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SCAR/SCOR Group of Specialists on Southern Ocean Ecology

Scientific Committee on Antarctic Research
Scientific Committee on Oceanic Research

GROUP OF SPECIALISTS
ON
SOUTHERN OCEAN ECOLOGY

Report of the meeting held in Trondheim, Norway 21-23 May 1990

1. Introduction
Dr J-C Hureau, the Convenor, welcomed the members of the Group of Specialists (names and addresses at Annex 1). Dr J P Croxall agreed to act as rapporteur.

2. Membership of the Group
Dr Hureau indicated that he wished to resign from the Convenorship. He was warmly thanked for all his efforts since the inception of the Group. Dr G Hubold was proposed as the new Convenor and unanimously accepted; SCAR and SCOR were invited to approve the change.

Dr Hureau had received a letter from Dr Bardin (USSR) requesting that Dr I Melnikov be added to the membership of the Group. It was agreed that Dr Hureau should reply to Dr Bardin pointing out that, as a Group of Specialists (rather than a Working Group), membership is by invitation and needs the approval of SCAR. Dr Melnikov had made valuable contributions to the workshop on the ecology of the Antarctic sea-ice zone but, pending decisions on the future role of the Group (see below), the Group agreed not to make any proposals to SCAR for additional members at this time.

3. Future role of the Group of Specialists
At its 1986 meeting, the group reviewed fields for Antarctic marine ecological research. Since its 1988 meeting the Group's major preoccupation has been to plan the development of an integrated research programme in the designated priority field of the Antarctic Sea-ice Zone.

A major step towards this is the report of the Workshop on the Ecology of the Antarctic Sea-ice Zone (see item 5 below). If SCAR approves the further development of this programme, the Group would expect to have a significant role in its organization and coordination. Whatever the exact outcome of this initiative, the Group felt that its next tasks should be to examine in more detail research programmes in other areas of Antarctic marine ecology in order to follow up on earlier initiatives and to ensure optimum liaison and interaction between these programmes and the main elements of the Antarctic Sea-Ice Zone programme.

The group noted especially the need for:

i. more active liaison between the SCAR and CCAMLR marine research communities;
ii. further development of the work of the krill and fish sub-groups.

It suggested these as important topics to be addressed at its next meeting.

4. Coordination between Antarctic research programmes

At its last (1988) meeting the Group had prepared, and SCAR had circulated, a questionnaire soliciting:

a) basic information on national marine research programmes in the Antarctic and

b) names of appropriate scientists to provide the group with more detailed information on the main research programmes.

Fifteen countries had completed the questionnaire and had nominated contact scientists (Annex 2). These members were thanked for their responses. The completed questionnaires indicated the following results:

1. Location of operations and main research areas (number of countries)

	Physico-chemical oceano-graphy	Marine biology	Sea-ice	Long-term monitoring, environ-mental	Long-term monitoring, biological	Resource management
Subantarctic Islands	6	7	2	2	6	4
Open ocean	14	12	5	3	3	2
Antarctic coastal shelf zone	12	14	8	8	8	4

2. Designated cruises
   Fourteen countries organized designated cruises regularly or at least in the very recent years.

3. Time of year
   Year round programmes are maintained by two countries around the sub-Antarctic islands, by two others in the open ocean and five along the Antarctic coastal shelf zone. Austral winter programmes only have been organized by one country in the open ocean and two along the Antarctic coastal shelf zone. Finally, austral summer programmes only are financed by six countries in the sub-Antarctic islands, by twelve others in the open ocean and nine along the Antarctic coastal shelf zone.

4. Time span of programmes
   Twenty-four short-to-medium term (5-10 years) programmes are maintained in the three defined locations, 5 around the sub-Antarctic islands, 10 in the open ocean and 9 along the Antarctic coastal shelf zone. Thirteen medium-to-long term (10-15 years) programmes are also organized, 3 around the sub-Antarctic islands, 5 in the open ocean and 5 along the Antarctic coastal shelf zone.

Members of SCAR who had not yet provided this information were urged to do so as soon as possible.

The Group agreed to initiate correspondence with the nominated contact scientists (in the first instance by providing them with personal copies of the workshop report) and urged all members of SCAR to nominate scientists to assist the group in its coordination and communication endeavours.

The Group agreed that further steps towards coordination of research should await decisions by SCAR on the nature and content of the major suite of programmes

contributing to IGBP and especially how biological programmes in the Antarctic Sea-Ice Zone may contribute to these.

5. Workshop on the Ecology of the Antarctic Sea-Ice Zone

The Group of Specialists received an outline draft report from the workshop on the Ecology of the Antarctic Sea-ice Zone and refined and further developed it into a final report (Annex 3). Drs J P Croxall and D G Miller acted as rapporteurs for this process.

The Group thanked Drs E Sakshaug and C W Sullivan, the co-convenors of the workshop, for their work in arranging the meeting. Dr Sakshaug and his staff were also especially thanked for organizing the excellent local arrangements.

The Group noted that the outline report distilled a considerable amount of expert comment on current and projected research in the Antarctic Sea-Ice Zone. This provided the basis for a critical appraisal of key features and processes of this system, especially in relation to its role in global processes and potential sensitivity to global environmental change. The Group of Specialists was deeply appreciative of the efforts made by all participants and especially by the various rapporteurs. The outline report did not, however, provide any detailed appraisal of relative research priorities within and between programmes and therefore the workshop had felt unable to develop suggestions on appropriate organizational structure for coordination and implementation.

The Group of Specialists recognized the impossibility of reaching this stage at the workshop and felt that it was also inappropriate for the Group to make suggestions in advance of the necessary comprehensive evaluation by SCAR of all research in the Antarctic Sea-Ice Zone. The Group therefore endorsed the conclusions of the workshop and addressed the following conclusions and recommendations to SCAR.

1. Biological processes in the Antarctic Sea-Ice Zone are of fundamental interest in their own right. With recent and current technological advances, the feasibility of multi-disciplinary biological research on key processes in this system is greatly enhanced and a coordinated programme of research is now both required and feasible.

2. The workshop indicated that, although biological processes in the Antarctic Sea-Ice Zone have the potential to modulate ocean-atmosphere fluxes of global importance, we cannot yet determine how significant the biological effects are or may become. The fundamental biological research needed under 1) above will, when linked at appropriate temporal and spatial scales with research on the physico-chemical fluxes, provide the first answers to these questions.

3. The workshop also suggested that the distinctive temperature and habitat (ice) modulated effects of the environment are closely coupled to many biological processes in the Antarctic Sea-Ice Zone. The closeness of this coupling implies that in processes and events with relatively low inter-annual variance, evidence of eg global warming might be detectable in the biota before becoming apparent in the physico-chemical fluxes themselves.

4. The Group of Specialists regarded these conclusions as providing overwhelming justification for a major concerted programme of multi- disciplinary biological research in the Antarctic Sea-ice Zone, closely linked to complementary programmes in other relevant disciplines.

5. A preliminary indication of existing and projected research initiatives relevant to the priority questions is at Annex 6.

6. The Group strongly endorsed the remaining conclusions of the workshop, on the need for:
   a. establishment of the framework for the coordination of directed multi-national research in the Antarctic Sea-Ice Zone;
   b. specialist panels to be convened to review the suitability of existing mechanisms and structures for implementing a) above and d) below and to make explicit detailed recommendations with respect to programmes in the Antarctic Sea-Ice Zone;
   c. coordination of the development and use of new equipment and techniques for data acquisition and analysis;
   d. the early establishment of a suitable data management and processing system.

6. Reports from sub-groups

a. Fish biology and physiology.
The Convenor, Dr Hureau, presented a verbal report on the activities of the sub-group. Dr M G White (Secretary of the sub-group) had contacted ichthyologists in 13 countries who worked on Antarctic fish and as a result of this had produced, in 1989, the first Antarctic Fish Newsletter. This was published in the journal "Cybium" and also sent separately to over 100 Antarctic ichthyologists world-wide. A second Newsletter is in progress.

The Group expressed its thanks to Dr White for initiating such an excellent means of information exchange and to the French Society of Ichthyology for facilitating the printing of the Newsletter. The Group requested that each of its members should be placed on the mailing list. It asked that the fish sub-group, through its Newsletter, keep Antarctic ichthyologists aware of the initiatives proposed by the workshop with a view to soliciting in future more detailed advice on coordinated research projects on fishes.

b. Krill biology and physiology
The Convenor, Dr D G Miller, made a verbal report on the sub-group's activities. Dr D Morris (Secretary of the sub-group) had developed a list of existing and potential topics for research on krill in the Antarctic. He circulated this to euphausiid biologists worldwide, seeking comments and suggestions. Six replies were received. At this time, Dr Morris moved jobs (away from the British Antarctic Survey) and the momentum of his initiatives had not been maintained.

In order to expedite a follow-up, Dr Miller felt that it was essential to have a new secretary; the Group agreed to his proposal of Dr J L Watkins (UK). The Group noted that Dr Miller and Dr Watkins were both involved in krill-orientated activities within CCAMLR and arising from the BIOMASS programme. The Group felt that it was very important that SCAR should, through its Group of Specialists, maintain close links with these activities. It asked the krill sub-group to provide the Group of Specialists with an overview of these and other relevant researches. The establishment of a krill Newsletter might significantly enhance interchange of general information.

