampled by a net. About 700 photographs covered a wide range of densities up to 550 krill per m^3. The values for back scattering strength obtained were similar to those obtained by the earlier authors.

The transformation of echo sounder data into krill biomass will be affected by calibration errors and by systematic errors in the ratios of target strength to length of krill and in the length/weight ratio of krill. These might be major sources of the variance in addition to the natural patchiness. Intensive net sampling would help to separate those two sources of variance. However, one cannot sample each acoustic target by nets and any net will be selective through a certain extent by not covering the entire vertical extent of a swarm and by possible net avoidance. So far all abundance estimates of krill in the survey areas based on net sampling are considerably lower than the acoustic estimates. *E.g.* NAST using RMT 8 estimated 1.37×10^6 t for the WALTHER HERWIG-box while the acoustic figure was *ca.* 6×10^6 t. On the other hand it is necessary to check from the routine (blind) net tows whether in certain areas krill might be so thinly spread that it is not picked up by the echo sounder.

Acoustic data of FIBEX should be further analysed for local estimates of swarms and superswarms, *e.g.* in the Elephant Island region. MATHISEN described the use of different frequencies for this purpose. The translocation of krill concentrations within and between the blocs from phase I to phase II may provide insight in the movement of krill patches relative to the general transport of near surface water masses.

EVERSON who had studied krill swarms off South Georgia discussed apparent day and night variations in krill abundance over one and the same small area. Those diurnal differences are presumably due to the more randomly scattered orientation of krill at night. In daytime krill is uniformly orientated in small dense swarms which give a higher echo per krill and large swarms are far more difficult to quantify than small ones. The possibility of obtaining overall figures of average day/night variations was discussed at the colloquium with the aim to come up with certain day/night correction factors. There again diurnal differences in net avoidance will make it difficult to verify such a correction factor by net sampling.

The horizontal and vertical distribution of krill of various age and maturity stages in relation to water depth and ice edge distance as well as to phytoplankton pigments and zooplankton biomass and composition can be studied on the basis of FIBEX acoustic data, *in situ* photographs of krill in swarms, net sampling of krill, and plankton and of environmental data. The PASCAL/R system is particularly powerful in assimilating queries on complex interactions, provided the necessary raw data on tape are made available by national laboratories.

7.3. *Krill biology data*

Further analysis of FIBEX data may also elucidate other parts of krill biology and krill production. For growth studies it should follow the changes in size composition of certain aggregations (charts) from phase I to phase II or during patch studies in an attempt to describe growth. This may be done under different environmental regimes and in different populations, *e.g.* coastal *vs.* oceanic krill, East Wind Drift krill *vs.* West Wind Drift krill etc. Those *in situ* data would provide most valuable comparisons to experimental laboratory work by MCWHINNIE and by MURANO, SEGAWA and KATO, as presented at the Tokyo Colloquium.

Stock separation might become possible by detailed statistical analysis of the length/weight/sex/maturity ratios in different parts of the FIBEX area. More important contributions to krill biology can be derived from FIBEX data in the fields of reproduction and recruitment. Data on the geographical and temporal distribution of gravid and spent females, the widespread occurrence of very large quantities of early larvae are still to be fully evaluated. Ontogenetic development of larvae and transport relative to water depth and water masses should be analysed by comparing phase I and phase II as well as the early and late samples of R.V. METEOR and R.V. MELVILLE. We should look for indications in changes in fecundity and/or in early survival as causes for the extremely high larval abundance. In 1983 and 1984 the effect of the strong 1981 year class should become noticeable in the subadult and adult krill stocks.

While *abundance* estimates were the main objective of FIBEX, estimates of krill *production* in different areas and its fluctuations from year to year are of similar importance. Global estimates of overall krill production/consumption do not help much, as long as there is no evidence for a quick circumpolar exchange of krill populations. For the verification of the new models by BEDDINGTON and by YAMANAKA and DOI an interaction of krill fishery, whale and seal stocks, better production and consumption data are needed, which were not contributed by FIBEX. However, some FIBEX data are available on chlorophyll and on herbivorous zooplankton. Combined with new experimental data on feeding rates of krill and of herbivorous zooplankton those figures might help to validate LUBIMOVA's conclusions on the ratio of krill production to primary production.

