SCOR WORKING GROUP 54 (WITH SCAR, ACMRR AND IABO) LIVING RESOURCES OF THE SOUTHERN OCEANS

Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS)

Summary of objectives and programmes

Preface

Within recent years, scientific and economical interest in the Antarctic waters has been steadily growing. Therefore the need was felt among those concerned with the study and conservation of the Antarctic oceans to develop a coordinated international programme for the study of the marine living resources of the southern oceans. A SCAR/SCOR Group of Specialists (SCOR Working Group 54) reviewed in 1975-1977 the present knowledge of the marine living resources of the Antarctic and developed a proposal for future cooperative studies in this area named 'Biological Investigations of Marine Antarctic Systems and Stocks 'BIOMASS' '. A detailed document was prepared by the Group of Specialists, containing the BIOMASS proposal together with background information on the living resources, their physical, chemical and biological interactions, as well as on the existing international organizations in the field of Antarctic research. It is being published jointly by SCAR and SCOR. The present brief document was prepared on the request of SCOR in response to the need by IOC for adequate information on the major scientific objectives of the BIOMASS proposal and its practical implementation.

1. **General objectives**

The need for a comprehensive international and interdisciplinary research programme in the southern oceans rests in science as well as in global food resources management. It stems from the fact that the circular current system of the southern oceans houses a food web which is very different from those of other parts of the World Ocean, individual weights of its key members being several orders of magnitude larger than comparable ones in other parts of the World Ocean. This gives an incentive to a unique mass exploitation of the southern oceans' key herbivores, the krill.

The principal objective of the BIOMASS programme is *to gain a deeper understanding of the structure and dynamic functioning of the Antarctic marine ecosystem as a basis for the future management of potential living resources.* Thus, we are primarily concerned with: a) contributions to man's understanding of the World Ocean and b) developing a sound ecological strategy for the exploitation of the living resources and for the conservation of the southern oceans' ecosystems. To achieve these goals of basic marine science and wise ecosystem management we need to consider several objectives. The list given below emphasizes krill as the major potential food resource of the Antarctic waters and as a key element of the marine food web. On the other hand it is recognized that there are other important fields of marine studies in the Antarctic which warrant the attention of the scientific community. BIOMASS will evolve while it proceeds and will hopefully attract new scientists with new ideas in the course of its development into a comprehensive study of the Antarctic ecosystem, its exploitation and conservation.

a) study of the physico-chemical environment, influencing krill and its food base, namely:

i) study of vertical advective and diffusive processes, as driving force of primary production.

ii) study of micro- and meso-scale horizontal processes in relation to swarming of krill and patchiness of phytoplankton.

iii) study of the large scale meridional and zonal water transport at various depths in relation to the life cycle of krill

b) Study of the variability between years and regions in the quantity and composition of phytoplankton.

c) Autecological studies of key organisms of the Antarctic ecosystem such as whales, seals, penguins, fishes, squids, krill, some other crustaceans, salps; assessment of their standing stocks/biomass and production in selected areas of the southern oceans.

d) Description of the major food chains in Antarctic waters with emphasis on the flux of energy and material between the various trophic levels in selected small areas.

e) Development of models to improve our understanding of the quantitative interaction between different elements of the ecosystem and the effects of climate, whaling and krill fishing on the structure and efficiency of the food chain.

f) Compilation and analysis of data from exploratory and commercial fishing.

g) Provision of scientific information on the Antarctic ecosystem to the scientific community, governments, industries, and other concerned bodies.