7. Any Other Business

a. Report of SCAR ad hoc *committee on the evolutionary genetics of marine organisms.*
In 1988 the Group had received a request to consider the formation of a sub-group on the above topic. After discussions within SCAR it was decided that it would be best for such a group to become an *ad hoc* group of the SCAR Working Group on Biology. The Group of Specialists appreciated receiving a copy of its report. It noted several items of relevance to fundamental processes (e g genetic basis of adaptations) in the Antarctic Sea-Ice Zone system and found the review of potential research topics most helpful.

b. BIOMASS planning meeting (4-5 April 1990)
The report on this meeting was tabled for information, especially in relation to the proposed BIOMASS Colloquium (18-21 Sept. 1991), to be held in association with the Antarctic Science Conference.

c. Antarctic science conference (23-27 Sept. 1991)
The report of an *ad hoc* meeting on 27 October 1989 was tabled for information.

8. Next Meeting
The time and place of the next meeting of the group would be established after the conclusion of XXI SCAR.

9. Close of Meeting
Dr Hureau closed the meeting by thanking the participants and especially Dr Sakshaug and his staff for their assistance.

ANNEX 1

Members attending the Group of Specialists Meeting (Trondheim, 21-23 May 1990)

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ANNEX 2

Nominated contact scientists

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- José F Gallo
- Enrique Marschoff

Australia
- Peter Nichols

Chile
- Antonio Mazzei Fernandez

China
- ?

Ecuador
- Hernan Moreano A

Finland
- Pentti Malkki
- Erik Bonsdorff

France
- Jean-Claude Hureau
- Guy Duhamel
- Pierre Jouventin
- Alain Guille
- Guy Jacques
- Paul Treguer

Germany (Federal Republic)
- Gerd Hubold

India
- Arun H Parulekar

Japan
- Yasuhito Naito

New Zealand
- G A Knox
- B A Foster
- J Macdonald
- S Battershill
- P Wilson
- V A Squire
- L S Davis

Norway
- Egil Sakshaug

South Africa
- Denzil Miller

Spain
- Aldo Tomo

Sweden
- Bo Fernholm

United Kingdom
- A Clarke
- J P Croxall
- I Everson
- R B Heywood
- J Priddle
- M G White
- P Williamson
- W J Gould

United States of America
- Cornelius W Sullivan
- Michael Tillman
- Rennie Holt
- Roger Hewitt

Uruguay
- Carlos M Martinez

USSR
- I Melnikov

ANNEX 3

Scientific Committee on Antarctic Research
Scientific Committee on Oceanic Research

Report of the Workshop on Ecology of the Antarctic Sea-Ice Zone

held in Trondheim, Norway 18-21 May 1990

INTRODUCTION

In 1988 the SCAR/SCOR Group of Specialists on Southern Ocean Ecology identified the urgent need for a coordinated multi-disciplinary research programme to investigate how the presence of sea-ice and seasonal ice dynamics influence ecosystem structures and fluxes of matter and energy in the Southern Ocean (SCAR Report 3:3-13). This recommendation was largely based on the potentially important links between fluxes in the Antarctic Sea-Ice Zone(*) and processes of significance for climate and global change.

The Group of Specialists recommended that in order to initiate the development of appropriate research programmes a multi-disciplinary workshop should be held. The terms of reference were:

- To review and evaluate past, present and future research on the Antarctic sea-ice zone, especially including the relevance of such research to investigating global changes;
- To develop an action plan to direct and implement research initiatives in the Antarctic sea-ice zone focused on the ecology of the Antarctic sea ice-zone and its relevance to assessment of global changes;
- To develop a suitable structure to undertake such research both on a national and a multinational basis.

The Workshop, convened by Drs E Sakshaug and C Sullivan, was held in Trondheim, Norway, 18-21 May 1990. A list of the 35 participants drawn from 11 SCAR nations is in Appendix 2.

The Workshop felt that the development of a coherent suite of research programmes and of a suitable structure to organize and coordinate these could not be undertaken until general agreement was reached on:

- The scope of scientific research programmes in all relevant disciplines;
- The relative priorities within and between programmes;
- The resources likely to be available to tackle these programmes.

Against this background, the Workshop developed:

1. A general statement of the rationale for and the primary objective of an appropriate research programme;

* The Antarctic Sea-Ice Zone is defined as the atmosphere, sea-ice, water-column and sea-floor associated with the areas of the Antarctic seasonally covered by ice.

2. A brief review of key features and processes relevant to the biology of the Antarctic Sea-Ice Zone. A more detailed review of the physico-chemical environment of the Antarctic Sea-Ice Zone is provided in Appendix 1;
3. A series of questions directed at understanding the spatial and temporal (seasonal and inter-annual) variation of key biological processes of the sea-ice, water column and benthic systems of both fast- ice and pack-ice areas;
4. Suggestions for research approaches and data requirements necessary to address the issues highlighted in (2) and (3) above.

RATIONALE AND OBJECTIVES

The ocean area bounded by the Antarctic Polar Front is a key component of the world's ocean-atmosphere system. It represents approximately 10% of the total global ocean area, and by virtue of its circum-continental and zonal configuration it acts as a link in the exchange of energy and matter between other ocean areas in the Southern Hemisphere. Much of the world's oceanic deep water originates in high latitude areas of the Antarctic Ocean.

Within this Ocean, one key environmental feature dominates the system. Sea-ice covers over half of the Ocean at its maximum winter extent, an area of 20 million km^2. Most of the sea-ice is seasonal rather than perennial - a dynamic system which contrasts with the more perennial sea-ice environment of the Arctic. Although only one or two metres thick, the sea-ice cover has a dramatic impact on all aspects of environmental variation. Thus it:

- affects the magnitude of fluxes of both heat and matter from the atmosphere;
- supports a unique and tightly coupled biological community;
- imposes changes on the fluxes within the underlying water column and to the benthos.

The annual cycle of advance and recession of sea-ice ensures that the Antarctic Sea-Ice Zone has a fundamental influence throughout biological systems (including the krill-dominated pelagic web) in the Antarctic Ocean. The structure and functioning of these systems and their reaction to possible changes in world climate is of considerable importance to the Southern Ocean as a whole.

Modelling of world climate in relation to projected increases in the levels of radiatively active gases in the atmosphere indicates that 'greenhouse warming' could produce most marked effects in polar latitudes. Because this would almost certainly result in drastic changes in the distribution, character and thickness of sea-ice, crucial alterations in Southern Ocean dynamics can be expected with consequent changes to current energy and matter fluxes. Sea-ice imposes spatial and temporal variation on an ecosystem whose scales of variability are fundamentally different from those in open-water. Thus processes whereby biota and environment interact in biogeochemical cycles, possibly at levels large enough to influence climate change, may undergo major alteration.

Consequently, this area also forms an important site for the monitoring of such change. For example, the ecological effects of reductions in sea-ice thickness may be detectable before changes in air-sea fluxes are apparent.

Given that the Antarctic Sea-Ice Zone is a key component of the Antarctic Ocean and has the capacity for significant interactive change with global climate fluxes, the overall objective of the proposed integrated research programme should be:

TO DETERMINE THE ROLE OF THE ANTARCTIC SEA-ICE ZONE ON ANTARCTIC MARINE SYSTEMS AND IN THE CONTROL OF GLOBAL BIOGEOCHEMICAL AND ENERGY EXCHANGES

This implies a need to understand how major changes in sea-ice thickness, structure and extent may affect physical, chemical and biological relationships between atmosphere, water column, benthos and sediments at both short and long time scales. In order to understand how the Antarctic Sea-Ice Zone system may respond to global change, knowledge of how it functions under currently prevailing conditions is required. Three topics in the Antarctic Sea-Ice Zone system which need priority attention are :

- The factors controlling the life cycles and survival of the biota;
- The impact of sea-ice and ice biota (*) on ocean-atmosphere exchanges, especially of $C0_2$ and other gases;
- The nature of biogeochemical cycles in the water column and benthos.

Our present quantitative understanding of these crucial topics ranges from rudimentary to very incomplete. The framework presented below is designed to stimulate research programmes which will identify and quantify the key parameters involved in these topics in order to develop a functional description adequate for the evaluation of the potential impacts of various levels and types of global climate change.

BIOLOGICAL PROCESSES IN THE ANTARCTIC SEA-ICE ZONE

THE SEA-ICE ECOSYSTEM

Introduction

Although only one metre thick, ice-cover has a marked effect on the physical scales of the upper water column. It provides a barrier for the exchange of heat, light, momentum and material between the water, atmosphere and land.

Ice and its overlying snow cover intercepts much of the solar radiation incident at its surface. This limits photosynthetic production both within the ice and in the underlying water column.

Ice also provides a feature which is absent from the open water - a solid substrate. Living organisms utilize this either as a permanent or temporary habitat. The physical structure of the ice therefore influences the dynamics of these organisms, from centimetre-scale variation in the physical and chemical environment of the microbiota to large-scale variation in ice distribution and its effects on the ecology of ice-associated birds and mammals.