7.4. *Other biological data*

The need for further analysis of FIBEX data on *phytoplankton* and *zooplankton* biomass *in toto* and by major taxa in relation to hydrography was again stressed by TRANTER at the Tokyo Colloquium. Much of the data are still kept in national laboratories.

Bird data are mostly in the data base and wait for further analysis along three lines: 1) usefulness of birds as indicators of krill resources, 2) impact of birds as predators of marine resources, particularly krill and 3) impact of man on Antarctic and Subantarctic birds.

Data for larval, juvenile and small pelagic *fish* were collected during the FIBEX krill surveys. They are still to be incorporated in the international FIBEX data base. It seems particularly interesting to look at their distribution in relation to krill swarms in order to predict the potential impact of a krill fishery on recruitment of fish stocks which are already under severe exploitation. During recent years geographical and ecological studies in Antarctic and Subantarctic fish have greatly increased, including a growing number of contributions on the feeding pattern of Antarctic fish, indicating the dominant role of krill in the diet of many species.

On the other hand, virtually no quantitative information is available on the abundance and ecological importance of squid and benthic cephalopods in the Antarctic. The particular experience of Japanese fisheries in collecting cephalopods may help to fill this gap. So far it looks as seals, penguins and toothed whales are able to collect squid far better than any human gear.

8. Summary

Since its first meeting in 1974, the SCAR/SCOR Group of Specialists on the Living Resources of the Southern Ocean had planned co-operative studies on particular aspects of the Antarctic ecosystem. The general programme was drafted in 1976, and in subsequent years a Technical Group on Programme Implementation and Co-ordination, assisted by specialised Working Groups and ad hoc consultations developed the detailed plans for a joint venture in 1980/81. The main objective of FIBEX, the first co-operative experiment of the Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) was to gain quantitative estimates of the total biomass of krill in some major areas of the Southern Ocean and to determine the variance in spatial abundance related to the patchy distribution of krill and krill swarms.

The key instruments were high frequency echo sounders with signal integrators

installed on all vessels. Those instruments were to run for *ca.* 22 days at about 150 nautical miles per day on meridional transects chosen by random in the West Atlantic Sector. After a broad scale first survey a second phase concentrated on subareas with high krill abundance, and a third phase was a patch study of large krill swarms. The survey strategy was somewhat different in the Indian Ocean and on two transects in the Pacific Ocean.

Catch data were needed for the interpretation of the echo signals. Environmental data on physical and chemical oceanography and phyto- and zooplankton were taken in order to relate krill abundance to the physical and biological environment both on the large-scale ocean-wide studies and in aggregations of krill.

The seagoing experiment in January to early March 1981, involved 12 vessels of 10 countries. They produced in a highly co-ordinated and standardized manner the largest amount of data ever collected during an international co-operation in biological oceanography.

The transfer of the data collected by the different vessels in a central computer system was achieved through an international FIBEX Data Workshop, held in Hamburg in September/October 1981. The workshop produced preliminary estimates of krill abundance in the four survey areas, also giving figures of variance.

In further smaller workshops the abundance estimates have to be refined and linked to the environmental data which also require further processing.

FIBEX, when properly analysed, will provide a picture of the distribution and abundance of krill in relation to the environment in some crucial areas of the Southern Ocean. This momentary picture has then to be supplemented by information on the production and dynamics of the krill dominated parts of the system. This will become the main objective of the Second International BIOMASS Experiment which is scheduled for late 1983 to early 1985.

Acknowledgements

Being the concluding contribution to the Tokyo BIOMASS Colloquium 1982 the author wishes to express his appreciation for the invitation. The Colloquium as planned and convened by Dr. T. NEMOTO became an excellent forum for the discussion of FIBEX and other facets of BIOMASS. It was an impressive presentation of the growing engagement of Japan's marine science in the Southern Ocean. The papers demonstrated that many academic and applied institutions in Japan with a good number of interested students work on a wide field of subjects in polar marine science.

The author's first acquaintance with Japanese marine science was with two Japanese scientists to whom he has passed away one month before the colloquium: Dr. SUGAWARA, the pioneer and organizer of marine chemistry intercalibrations on a world wide scale and Prof. M. UDA, the eminent physical oceanographer who has been the international leader in fisheries oceanography. Dr. UDA would have been interested to see the first results of the new co-ordinated efforts of oceanographers and biologists in the Southern Ocean.

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