2. The research programme

The objectives of BIOMASS require actions along three lines:

a) Seagoing operations of research vessels. These include detailed multidisciplinary studies in limited areas of special interest (cooperative 'experiments') as well as some large scale surveys, building on the experience of the former survey work done by research vessels including *Discovery, Ob* and *Eltanin* and of recent exploratory cruises.

b) Other operations at sea. Exploratory and commercial fishing and whaling vessels, supply vessels and others are expected to be operating in the Antarctic during the BIOMASS period. Observations from these vessels will be used to supplement the work of the research vessels especially in relation to the harvestable resources. The seagoing operations should be supported by remote sensing work.

c) Shore-based studies. Investigations on feeding, growth and reproduction of krill and other key organisms at the established coastal stations should complement and add year round continuity to the offshore ship-based studies.

d) Data analysis. Arrangements will be made to ensure proper compilation, storage, dissemination and analysis of information arising from all relevant activities in the Antarctic.

e) Modelling. Stepwise development of models making immediate use of information from published and unpublished sources but augmenting it progressively with field and experimental data as they come in from a), b) and c).

2.1 Seagoing activities of research vessels

In the first operational stage culminating in the First International BIOMASS Experiment (FIBEX), 1980/81, these investigations would be concentrated in a suitable area such as the Scotia Sea or the Atlantic sector in general. It is in this sector where the resources appear most abundant and most likely to be harvested. Studies of other sectors must follow.

2.1.1 Macroscale studies of krill in relation to hydrography

The drift of krill during its 2-3 years life time is of the order of 10^3 km. It is mainly governed by surface and deep currents. The assumed 'development ascent' may include the upper 2000 m of the water column and together with the larval development it takes 10^1 - 10^2 days. The proposed Weddell Sea Gyre project, and the International Southern Ocean Studies (ISOS) of water circulation as well as remote sensing of the variability in oceanic fronts and ice movements are of the right scale to provide information on the transport mechanisms. The near surface distribution of krill in summer has been described in considerable detail by earlier expeditions. However, the transport of the various life history stages and the links between the various populations are not sufficiently known in space and time. Quantitative sampling of krill in the various depths should be carried out in various areas and seasons. The sampling programme should be guided by oceanographic observations and supported by echosurveys; at least two research vessels are needed for the physical and biological work in each of the selected large areas. There is a very urgent need for extending the life history studies of krill into autumn and winter and into the pack ice zone.

2.1.2 Microscale studies on the ecology of krill swarms

The interaction between phytoplankton composition and biomass and the swarming of the krill under the influence of oceanographic factors can be studied at scales of the order of 10 km and 10 days. Two to three ships are needed in a complete experiment of this type.

Measurements to provide information on vertical transport and stability and on advection. Sampling the spatial distribution and densities of swarms of krill in relation to the abundance and size spectra of phytoplankton, in order to understand the reactions of a krill swarm to its food base and the effects of grazing on the phytoplankton. Quantitative recordings and sampling for analyses of phytoplankton distribution and zooplankton abundance and composition in different depth layers and at different times of day and night will provide additional information on the spatial structure of the biotic environment of krill.

Echo-sounding and sonar observations should provide three-dimensional pictures of the changes in the zooplankton concentrations in time.

Those studies should be carried out at several selected places, mainly in different areas of high krill concentrations of the ice edge, in the neritic zone of the Antarctic Peninsula and of the Antarctic islands as well as in the open ocean of the west wind drift, the east wind drift and the upwelling zones. If possible they should be repeated at different seasons.

2.1.3 Microscale studies of food chain structures and functions

In order to learn more about possible future effects of krill fishing on the structure of the first and second trophic level, composition of phytoplankton and its productivity should be studied in places and seasons which differ in relative abundance of krill, salps or other herbivores. Those studies have to be based on quantitative plankton sampling in various depth layers and can be considered as an extension of 2.1.2 beyond the krill swarms into areas and seasons where alternative grazing and predation strategies lead to changes in the quantitative composition of the herbivore level.

2.1.4 Macroscale studies of zooplankton, nekton and benthos

There is still a need for further quantitative sampling of zooplankton, pelagic squids and fish in various regions of the southern oceans. The Benthos of the Antarctic is very poorly known.

Beyond such faunistic surveying of the area, quantitative data are needed on the abundance of the dominant elements of plankton and benthos in the different regions. The position of the dominant species within the food chains should be ascertained by studies of stomach contents and feeding apparatus.