Given that the effects of the presence and structure of the ice are not only felt in the ice-associated community but in the underlying water column, processes in midwater, in deep water and in the sediments are likely to be keyed to the overlying ice. Pelagic primary production in the Antarctic Sea-Ice Zone may be closely coupled to the frontal structure at the marginal ice zone. This will then influence subsequent biogeochemical cycles.

Sea-ice Formation and Colonization Processes

Both pack-ice and fast-ice may share common ice crystal structures, each containing some large-grained (cm size) congelation ice and some small-grained (mm size) ice resulting from frazil formation. Usually pack-ice is more variable and may be composed primarily of frazil ice whereas fast-ice is more often composed primarily of congelation ice. Each ice type is formed in a different way and other regionally localized ice-formation processes

* Sea-ice biota are defined as organisms at all trophic levels which live in, on, or depend upon the ice during all or part of their life cycles. There are three groups of ice-associated organisms: microbiota, macrobiota and marine birds and mammals.

may result in additional features such as frozen snow/sea-water mixes and incorporation of under-ice platelets. The ice crystal surfaces and the structures they form create a solid substrate for the colonization and growth of microbiota and on larger scales provide a refugium for prey organisms and resting/breeding platforms for marine birds and mammals.

The thickness of annual ice is about 0.5 to 1.5 m. Snow cover is variable but is usually less than 1 m. Multi-year ice is thicker, less saline, may survive for longer than two summer meltings and often has an overlying snow cover ranging from 0.5 to 1.5 m thick. Multi-year ice is often deformed by rafting.

Different ice-forming processes lead to a variety of ice structures and varying species composition of biota associated with ice. Ice microbiota may become associated with ice by either passive (physical) or active biological processes. The microbiota found in ice in part reflect the assemblages present in the water column, or the benthos in shallow areas, over which the ice was formed. Knowledge is required on:

- What is the regional and/or areal extent of different ice-forming processes at small-, meso- and large scales and how do they influence ice?
- How is the composition of the sea water and resulting brines altered when they freeze?
- What chemical, physical and biological processes are involved in attachment, nucleation and adhesion processes?
- How and when does colonization by ice biota take place (eg during initial ice formation or continuously? Is it active or passive?) ?
- Does space availability limit colonization of the ice?
- What is the relative importance of the various colonization pathways (eg harvesting, scavenging, sieving and propagation of wave field)?
- How do the biota influence the physical and chemical characteristics of the sea ice?

Sea-ice Community Organization

Understanding is needed of how sea-ice and seasonal ice dynamics influence community structure. Understanding is also required of how ice influences the nature and rates of biotic process in the ice, on the ice, and in the water column beneath or adjacent to the ice, in the open waters of the marginal ice zone and beyond to waters uncovered during the annual ice retreat.

The above requires knowledge of the geophysical features of sea ice from mesoscale features to the microstructure of the ice fabric, the organic and inorganic chemistry of ice and brine inclusions and the optical properties of sea ice. While these topics are generally the domain of physicists and chemists, biologists must be aware of and focus on those aspects of these topics most likely to influence the sea-ice biota. Sea-ice microbiota are likely to be of considerable importance seasonally, because they include microbial biomass which is highly concentrated and available to microbial and metazoan grazers. Topics to be addressed:

- What is the composition (species/major taxa/trophic level and role) of the sea-ice assemblages?
- What regulated the species composition, distribution, age structure and biomass of sea-ice macrofauna?
- Are there recognizable spatial and temporal patterns of species succession and community development associated with different types of sea-ice and/or different geographical/ecological environments?
- At what life history stages and times of year do macrobiota, fish, birds and mammals inhabit/ utilize sea-ice?
    - Where are they found at other times/stages?
    - How do they use the sea ice? As a feeding site? As a breeding site? As a refuge from predation?
- What proportion, in terms of number, biomass, and age distribution, of the populations of Antarctic Ocean macrobiota, fish, birds and marine mammals are found in the Antarctic Sea-Ice Zone? How do these vary seasonally?

- What is the relative importance of polynyas, leads and the under-ice environment in influencing these distributions?

Sea-ice Community Production

The rates and types of biological processes related to the carbon cycle are substantially influenced by the presence and dynamics of sea-ice. This is best established for the microbiota, marine mammals and birds. Our knowledge is least for the ice macrobiota and we are still discovering what species, and in some cases phyla, are present in the ice.

Primary and secondary production is active seasonally even when under- ice water column production is nil. Priority areas for research include how various physicochemical and biotic aspects of the sea-ice habitat act together to influence the growth and development of the sea-ice microbial community.

- What is the "net" community production in sea ice and how does this vary temporally and spatially (e.g., what fraction is consumed in situ by heterotrophs)?
- Is ice-based production largely "new" or "recycled" production? Does this differ between pack- and fast-ice systems?
- Does the use of sea ice as a breeding and/or nesting site by seabirds and seals significantly influence (through nutrient input) the distribution and dynamics of other sea-ice biota and processes?

Adaptations of Sea-ice Biota

Ice-associated organisms must adapt at the molecular, physiological, and behavioural level to strong gradients in temperature, salinity, nutrients and light, in addition to the presence and activities of other ice biota.

- What are the physiological and ecological limits to the adaptations of key organisms of the sea-ice biota?
- How are the genetic adaptations of Antarctic biota influenced by the low temperature environment and how might these adaptations respond to long-term increases in temperature?
- How do sea-ice biota adapt to life (survival, growth, reproduction) at subzero temperatures and at salinities ranging from fresh waters to concentrated brines?
    - How do planktonic organisms survive the winter (eg through encysting, building-up lipid reserves)?
    - How do ice algae adapt to a low and spectrally altered irradiance field?
    - How does the combined influence of low light, low temperature and high salinity influence growth rates of sea-ice biota?
- Are pack-ice biota physiologically active and capable of in situ growth?

THE WATER COLUMN AND BENTHIC ECOSYSTEM OF THE ANTARCTIC SEA-ICE ZONE

Introduction

Water column and benthic processes are significantly affected by the presence and cycles of advance/recession of sea-ice. By providing a habitat for biota and by influencing both the size and duration of phytoplankton blooms, sea-ice governs euphotic zone production. This influence extends to the underlying water column through the role of sea-ice in the timing of the vertical flux of energy and matter, and by providing a habitat for grazing and consumer organisms. Zooplankton and nekton intercept part of the vertical flux, modifying it on the way down and transporting it within and outside the system by both vertical and horizontal migration as well as advection. The biomass and turnover of the benthos are also related to the downward flux of material.

Melting of the sea ice, stabilisation of the water column and seeding of the water with actively growing microbes provide appropriate conditions for subsequent ice-edge blooms. The Southern Ocean primary production cycles and their dependence on nutrient input seem to differ from other oceans. Thus primary production is lower than expected in the euphotic (illuminated) zone of the Southern Ocean given the apparently superabundant

supply of inorganic nutrients. Therefore, the concept of new versus regenerated production requires re-examination for Antarctic marine ecosystems. In conventional terms, C, N and Si cycles are uncoupled in most situations. There is also a need to identify the most appropriate measurements to define the output of phytosynthetic production to biogeochemical cycles. This output is presumably close to 'export production' (i.e. the flux of organic matter that leaves the euphotic zone).

Water Column Processes

Primary Production

Incoming radiation is attenuated with depth due to absorption and scattering by the water and, more importantly, the particles suspended in it. This obviously influences the rates of photosynthesis by phytoplankton at different depths in the water column, and defines the maximum depth at which net growth can take place. Mixing will expose the phytoplankton to a range of irradiance, perhaps taking them below the critical depth and thus placing them in an environment where net growth is not possible. Such rapidly changing light environments also make it impossible for the phytoplankton to optimize their photosynthetic performance for a particular irradiance.

- How do changes in the availability of light influence photosynthesis and primary production?
  - What is the magnitude and spectral distribution of incoming incident radiation?
  - How is the spectrally related attenuation in the water column related to vertical distribution of phytoplankton and other particulates?
  - What is the productivity of the water column beneath the seasonal sea ice and how is this affected by the transparency of the ice?
- How do changes in nutrient levels and nitrogen pools affect photosynthesis and primary production?
  - What is the chemical composition of nitrogen pools with particular reference to dissolved organic nitrogen (DON), urea, ammonia and nitrate?
  - Are the high nutrient concentrations in the water column measured by chemical methods available to phytoplankton? (eg Is nitrate uptake light- or temperature-limited and can uptake of nitrogen be suppressed by ammonia at times?)
  - Is the availability of silica possibly controlling production in bloom areas?
  - Do micronutrients (eg trace metals such as iron) limit primary production?
- How does mixing influence the availability of light and nutrients?
  - How are valid measurements of mixing, as opposed to mixed-layer, and euphotic zone depth to be obtained?
  - How important are the frequency and intensity of storms in vertical mixing processes?
  - What is the spatial and temporal extent/influence of meltwater on water column structure and productivity?
- How do phytoplankton blooms develop?
  - What determines over-winter survival of phytoplankton?
  - Are pack-ice algae able to seed ice-edge blooms?
  - How does seeding-stock size relate to the rate and magnitude of phytoplankton blooms?
- How are sedimentation and production rates of algal biomass inter-related? Can sedimentation rates control the development of algal blooms?