Benthos studies may be combined with observations on sedimentation and decomposition of fecal pellets, dead zooplankton, particularly krill, and diatoms.

The biological and sedimentological surveys are very time consuming. More than one research vessel is needed, even if one wants to cover one of the Ocean sectors within one summer.

2.2 Sea-going activities of other vessels

The sea-going research tasks require the cooperation of a number of oceanographic and other vessels in the southern oceans. The majority of the seagoing studies need fully equipped research vessels. This is particularly the case in the multidisciplinary studies on the relationship between krill and the environment. The success of the biological programmes would largely depend on a well designed coupling with observations on horizontal transport and vertical mixing. It would not be sufficient nor economical to add small biological programmes to physical expeditions and vice versa but rather to combine full scale programmes of both disciplines in large process-oriented exercises. (On the other hand, one should avoid to try to measure and sample 'everything'.) International cooperation is essential in view of the large support needed for a multidisciplinary study which includes several vessels and a considerable number of specialists.

The work of the research vessels can be greatly assisted by coordinated survey efforts of exploratory and commerical trawlers, a few whaling vessels which are still in existence as well as by supply ships and icebreakers. A brief summary of the advantages and limitations of the different types of vessels with regard to the research objectives of BIOMASS is given in table 1. Given the ambitious objectives of BIOMASS, its success will depend on making the best use of all types of vessel.

In view of the importance given to resource management, special emphasis will be given to obtaining information from those vessels most directly concerned with the harvestable stocks, i.e. exploratory and commercial vessels, particularly those directed at krill. Information from them will include details of the catch, the distribution and, as far as possible, the relative abundance of the stock, and size, maturity, food etc of the animals caught. All of these are important in studying the population dynamics of the exploited stock. In addition, where opportunity offers, other biological observations using simple equipment e.g. plankton nets, will be made from these and other non-research vessels.

Table 1. Summary of Research Opportunities and Constraints from Platforms available for Southern Oceans Studies

	Research Vessels	Shore Bases	Exploratory Trawlers	Commercial Trawlers and Whaling Ships	Supply Ships and Ice-Breakers	Satellites
Constraints	• Limited (large scale) trawling capacity	• Poor (large scale) trawling capacity • Limited access to open ocean • Limited geographic coverage	• Limited spectrum of oceanographic opportunities	• Uncontrolled operational area • Fishing bias • Narrow spectrum of oceanographic opportunities • Limited year-round coverage	• Few station opportunities en route • Lack of trawling capability • Poor year-round coverage	• Lack of "Ground Truth" • Ice cover • Cloud cover • Turbulent sea surface
Opportunities	• Flexibility • Multiple sampling capability • Interdisciplinary research • Water column studies • Acoustic surveys for krill, squid, and fish • Benthic sampling • Underwater photography	• Stable platforms • Experimental studies • Year-round coverage • Time series studies • Inshore benthic sampling • Larval surveys • Sampling predators of krill, fish and squid (seals, penguins, etc.) • Population dynamics of seals, penguins, etc. • "Ground Truth" for remote sensing of intertidal macroalgae	• Acoustic survey for krill • Efficient sampling for krill • "Ground Truth" for acoustic survey of krill by other vessels • "Ground Truth" for remote sensing of krill • Acoustic survey for squid and fish	• Acoustic survey for krill • Efficient sampling for krill • "Ground Truth" for acoustic survey of by other vessels • "Ground Truth" for remote sensing of krill • Acoustic survey for squid and fish • Squid and fish sampling from sperm whaling operations	• "Ground Truth" for satellite survey of surface temperature and chlorophyll • Deployment of drifting sensors in communication with satellites • Occasional opportunities for time series observations near coast and at at edge of ice pack • Observations on occurence of seals and penguins	• Remote sensing of surface temperature. chlorophyll, and krill swarms • Year-round coverage • Remote sensing for macroalgae • Communication with unmanned buoys and sensors

Information from fishing vessels is however no substitute for observations from research vessels. Indeed, to the extent that the number of the former increases i.e. exploitation intensifies, there will be a greater urgency for timely scientific advice on management. This will increase the need for some information only obtainable with well-equipped research vessels.

In view of the importance of the large area under the pack ice, there is an urgent need for icebreakers capable of conducting deep biological sampling under the pack ice.

An increasingly useful method of studying large areas is remote sensing by aircraft or satellite. Since remote sensing is only suitable for observations of surface or near-surface conditions, and the extent of cloud cover make even some of these observations difficult, the application of remote sensing to BIOMASS may be limited. Nevertheless, attention will be paid to making the best use of available facilities, especially the *Nimbus-G* satellite, for those observations that may help the BIOMASS programme of variations in ice cover.

2.3 Shore-based studies

So far only a few experiments were successful on krill and other Antarctic plankton organisms in captivity on board research vessels and in shore stations. Basic data on productivity – respiration, growth and reproduction – should be obtained together with data on rates of filtration, feedings, digestion and on metabolism under different controlled environmental conditions in tanks and aquaria. Attempts to culture krill experimentally should provide further information on the duration of various life history stages and on biochemistry and histology of moulting and sexual maturation. Pressure tanks might be needed for the eggs and early larvae. Research on enzyme kinetics and microbial activity is needed in parallel with studies on the energy budget and decomposition processes in large containers.

Recently considerable experience has been gathered on plankton experiments in various types of inshore and land-based enclosures. Studies in feeding and predation of krill under semi-natural and semi-controlled conditions might bridge the gap between the physiological laboratory studies and field observations. Experiments on shoaling, vertical migration and sonar target responses of marine organisms such as krill in enclosures would be complementary to field studies.

Year-round studies of the Antarctic fauna and flora are essential because most species have marked seasonal cycles. The shore station bases – although limited in their seagoing facilities – provide opportunities for continuous year-round observations of near shore communities in plankton and benthos as well as in magnitude and seasonal variation in predation by fishes, sea birds and seals. The great number of experimental studies and their methodological diversity require considerable international and interdisciplinary collaboration in more than one well equipped shore station with easy access to krill stocks.

Further information is required on the programmes, technical facilities and man-power of the various stations, in order to launch new internationally coordinated programmes as outlined above.

2.4 Data analysis

Much of the information arising from, or relevant to, BIOMASS requires some form of central compilation, storage, analysis and dissemination. The types of information include oceanographic data; catalogues of biological data; biological samples for sorting and identification; statistics of harvest; and bibliographic information.

Different types of data will require different arrangements. Some can be handled by existing facilities. For example, oceanographic data by National and World Data Centres, and fishery statistics (at least in the first instance) by FAO. In other cases new arrangements may have to be set up, or existing facilities strengthened; for example, if a large volume of detailed biological and statistical data becomes available from large-scale krill exploitation.

2.5 Biological modelling for the Antarctic oceans

Expertise on the best form of biological models applicable to the Antarctic ecosystem should be sought from scientists in the field as well as from SCOR Working Group 59. It may be useful initially to divide the problems of modelling the Antarctic ecosystem into two parts.

a) In the first model one might consider physical/chemical parameters, such as the depth of mixing, the rate of upwelling, the input of radiation, nutrient levels etc, as forcing functions in generating different levels of primary production. If possible the model should not be confined to an output in terms of the quantity of photosynthetic carbon, but should include also at least two outputs showing the relative quantity of photosynthetic carbon fixed separately by nano-plankton and net-plankton. Ideally the computed primary production might be considered in a broader size spectrum, including a dozen or more different size categories of primary producers.

b) Using known extremes in seasonal and regional variations in primary production, a second model should be developed in which primary productivity is used as a forcing function on the growth and mortality of herbivore populations (particularly krill). Such a model should help to elucidate competitive grazing, life cycle and growth strategies of all major species of herbivores so as to create a scenario of factors affecting the relative abundance of the major filter feeding zooplankton in the Antarctic ecosystem including krill, salps, copepods and amphipods. Various predatory strategies of whales, seals, penguins and fish should be included in order to examine seasonal and regional differences in krill abundance, in as much as this abundance may be due to purely biological effects. A first step in this model should deal with the interaction between krill, whales, seals and penguins in order to provide a rationale for management decisions.