Primary Consumption

Important topics concerning the fate of the primary production involve the relative abundance and importance of the different components of the grazing community.

- What are the relationships between rates of production of algal biomass and rates of grazing by consumers? Can grazers control the development of algal blooms?
- What are the dominant seasonal components of the grazing community (micro-, meso- and macro-plankton)?
- What is the relative importance of the various classes of primary producers (bacteria, picoplankton, nanoplankton, diatoms), and how does this influence grazing food web structure?

Secondary (and higher) Consumption

The Antarctic Sea-Ice Zone may play a critical role in the life and life-cycles of secondary consumers like krill and other pelagic zooplankton and of higher-level consumers, such as seabirds and seals. The existence of perennial polynyas may be vital for some higher predators.

- What is the significance of the ice-zone to the survival of krill and other macro-zooplankton?
  - Is the ice-zone a refugium for juvenile krill at certain times of the year and/or in certain locations?
  - Do krill and other zooplankton feed and grow in the sea-ice zone?
  - What is the nature of zooplanktonic migration between the pelagic and sea-ice communities?
- What is the biomass, diversity, turnover and organization of the pelagic community?
  - What are the components of the food web that support the top predators, and how do these vary seasonally?
  - What is the importance of sea ice, and polynyas within sea ice, as a habitat for birds and marine mammals?
  - How does the ice modify the availability of prey to seabirds and marine mammals?

Benthos

Antarctic benthic communities are organized around the nature, abundance and predictability of organic inputs and their subsequent utilization. Sea-ice influences the productivity of ice algae, phytoplankton and, in shallow waters, benthic algae. The composition of the benthic communities determines the amount and quality of matter which will be finally stored in the sediment and thereby provide some form of geological signal.

Existing descriptions of the benthic communities are extremely limited but emphasize the primary influences of depth and advection. This suggests that the pelagic-benthic coupling depends upon zooplankton consumption of organic material and oceanic currents resulting in the advection and supply of organic material. Where currents are strong and organic material available, filter-feeding associations of sponges, cnidaria and bryozoans are conspicuous, whereas in other areas deposit- feeding associations dominate.

- What is the relative importance of the different size classes of benthos (microfauna, meiofauna and macrofauna), and how does this vary from site to site?
- What is the biomass and composition of the benthic community beneath ice shelves, particularly in relation to advective currents?
- To what extent do benthic macro-, meio- and microfauna release dissolved and particulate matter into the overlaying water and how does this vary with time and topography?

Fluxes and Interactions

The flux of biogenic particles out of the photic zone is a central process in the oceanic carbon cycle. Despite the perceived importance of the Antarctic Sea-Ice Zone in regulation of carbon cycles, few direct measurements of carbon and other elemental fluxes have been made to date in this region. Additionally, the Southern Ocean as a whole may also play an important role in the flux of opaline silica and calcium carbonate.

Food-web relations among the sea-ice macrobiota are largely unknown, but potentially important, especially with respect to energy and nutrient fluxes between sea-ice, water column and benthos. The microbiota may be grazed by organisms such as amphipods and krill which in turn are consumed by a variety of invertebrate and vertebrate predators. Little is known of the feeding ecology of the cryopelagic fauna or of the behavioural adaptations of epipelagic fauna which exploit the resources of sea-ice. Consequently there is little information on the diet and energy budgets of the seals, seabirds and whales characteristically associated with this zone. Dietary data from seabirds foraging in the pack-ice zone will also provide valuable information on the distribution of sea-ice macrobiota where conventional sampling methods may be inadequate.

- What is the annual pattern of flux of biogenic C, N, Si, P and carbonate and the elemental composition of particles over the shelf, at fronts and over the open ocean in association with the advance and retreat of the sea ice?

- What is the relative importance of sinking pelagic particles such as zooplankton faeces in the flux of chemical elements (C, N, Si, etc.)?
- What are the seasonal and vertical patterns of physico-chemically and biologically mediated processes of remineralization and modification of organic matter in relation to ice cover? What is the influence of advection?
  - How is production and consumption of dissolved organic matter (DOC) related to autotrophic and heterotrophic production and how is this related to DOC concentrations in deep waters?
  - How is carbon partitioned between organic and inorganic forms? Do analytical distinctions between labile and refractory DOC correspond to microbial, heterotrophic utilization?
- What are the chemistry and fluxes of POC and DOC between sea ice, water column and benthos?
  - What fraction of the primary production in ice-covered ocean leaves the euphotic zone (export production)? How much of the export production reaches the benthos and how much eventually becomes stored below the zone of bioturbation?
- How is the biomass, turnover, diversity and community structure of the benthos related to water column production and processes?
  - What are the relationships between the benthic community and planktonic species over-wintering just above the bottom?
  - What are the relative contributions of plankton and benthos to nutrient turnover and how does this relate to water depth?
- What is the relative importance of the pathways (eg diffusion, sedimentation, trophodynamics, migration) by which the sea-ice biota transfer energy/matter to the water column and benthos?
- What is the relative importance of the energy flux pathways through krill and through other macro-zooplankton?
- What is the relative importance of advection and vertical flux to the benthic community beneath sea-ice?
- What are the dynamics of competitive interactions between sea-ice and water column biota? How do these change seasonally?
- How do seasonal changes in sea-ice cover affect the demography and trophodynamics of key organisms within the pelagic (krill-dependent) food-web?
- What fraction of the primary production of ice-covered oceans leaves the euphotic zone (export production)? How much of the export production reaches the benthos and how much eventually becomes stored below the zone of bioturbation?

PALAEOENVIRONMENT: THE SEDIMENT RECORD

One of the primary aims of the sea-ice and water column studies is to estimate the major fluxes of carbon and other elements to the seabed. The great scientific value of the sediment record is that this reveals the past history of such fluxes. In the shorter (hundreds of years) time-scale this may indicate ecosystem changes associated with human influence. Over longer time-scales (thousands to millions of years) the sediment record documents major changes such as those associated with glacial and interglacial episodes. The boundaries and principal features of the water masses (the Polar Frontal Zone, the zone of seasonal sea-ice, the edge of the continental ice-shelves) are likely to have been further north during glacial maxima. To document these changes it will be necessary to sample sediments over a wide latitudinal range, perhaps to 60°S.

These studies will provide essential historical data for the interpretation of the sea-ice and water column studies, and will necessitate collaborative research with oceanic geophysicists and palaeontologists. Initial biologically-oriented questions include:

- What can the sedimentary record tell us about historical changes in water column processes?
  - To what degree do sinking particles reflect processes in the overlying habitat and can the resolution of such processes be resolved from the sedimentary record?
- How might climatic change result in alteration of the importance of calcareous micro-plankton (thereby resulting in dramatic changes in the carbon economy)?

RESEARCH APPROACHES AND DATA REQUIREMENTS

The Workshop identified two major initiatives, system modelling and monitoring of environmental change, which need to proceed in close conjunction with the development of the other experimental research on key processes in the Antarctic Sea-Ice Zone. In addition the Workshop addressed, in general terms, some major considerations relevant to the development and implementation of an overall research programme framework.

SYSTEM MODELLING

Models of interactions between physical and biological processes at various temporal and spatial scales should form a central component of research on the ecology of the Antarctic sea-ice zone. A general aim in the production and utilization of such models should therefore be to synthesize research activities as a whole. At a more detailed level, the development of suitably representative models will serve to parameterize key coefficients, will provide a basis for the testing of key concepts and further refinement/advancement of existing models. Model construction should therefore adopt an iterative approach based on actual observations and will involve both box and simulation models. The need for laboratory validation and hypothesis testing is emphasised. There should be strong emphasis on efficient communication between modellers and field researchers in order to promote the exchange of information and dissemination of new ideas. As such, modelling would serve to assemble information, disseminate ideas on key research areas and promote links with other research programmes which are also engaged in similar activities. It will also be used to test available hypotheses, to identify key parameters, to provide for data reduction/analysis and to provide predictive capabilities. The key objectives of modelling activities on the ecology of the Antarctic sea- ice zone are:

- to model ecosystem dynamics in the Antarctic Sea-Ice Zone;
- to develop models of ecosystem responses to environmental forcing and anthropogenically derived influences;
- to develop box and simulation models of primary production and carbon flux;
- to undertake sensitivity analysis to identify key parameters of dynamic interactions between environment, sea-ice and biotic factors;
- to identify key species and elements involved in the above interactions.

MONITORING AND MEASUREMENTS OF CHANGE

The recent interest concerning global climate change has emphasized the extreme value of time-series data. Powerful spectral analysis techniques depend on regular measurement with adequate replication to evaluate variance.

The aim of identifying and measuring long-term change raises different problems to those focussed on the quantification of contemporary nutrient pools and exchange processes. It is clear that more emphasis must be placed on measurements made from platforms other than ships. The study of change will need to be established as soon as possible and be repeated or continued for a longer period than the projected life of the main programme.

Evaluation of existing data sets

Although long-term data sets are few and are often non-systematic, they remain the only source of baselines for evaluation of long-term change. Shore-based measurements of the neritic environment have been undertaken for a decade or more, and these need to be analysed in detail in order to identify the magnitude and periodicity (seasonal and longer cycles) of environmental variation, and to select key variables for continued measurement. Operators of such programmes should be encouraged to continue them and to expand their coverage to include additional biological and physico-chemical processes directly relevant

to climate change and biogenic fluxes. Microbial heterotrophic cycles, including the cycling of radiatively active gases might be an appropriate topic for the former; monitoring winter sea-ice thickness from year to year would be an example of the latter.

There are several relatively recent archive data sets which might usefully be re-evaluated in this context. However, the production of higher-level data, such as synoptic ice- mapping, needs to take account of technical changes during the period under study.

Control and Inter-calibration

The reliance on remotely-sensed data, on autonomous instrumentation, and on data from neritic habitats all raise specific problems of inter- calibration before these data can be applied in the wider sphere for monitoring climate change.

Properties of the Antarctic Sea-Ice Zone which can be recorded by remote sensing provide a potent means of collecting synoptic data. In a number of cases, such data require habitat- or area-specific algorithms which allow the accurate conversion of the measured variable to a biological or environmental quantity. For example, ocean colour measurements from CZCS may require a different algorithm to yield chlorophyll biomass for that routinely used in coastal waters for lower latitudes, to the extent that there may be 40% underestimation of biomass using the latter. A further input of inter-calibration data is needed before phytoplankton biomass can be equated to photosynthetic activity.

As noted above, neritic areas are much more attractive than open ocean areas for field monitoring programmes, because the logistics of measurement and sample collection are simpler in the former. To use these data in programmes addressing long-term change in larger areas, requires determining the relationships between these nearshore data and offshore processes. Dedicated cruises to traverse from the monitoring site to open ocean would be one method, the use of in situ instrumentation on the continental shelf and/or in deep water would be another.

Requirements for a database

The participants to the workshop undelined the necessity to develop a database which should be able to handle the large volume of data produced by the proposed programme, particularly from remote sensing experiments.

PROGRAMME IMPLEMENTATION

The research approach and key questions developed during the workshop highlighted inter-dependent elements crucial to the development of coordinated research initiatives focussed on the ecology of the Antarctic Sea-Ice Zone and its relevance to assessment of global change. These elements require determination of the key processes regulating:

- survival of biota;
- biogeochemical cycles and
- ocean-atmosphere exchanges

in the Antarctic Sea-Ice Zone at a level of detail sufficient to understand their

- significance for global processes and
- likely responses to changing environmental conditions.

This requires a major long-term programme of inter- and multi- disciplinary research at a variety of temporal and spatial scales on an annual basis. Year-round studies are essential and winter observations are particularly necessary.

In order to achieve this, two broad areas of research activities are identifiable. These are:

a. experimentally-based studies of key processes and geographical areas, and
b. the acquisition of data through remote sensing.

Such activities are extensively inter-dependent through their common need for information gathered from ship- and shore- based research. A minimum 10-year programme will be required.

The implementation of such a programme also requires coordination and direction of research activities in the Antarctic Sea-Ice Zone, but there are three pre-emminent requirements.

First, the fundamental requirements for an effective research programme in the Antarctic Sea-Ice Zone is coordination of directed multi-national research. The scientific framework for this should be established as soon as possible.

Second, the success of these programmes will depend extensively on the development and use of standardized equipment and techniques for data acquisition and analysis. Coordination of such activities and their direction to the goals of the proposed programme should start soon.

Third, the early establishment of a suitable data management and processing system is essential. This system must be capable of handling, processing and disseminating potentially enormous quantities of data on an interactive basis in as close to real time as is appropriate.

To meet all three requirements, specialist panels should be convened to review the suitability of existing mechanisms and structures and to make explicit detailed recommendations with respect to programmes in the Antarctic Sea-Ice Zone.

APPENDIX 1

THE SEA-ICE ZONE ENVIRONMENT

Introduction

The physics of the sea-ice zone is characterized by frequent strong winds throughout the year which give rise to effective stirring of the mixed layer and to large surface stresses which drive the horizontal drift of the sea ice and ocean surface water. The presence of the sea ice allows the surface temperature over the sea ice areas to be greatly reduced compared to the temperature of the ocean water. Sea-ice affects heat and moisture loss from the ocean through albedo, gas exchange with atmosphere and mixing characteristics. Namely:

- Heat and moisture loss from the ocean are greatly reduced by the ice and are concentrated to the open water areas;
- The high albedo of the sea ice reduces short wave solar radiation absorption especially where the ice is covered by snow;
- The annual cycle of air-sea exchange of atmospheric gases influenced by the annual cycle of temperature and sea-ice cover as well as wind speed and vertical mixing;
- In summer the ocean is characterized by a relatively fresh surface mixed layer resulting from the accumulation of precipitation and the melting of sea ice. The frequent high wind speeds tend to ensure strong mixing of the upper layer of the ocean to the depth of 100-200 m, except in the marginal sea-ice zone;
- In winter the salt rejection from the freezing of sea ice causes convective mixing of surface water to lower levels, particularly over the continental shelves, where in some locations the transport

penetrates to the bottom water providing oxygenation. This deep convection also mixes circumpolar deep water upwards into the surface mixed layer;

- Horizontal ocean transport associated with the surface ocean circulation brings surface water southwards in some locations and drives it northwards in other locations, largely governed by bottom topography and the mean wind patterns, and
- The influence of the atmosphere on the sea ice and ocean, with the feedback to the atmosphere, gives rise to strong coupling of the atmosphere-ice-ocean system in the Antarctic sea ice zone.

Physico-Chemical Factors

The carbonate system in the Southern Ocean is largely unknown. Additional data on the distribution of total inorganic carbon, alkalinity, pCO_2 and dissolved organic carbon are needed. Inverse models calibrated by using such data will facilitate estimation of the rates and distribution of organic matter production (POC and DOC) and remineralization of this matter. Repeated surveys of these properties are required in order to estimate directly CO_2 uptake. In the light of recent hypotheses concerning the regulation of primary production in the Southern Ocean, additional data on micronutrient concentrations (for example Fe, Co etc) are required. The following specific questions are directed at improving data and understanding of physico-chemical factors in the sea-ice zone.

- How do seasonal and long-term changes in sea ice affect water column structure, nutrient supply, primary production and sedimentation rates beneath the sea-ice and at the sea-ice/open water interface?
  - What are the characteristics and effects of the physical environment (especially meteorological conditions, oceanic circulation and advection) on the distribution of seasonal sea- ice?
  - What is the spatial and temporal extent/influence of meltwater on water column structure and productivity?
- How does the sea-ice environment and its effects vary temporally and geographically?
  - What physical and biological processes are associated with spatial and temporal patchiness in the sea-ice zone and its associated biota?
  - What is the productivity of the water column beneath seasonal sea-ice and how is this affected by the transparency of the ice?

Air-Sea Exchanges

In general terms, the natural carbon cycle in the Southern Ocean may be characterized by two competing processes:

a. the upwelling of intermediate water rich in total CO_2 which promote outgassing, and
b. incorporation and downward export of carbon via primary production thereby promoting uptake from the atmosphere.

In turn anthropogenic perturbation impinges directly on this natural system. At present atmospheric data imply that there is essentially no net uptake of CO_2 in the Southern Hemisphere while on the other hand oceanographic data imply the converse. Model results also imply that outgassing, not inorganic carbon uptake as traditionally assumed, may have characterized the pre- industrial (i.e. pristine) situation in the Southern Ocean). There is thus still considerable uncertainty concerning the direction and magnitude of fluxes in the exchange of CO_2 between the atmosphere and ocean throughout the annual cycle. In particular, data are completely lacking on partial CO_2 concentration in the ocean of the sea-ice zone during winter. The following key questions are aimed at improving understanding of seasonal and longer-term changes in the nature and extent of air-sea exchanges in the region influenced by sea-ice:

- What is the seasonal and spatial variation of air-sea exchange of CO_2 in the Southern Ocean and what are the specific mechanisms controlling these variations?
- Given that sea-ice cover may inhibit gas exchange, how do seasonal changes in the nature and extent of the sea-ice cover affect local and global air-sea exchange in the Southern Ocean of CO_2 and other trace gases important for the Earth's radiation balance?
- How are surface current patterns affected by seasonal ice-cover and polynyas?

APPENDIX 2

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ANNEX 6

Existing and Projected Field Research in the Antarctic Sea-Ice Zone relevant to Priority Questions

This summary consists of material from three sources:

1. Existing national proposals for multi-disciplinary research from:
   France
   Japan (Sea-Ice Ecology and Flux Study
   United Kingdom (Southern Ocean BOFS Study)

The extracts comprise the title page, summary objectives, location and proposed timetable of research.

2. Extracts, from 1989 reports to SCAR, of major relevant projects scheduled for 1989/90, by:
   Chile
   Finland
   Italy
   Korea
   Norway
   USA
   USSR

3. Summaries, provided at the Workshop, of some potentially relevant forthcoming planned cruises, from:
   Germany (Federal Republic)
   South Africa

This summary is inevitably incomplete; additional and corrected information should be sent direct to the Convenor of the Group of Specialists.