These two models on primary production and on filter feeders may be developed simultaneously. It is even possible to start with the filter feeders model by taking published figures on primary production. Although the final goal of both models is a description of the Antarctic waters in general, regional submodels may provide a useful starting point.

3. Time-table and coordination of BIOMASS (fig. 1)

The three major types of activities under BIOMASS (seagoing experiments and surveys; shore-based experiments and year round observations; data analysis and modelling), have to be adjusted to each other. Observations on krill swarms and on the ecological physiology of key organisms of the Antarctic ecosystem should be started immediately and continued both at sea and shore stations. Systems of data reporting and handling should be developed as soon as possible. The programmes by FAO as discussed and approved by its Committee on Fisheries includes the development of a statistical data base and of a collection of scientific reviews on the living resources and their present and potential exploitation. Some standardization with regard to sampling and sorting of plankton and nekton in the southern oceans are also required at an early stage of the BIOMASS programme.

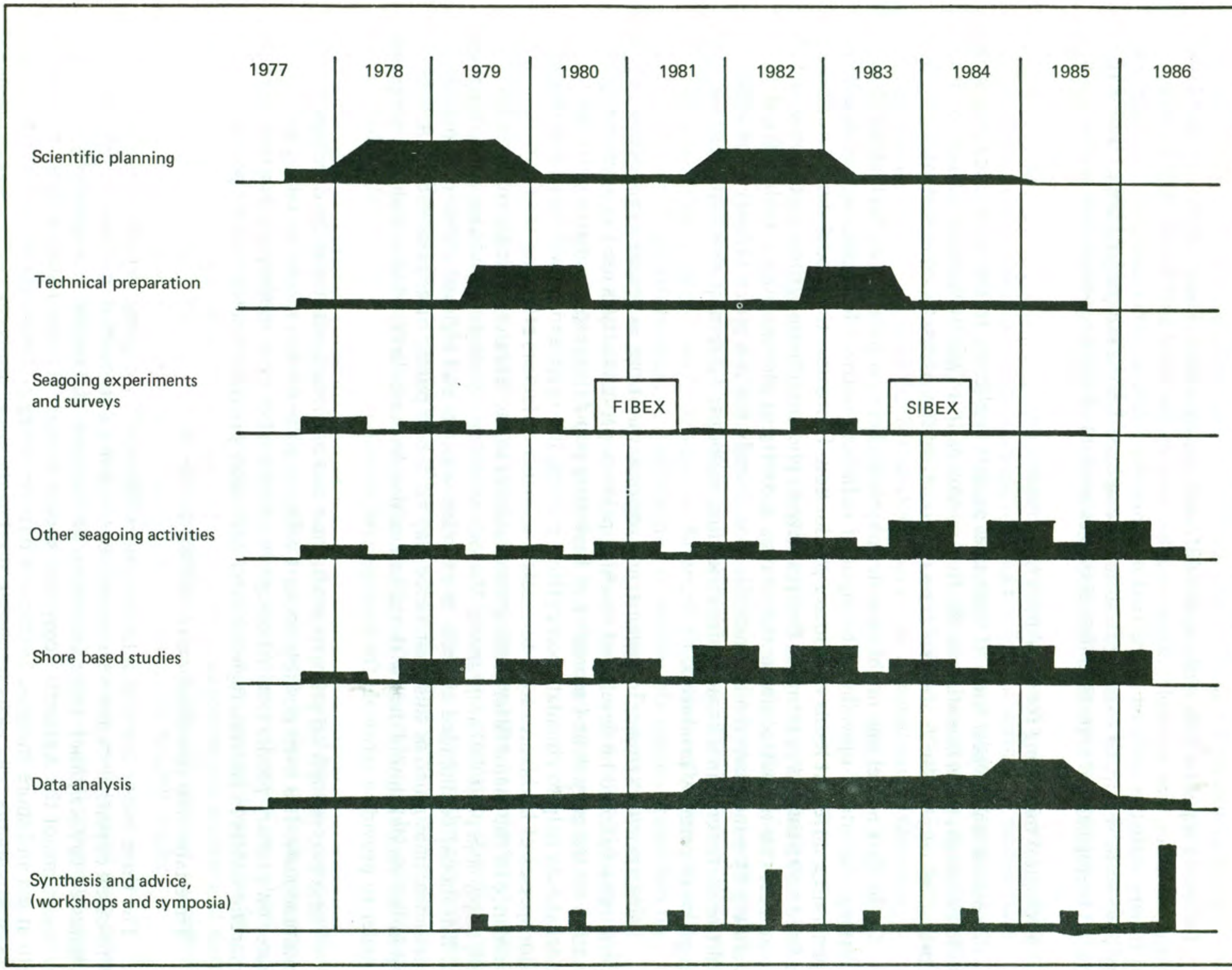
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
Scientific planning
Technical preparation
Seagoing experiments and surveys
FIBEX
SIBEX
Other seagoing activities
Shore based studies
Data analysis
Synthesis and advice, (workshops and symposia)