Scientific Committee on Antarctic Research
Scientific Committee on Oceanic Research

GROUP OF SPECIALISTS
ON
SOUTHERN OCEAN ECOLOGY

Report of the meeting held in Bremerhaven, Germany 17-18 September 1991

1. Introduction

Dr G Hubold (Convenor) welcomed the members of the Group of Specialists on Southern Ocean Ecology (GOSSOE) (names and addresses at Annex 1; a list of acronyms is at Annex 2). Drs J P Croxall and D G Miller agreed to act as rapporteurs.

2. Review of the EASIZ Implementation Workshop

The Group received the draft report from the Workshop on the Implementation of the SCAR Ecology of the Antarctic Sea-ice Zone (EASIZ) Programme. After further refinement and development, this report was finalized (Annex 3). Dr J P Croxall acted as rapporteur for this process.

Review of National and International Research Programmes

The Group of Specialists noted that the Workshop's review of current national and international initiatives had focused particularly on:

a. Southern Ocean JGOFS (SO-JGOFS), a major new international programme addressing most EASIZ objectives in the field of carbon flux at lower trophic levels in the ASIZ;
b. SO-GLOBEC, a proposed international programme of wide objectives, broadly complementary to SO-JGOFS, focusing on the role of physical and biological processes influencing the dynamics of marine animal populations within the context of global change.

Evaluation of the Trondheim EASIZ Workshop Report and Progress Towards Implementation

The review of the questions in the Trondheim Workshop Report had confirmed that the research framework provided there was highly appropriate to developing a programme of good scientific quality addressing objectives of both regional and global priority.

In addition, the current Workshop identified the coastal and shelf zone as a region for which further development of research priorities was required before implementation could proceed. A rationale for this had been provided, suggestions made for priority research topics and necessary tasks identified which were essential precursors to the development and implementation of actual research programmes.

The programme for SO-JGOFS was already assured of implementation. More work on data management and related topics, however, would be needed to ensure the most effective use of the results of the field programmes. In addition, however the Workshop had identified the need for implementing fully SO-JGOFS in coastal and shelf areas.

SO-GLOBEC was, at present, simply an outline proposal for an exceptionally ambitious research programme. However, this programme did plan to cover most of the research objectives of EASIZ outside those treated within SO-JGOFS. It therefore merited a serious attempt to establish it as a major forthcoming biological intiative in the ASIZ. The Workshop stressed that this could only be achieved through multinational, interdisciplinary participation and would require the full cooperation and commitment of SCAR.

3. Advice to SCAR on Implementation of the EASIZ Programme

The Group of Specialists endorsed the conclusions of the Workshop (Annex 3, pp 39-40).

Advice to SCAR was developed in four ways:

1. Recommendations for action to advance and plan the implementation of international programmes, accompanied by specific suggestions for ways to achieve this;
2. Information on the proposed future initiatives of the Group for developing new programme implementation plans;
3. Recommendations to SCAR on the role of the Group in promoting coordination with research in the ASIZ by other international bodies;
4. Requests to the SCAR Secretariat concerning support for the work of the Group.

International Programme Planning and Implementation

SO-JGOFS

The Group *recommended* that SCAR co-sponsor SO-JGOFS activities and take an active role in the development of that programme, including promoting related studies in the coastal and shelf zone.

The best way to initiate and maintain interactions between SCAR and SO-JGOFS would be for SCAR to request that an appropriate member of the Group of Specialists should attend all future meetings of the planning committee of SO-JGOFS.

SO-GLOBEC

The Group *recommended* that SCAR, in conjunction with SCOR, seek to participate fully in the further planning and implementation operations concerning SO-GLOBEC.

SCAR should note that the proposal for an SO-GLOBEC Planning Group (Appendix) envisages SCAR making some nominations for membership. The Group reviewed the membership of the Planning Group proposed by the US-GLOBEC Scientific Steering Committee in the light of the nature of the eight working groups which had generated the current Southern Ocean research proposal at the San Diego meeting. Of the five members suggested with Antarctic experience, one was a modeller, two were experts in biogeochemical cycling and two were specialists in microzooplankton population dynamics. Research fields not represented in the proposed Planning Group membership are, therefore, physics and climate, micronekton especially krill, benthos, top predators and physiological processes. Furthermore, none of the members so far proposed has any extensive experience of BIOMASS and CCAMLR research.

The Group *recommended* that SCAR nominate to the SO-GLOBEC Planning Group, scientists, including at least one from the Group of Specialists, who are best able to represent research fields not covered by the proposed membership.

The Group also noted that if suitable progress in defining programme and implementation aims was made by the SO-GLOBEC Planning Group, it was highly likely that the Group would be recommending that SCAR formally co-sponsor this programme.

Data management

General issues
In the report of its last meeting the Group of Specialists recommended the early establishment of data management systems to support the EASIZ research objectives. It suggested that a specialist panel be convened to consider this. Subsequently SCAR reviewed the whole topic of coordination of Antarctic data and established an ad hoc group to examine this. The Group of Specialists had nominated Dr. D.G. Miller to the ad hoc group, but so far there was little indication that any progress had been made

The Group of Specialists *recommended* that SCAR proceed with its data management initiatives as a matter of urgency.

The research programmes being prepared within EASIZ require the management of multidisciplinary data as a high priority. This will need evaluation and development by appropriate specialists and cannot be done by the Group itself.

BIOMASS Data Centre
The Group noted that with the imminent conclusion of the BIOMASS programme the BIOMASS Data Centre would be arranging the distribution to contributors of the complete data holdings of the Centre. The data would therefore be freely available for further analysis.

The Group *recommended* that SCAR should encourage members to undertake further work using these data, especially of an interdisciplinary nature and including the development of models to guide future research initiatives.

Development of Implementation Plans for Research on Coastal and Shelf Zone Processes
The Group of Specialists agreed to form a Task Group on EASIZ Programme Coordination and Implementation for Coastal and Shelf Zone Processes in order to develop these programmes, with the following terms of reference:

- To review existing and historical programmes and information;
- To coordinate existing research initiatives relevant to the Trondheim EASIZ Workshop questions;
- To develop any necessary additional research initiatives relevant to the Trondheim EASIZ Workshop questions;
- To address the standardization of methods for existing and projected research.

The Task Group, comprising invited participants, would undertake these tasks at a three day workshop to be held in conjunction with the next meeting of the Group of Specialists.

Coordination of International Research in the ASIZ
A number of other international programmes, relevant to the objectives of EASIZ, are already underway or being planned for the ASIZ. These include research within WOCE and planning within SCOR. The Group therefore needed to improve liaisons with those bodies and particularly with SCOR.

The Group *recommended* that SCAR request SCOR to ensure that members of the Group of Specialists with appropriate experience are represented on SCOR Working Groups concerned with the Southern Ocean.

Support for the Work of the Group of Specialists
The Group noted with concern that the Report of the Trondheim Workshop still had not been published nor circulated by SCAR. Thus 15 months had elapsed since the development of the research objectives for the only marine biological programme contributing to SCAR's priority IGBP initiatives. It was essential that the SCAR marine biological community be informed as soon as possible of the content of the EASIZ programme.

The Group *recommended* that SCAR publish simultaneously and circulate immediately the reports of both EASIZ Workshops to National Committees.

These reports should also be sent to all the contact scientists identified at the Trondheim Workshop and to all participants in both workshops.

General comments to SCAR
There are significant implications for SCAR in the initiatives being developed by this Group of Specialists.

The EASIZ Programme is the framework for SCAR's only major multinational interdisciplinary programme of Antarctic marine biological research. It will contribute directly to the objectives of SCAR's IGBP Programme and therefore has developed good links with appropriate physical and chemical programmes in the same areas.

If SCAR wishes to continue a role in developing significant marine biological research in the ASIZ it will be essential to start making plans now to ensure the availability of appropriate logistic capabilities for a five-year period commencing in about 1995-96.

Necessary facilities will include remote sensing by aircraft, submersible and satellite, *dedicated* cruises of research vessels, moored and mobile instrumented platforms etc.

4. Reports from Subgroups

Fish Biology and Physiology
The convenor, Dr J C Hureau, presented a verbal report on the activities during the past year. A meeting of members of this subgroup is to be held in association with the BIOMASS Colloquium. The secretary (Dr M G White) had convened a workshop on Antarctic Ichthyology at the European Ichthyological Congress at The Hague in August 1991. Drs M G White and A W North had prepared a second Antarctic Fish Newsletter which was circulated in 1991. It is hoped to publish these newsletters annually in future. The subgroup had also undertaken an exchange of otoliths of Antarctic fish to develop further aging techniques and a workshop on aging of Antarctic fish is being convened by Dr J C Hureau in Paris in December under the auspices of the European Science Foundation. There has also been progress towards creating a network of European ichthyologists interested in Antarctic fish with a theme of Evolution in Antarctic Fish. Dr White was thanked for his hard work in promoting all these valuable initiatives.

Krill Biology and Physiology
The convenor, Dr D G Miller, made a verbal report on activities during the past year. There had been two major activities. A BIOMASS Workshop on Krill Ecology was held at Cambridge in May 1991. The report of this meeting would appear in the BIOMASS Report Series and a publication coordinated by Dr J Watkins (Secretary of the subgroup) on behalf of the Workshop is in preparation for submission to the primary literature. The CCAMLR Working Group on Krill had held its third meeting in the USSR in August 1991 at which 47 scientists representing 13 nations were present. A wide variety of research on krill was discussed, especially in relation to estimating yield. These included acoustic echo integration techniques, design of acoustic surveys, estimation of demographic parameters, growth rates, production-to-biomass ratios and quantitative relationships between krill and

its predators. One important consequence was the need to re-analyze the FIBEX acoustic estimates of krill biomass in the light of recent advances in the determination of krill target strength.

5. Future Membership and Role of the Group of Specialists

Role
The Group has made substantial progress towards its task of coordinating and developing research and implementation plans for marine biological research in the ASIZ. In particular the Trondheim Workshop defined the key questions and priorities within the EASIZ framework.

The development by the Group of Specialists of links with the evolving SO-JGOFS Programme should now lead to SCAR co-sponsorship of this programme, bringing significant mutual advantages. This would also create additional responsibilities for the Group.

The involvement of the Group of Specialists at the early stages of planning towards SO-GLOBEC is essential if this programme is to develop to the advantage of the international marine research community operating within the ASIZ. The group, therefore, has a crucial role to play in this process.

The Bremerhaven Workshop has taken the first practical steps towards developing appropriate coordinated research on coastal and shelf processes. These steps have generated much interest amongst key research groups in several SCAR nations. There is an important role for the Group of Specialists in coordinating future developments and in ensuring that these contribute to the EASIZ framework and approaches.

Additional tasks, involving closer liaison with the work of the SCAR ad hoc Data Coordination Group and with appropriate SCOR working groups also indicate an enhanced role for the Group of Specialists.

Membership
The additional roles for the Group of Specialists indicates a need to consider whether the changes to its membership are desirable. Two proposals were considered. First, to develop a process whereby at least some of the existing members are replaced by rotation. Second, to change the membership to reflect the nature of the expertise required to undertake the prospective tasks of the Group (in particular in relation to liaison with SCOR, SO-JGOFS, SO-GLOBEC and research initiatives in the coastal and shelf zone).

The Group agreed to develop appropriate plans at its next meeting. In the meantime it was felt essential to find some way of enabling additional scientists to gain experience of the work of the group. It was agreed that a small number of scientists, representing appropriate marine biological research disciplines, would be invited to attend the next meeting of the group as observers. Preference would be given to scientists who can provide links with SO-JGOFS, SO-GLOBEC and SCOR working groups.

6. Other Matters

Next Meeting
The next meeting of the Group will be held at the British Antarctic Survey, Cambridge, probably in September 1992. Members of the Group would be ballotted in order to find the most convenient date.

Budget

1991 The 1991 budget of the Group of Specialists was $15,000 for both the Workshop and the meeting of the Group. Thanks to attendees and members receiving institutional and other funding, both meetings were accomplished for $13,000.

1992 The budget allocated to the Group for 1992 ($10,000) was based on the assumption that only a meeting of the Group would be required. However, the Group now needs to organize the Workshop of the Task Group on EASIZ Programme Coordination and Implementation for Coastal and Shelf Zone Processes and to hold a meeting of the Group of Specialists in association with this.
Accordingly the Group submits the following revised budget for 1992 to SCAR:

Workshop (includes surplus from 1991)	5,000
Group of Specialists Meeting	10,000
Total	**$ 15,000**

1993 The projected outline budget for 1993 reflects the Group's enhanced activities in coordinating Southern Ocean research with other international bodies:

Group of Specialists Meeting	10,000
Attendance at Steering Group Meetings (SO-JGOFS, SO-GLOBEC, SCOR)	5,000
Total	**$ 15,000**

1994 The Group plans to hold a major Workshop (in association with the SCAR Biology Symposium in Italy) to coordinate implementation plans for major marine biological initiatives in the ASIZ which are currently scheduled to commence in 1995/96. A preliminary budget estimate is:

Group of Specialists Meeting	10,000
Workshop	10,000
Attendance at Steering Group Meetings	5,000
Total	**$ 25,000**

Representation at XXII SCAR
A report on the Group's activities has to be presented to the next meeting of SCAR at Bariloche, Argentina, in June 1992. If Dr Hubold is unable to attend Dr Croxall agreed to do this.

Contribution to SCAR Document for the Antarctic Treaty Meeting, Bonn 1991
A contribution of 500 words on the future of Southern Ocean Ecology, to be produced by the end of the BIOMASS Colloquium, was requested from the Group. The convenor agreed to arrange this.

7. Close of Meeting

In closing the meeting Dr Hubold thanked the Director of the Alfred-Wegener-Institute for permission to hold the meeting there, Dr S Schiel for organizing all the arrangements, the participants and rapporteurs for producing the report and Mrs D Burhop for typing it.

APPENDIX

Proposal for a GLOBEC Planning Group on Southern Ocean

Preamble

In May 1991 a GLOBEC-sponsored workshop was held at Scripps Institution of Oceanography which had as its general objective the development of a science plan that can be used to outline an international GLOBEC initiative in the Southern Ocean. This workshop brought together approximately 40 scientists from 10 nations. Discussions at the workshop centered around eight working groups that considered issues relating to physics and climate, zooplankton and krill, benthos, top predators, modelling, physiological rates, new technology and population dynamics. The consensus of the working groups was that a GLOBEC initiative be planned for the Bellingshausen Sea adjacent to the Antarctic Peninsula coastal region. This area was chosen because available information indicates that it contains an identifiable gyre that would provide a means to isolate populations with planktonic stages. Also, this region contains relatively large populations of the key species recommended for study, including krill, a variety of benthic species and important species of fish, seabirds and seals. Finally, sea-ice is a consistent feature in the eastern Bellinghausen Sea, which will allow study of sea-ice dynamics in relation to population dynamics and habitats of key species.

In September 1991 a SCAR-sponsored workshop was held at Alfred-Wegener-Institut für Polar- und Meeresforschung to consider scientific problems in the Antarctic sea-ice zone (EASIZ), attended by approximately 35 scientists from 15 nations. The Workshop noted that the GLOBEC Southern Ocean Programme covered in outline many of the questions contained in the EASIZ Trondheim report of 1990. The Workshop recommended "that SCAR, in conjunction with SCOR, should seek to participate fully in the further planning and implementation operations concerning this programme".

Proposal Objective

The results of the GLOBEC Southern Ocean Workshop and the EASIZ Workshop clearly demonstrated that there are major scientific questions to be addressed in the Antarctic that are consistent with the objectives of GLOBEC. To continue the enthusiasm and momentum generated in the scientific community, it is timely to convene a planning group to coordinate the international aspects of such an initiative. The US-GLOBEC Scientific Steering Committe has proposed six members for this group, and now asks for the advice of SCAR in appointing one or two additional members.

Terms of Reference

- to coordinate long-range planning for a Southern Ocean GLOBEC initiative
- to evaluate future opportunities for international collaborations in developing a GLOBEC initiative in the Southern Ocean
- to assess programmes and methods relating to investigations of the Southern Ocean within the contect of GLOBEC objectives
- to report to the GLOBEC Scientific Steering Committee and SCAR on the development of a Southern Ocean GLOBEC initiative.

Proposed Membership

E Hofmann	US-GLOBEC	J Priddle	United Kingdom
M Huntley	US-GLOBEC	V Smetacek	Germany
V Marin	Chile	J O Strömberg	Sweden (SCOR)

ANNEX I

Members attending the Group of Specialists Meeting

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ANNEX 2

List of Acronyms

BAHC	Biospheric Aspects of the Hydrological Cycle (IGBP)
BIOMASS	Biological Investigations of Marine Antarctic Systems and Stocks (SCAR/SCOR)
CCAMLR	Convention of the Conservation of Antarctic Marine Living Resources (Antarctic Treaty System)
EASIZ	Ecology of the Antarctic Sea Ice Zone (SCAR)
FIBEX	First International BIOMASS Experiment
GAIM	Global Analysis, Interpretation and Modelling (IGBP)
GCTE	Global Change and Terrestrial Ecosystems (IGBP)
GLOBEC	Global Ocean Ecosystems Dynamics Research (US Global Change Research Program)
GOEZS	Global Ocean Euphotic Zone Study (IGBP)
IGAC	International Global Atmospheric Chemistry Project (IGBP)
IGBP	International Geosphere Biosphere Programme (ICSU)
IOC	Intergovernmental Oceanographic Commission (Unesco)
JGOFS	Joint Global Ocean Flux Studies (SCOR/IGBP)
JOI	Joint Oceanographic Institutions Inc. (US organization)
LOICZ	Land-Ocean Interactions in the Coastal Zone (IGBP)
PAGES	Past Global Changes (IGBP)
RACER	Research on Antarctic Coastal Ecosystem Rates (US National Program)
SCAR	Scientific Committee on Antarctic Research (ICSU)
SCOR	Scientific Committee on Ocean Research (ICSU)
SIBEX	Second International BIOMASS Experiment
SO-GLOBEC	Southern Ocean GLOBEC
SO-JGOFS	Southern Ocean JGOFS
STIB	Stratosphere-Troposphere Interactions and the Biosphere (IGBP)
WCRP	World Climate Research Programme (WMO/ICSU)
WOCE	World Ocean Circulation Experiment (WCRP)

ANNEX 3

Scientific Committee on Antarctic Research
Scientific Committee on Oceanic Research

Report of the EASIZ Programme Implementation Workshop

held in Bremerhaven, Germany
14-16 September 1991

INTRODUCTION

Dr G Hubold, Convenor of the SCAR/SCOR Group of Specialists on Southern Ocean Ecology, welcomed the 37 participants from 14 SCAR nations to the meeting. He thanked the Director of the Alfred Wegener Institute, Prof G Hempel, for his kind offer to host the meeting over a weekend in Bremerhaven. He especially thanked Dr S Schiel for the excellent arrangements for organizational and logistic support. Drs J P Croxall, P K Dayton, D G Miller and J H Priddle acted as rapporteurs.