Figure 1

The major implementation phase consists of at least two major international multiship experiments as well as of a number of loosely connected experiments at sea and ashore and of national macro-scale surveys.

A time-table for large scale seagoing operations has to take into account other large scale oceanographic activities such as FGGE but also the need for sufficient time for scientific planning, logistic preparation, and development of instrumentation. Austral summer 1980/81 was chosen for the "First Internation BIOMASS Experiment" (FIBEX) as a major multidisciplinary process-oriented study which should involve several vessels in microscale experiments and macroscale investigations of transport mechanisms and of ecosystem variability in space and time. It should concentrate on the Atlantic sector but include Drake Passage and its western approaches. On-going marine research activities – both sea going and landbased – in the Antarctic should be used as far as possible to prepare the ground for the international BIOMASS experiment 1980/81.

Data analysis will go parallel to the field work, laboratory studies and modelling. There will be a need for meetings of small groups of specialists for the planning of seagoing and shore-based experiments, for the development of methodology, data handling and concepts of modelling. An interim synthesis of data and results should be aimed at by specialized workshops from 1979 onwards and presented at a small symposium in 1982 and a major, concluding one about 1986.

Preparatory and coordinating arrangements for the implementation of BIOMASS will be needed at the scientific and administrative, non-governmental and governmental levels. The group felt that those tasks should largely be entrusted to the existing bodies of SCAR/SCOR and of IOC which should also be the principal sponsors of BIOMASS.

The group of specialists proposed the following system of coordination.

a) SCAR/SCOR scientific planning group. A group of scientists selected according to their individual expertise, who would recommend methods and techniques and draw up scientific programmes for cooperative field work and land based studies and for the analysis of data. Subgroups may be established for special technical tasks. The existing group of specialists on the Living Resources of the Southern Oceans (SCOR Working Group 54) could (with perhaps enlarged membership) undertake this task with its new terms of reference.

b) BIOMASS Coordinating Group as a subgroup of the existing IOC International Coordinating Group for the Southern Oceans (ICG/SOC) with the responsibility of implementation of the BIOMASS programme acting on the scientific advice of the SCOR/SCAR scientific planning group. Consideration might be given to the appointment of an International Coordinator. SCOR, SCAR and IABO should be invited to participate in the work of the BIOMASS coordinating groups. It is expected that FAO and the International Whaling Commission (IWC) will contribute to the efforts of the BIOMASS coordinating group.

The proposals on the coordination of BIOMASS and on exchange of information and data are summarised in the recommendations of the group, published in *SCOR Proceedings*, Vol. 12, Annex VI.