Dr J C Hureau, the Convenor of the Group from its inception in 1986 until 1990, reviewed the history of the Group, leading to the Workshop at Trondheim in May 1990 at which the priorities and key questions for marine biological research in the Antarctic Sea Ice Zone were developed. The subsequent recommendations of the Group of Specialists were that:

1. SCAR should decide on the implementation of a multi-disciplinary programme in the Antarctic Sea-Ice Zone.
2. SCAR should task the Group of Specialists to develop and coordinate the scientific, logistic and technological framework of such a programme by establishing and coordinating specialized sub-groups and specialists panels.
3. SCAR should provide for the creation of specialized sub-groups and expert panels.
4. SCAR should provide an administrative structure to assist the Group of Specialists in this task.
5. SCAR should sponsor a programme implementation workshop, which could be held during 1991 in connection with the Antarctic Science Conference.

SCAR accepted these recommendations in August 1990. It agreed that a multidisciplinary programme on the Ecology of the Antarctic Sea Ice Zone (EASIZ) was an essential part of the SCAR contribution to IGBP. However, SCAR is at present unable to provide either funds or administrative support to assist in the development of the programme. It agreed, however, to sponsor a programme implementation workshop to be held in Bremerhaven prior to the BIOMASS Colloquium in September 1991.

The terms of reference for this Workshop were:

1. to review national and international research plans for the Antarctic sea-ice zone
2. to evaluate the scientific questions developed by the "Trondheim Workshop 1990" in terms of viability and practical implementation, taking in account national and international research plans
3. to identify gaps in international research and prepare a revised research plan providing sea-ice zone related biological inputs to
   - IGBP core programmes 1, 4 and 5
   - SO-JGOFS
   - SO-GLOBEC
   - CCAMLR

4. to formulate a strategy for the research plan's implementation and coordination with other programmes.

INTERNATIONAL RESEARCH PROGRAMMES

IGBP

The research programmes contributing to SCAR-IGBP were defined at meetings in 1990 and are as follows:

1. Antarctic sea-ice zone marine biota and their role in ice-associated biogeochemical processes, including carbon cycling and biogenic gases
2. Global palaeoenvironmental records from the Antarctic ice sheet, and marine and land sediments
3. The mass balance of the Antarctic ice sheet and sea level
4. Antarctic stratospheric ozone and biospheric (including uv-b) effects
5. The role of the Antarctic in global biogeochemical cycles and exchanges
6. Detection and prediction of global changes in the Antarctic.

Simultaneously the Steering Committee for the global IGBP Programme was also defining its key questions and their associated core projects. These were defined as follows:

1. How is the chemistry of the global atmosphere regulated and what is the role of biological processes in producing and consuming trace gases?
   IGAC - established
   STIB - proposed
2. How do ocean biogeochemical processes influence and respond to climate change?
   JGOFS - established - field programme since 1989
   GOEZS - proposed
3. How will changes in land use affect the resources of the coastal zone, and will change in sea-level and climate alter coastal ecosystems?
   LOICZ - under establishment
4. How does vegetation interact with physical processes of the hydrological cycle?
   BAHC - established
5. How will global changes affect terrestrial ecosystems?
   GCTE - established
6. What significant climatic and environmental changes have occured in the past, and what were their causes?
   PAGES - established
7. How can our knowledge of components of the Earth system be integrated and synthesized in a numerical framework that provides predictive capacity?
   GAIM - proposed.

Table 1. Cross-reference matrix between IGBP questions (1-7) and SCAR-IGBP research topics (1-6)

	SCAR 1	SCAR 2	SCAR 3	SCAR 4	SCAR 5	SCAR 6
IGBP 1	part			whole	part	
IGBP 2	part				part	
IGBP 3						
IGBP 4						
IGBP 5						
IGBP 6		whole	part?			
IGBP 7	part?		part?		part?	whole

The relationships between SCAR-IGBP and global IGBP Programmes are summarized in Table I. The Workshop noted that with the exception of programmes on ocean

biogeochemistry (SCAR 4, IGBP 1) the SCAR-IGBP and global IGBP programmes in the marine environments lack substantial congruence. The Workshop noted the importance of retaining EASIZ as an integrated research programme and recommended that SCAR retain it as such in any revisions of its IGBP programme.

Southern Ocean - JGOFS
Dr J H Priddle introduced the SO-JGOFS Programme and tabled the list of contents and key extracts from the overall SO-JGOFS reports. Copies of the final report can be obtained from the SCAR Secretariat. This programme is already an established part of JGOFS and has developed a full implementation schedule. It has, however, received no input from SCAR so far.

Southern Ocean - GLOBEC
Dr M Huntley introduced the proposed Southern Ocean GLOBEC Programme on Marine Animal Populations and Climate Change in the Southern Ocean. This programme is a development arising from the GLOBEC element of the US Global Change Research Program. The Southern Ocean proposal was a product of an international workshop held in San Diego in May 1991. The summary and recommendation section of this report was tabled; a full copy of the document can be obtained from JOI in due course.

The SO-GLOBEC Programme provides a framework for implementing a multinational interdisciplinary study of physical and biological processes that affect the population dynamics of selected Antarctic biota with the object of assessing potential responses to global change. The programme will provide the scope for utilizing historical data for site-specific modelling activities to precede field studies. It will also encourage the development and application of new technology required to enhance observational capabilities.

CCAMLR
Dr J P Croxall summarized the research being carried out within CCAMLR in support of its management of marine resources and of its programme investigating relationships between harvestable resources (especially krill and fish) and the species naturally dependent on these.

NATIONAL PROGRAMMES

Brief oral presentations on relevant national marine research programmes were given by participants from Australia, Chile, France, Germany, Italy, Japan, Netherlands, New Zealand, Norway, Poland, South Africa, USSR, United Kingdom, USA. Written summaries of most presentations were prepared and are archived with the SCAR Secretariat.

RELATIONSHIPS BETWEEN ANTARCTIC MARINE RESEARCH PROGRAMMES AND THE EASIZ PRIORITIES AND QUESTIONS DEVELOPED AT THE TRONDHEIM WORKSHOP

The workshop conducted this review by forming three ad hoc groups to consider programmes in particular research areas.

1. Report of Coastal and Shelf Zone Systems Group

Introduction
The group agreed that considerably more emphasis needed to be placed on the Antarctic coastal and shelf zone system as part of the EASIZ programme than was provided for by the framework of the Trondheim questions. A major reason for this was that the Antarctic coastal and near-shore ecosystem is substantially different from that dominated by the oceanic seasonal pack-ice. Although on further review it was found that most of the

questions contained in the Trondheim report were applicable to the coastal and shelf zone, it was agreed that a major task for the Group would be to highlight specific scientific activities to be undertaken in that zone. It was emphasized that the presence of shore stations adjacent to the coast provides a useful logistic basis for research in the Antarctic coastal and shelf zone. Nevertheless, since this zone includes shelf-areas, regular sampling off-shore will still be necessary to address all the objectives relevant to the EASIZ Programme.
The group reviewed the main differences between the coastal and shelf systems and the oceanic systems. It also outlined some priority topics for scientific investigations.

Sea-ice Physics
Important ecological differences between the coastal and shelf zone and the pack-ice include:

1. the anchor-ice phenomenon and its ecological effects;
2. increased amounts of frazil ice and platelets in the nearshore region which offer more habitat to the ice community;
3. freshwater melt ponds, which are sites of high primary production;
4. wind blown terrestrial debris; and
5. the many icebergs in the coastal zone, which modify the surrounding water in various ways (fresh water output, affecting the currents, seeding the surrounding water with species melting out of the ice, disturbing the benthos).

Sea-ice Communities
The pack-ice and coastal zone ice communities have strikingly different physical structures and mechanisms of formation that are biologically important. The coastal zone communities have different suites of species at all levels (micro-/meio-/macrofauna/flora) and dramatically higher biomass than the pack-ice. Further, the cryo-pelagic life styles are very different. It is important to contrast and compare the functional differences between shelf and pack-ice habitats in assessing the overall productivity of the sea-ice ecosystem.

Water Column
The pelagic species in the coastal zone are very different from those in the pack-ice. These differences, which occur at all trophic levels from protozoa to mammals are sufficient to imply functional differences as well.

Benthic and demersal biota
The benthic component is one of the most significant differences between coastal zone and pack-ice zone communities. The coastal and shelf zone benthos is a more interactive component of the system than in the pack-ice zone.

The bottom topography has important effects on the physical oceanography resulting in enhanced mixing, variable benthic-boundary layer relationships, and different patterns of larval transport. The coastal topography (both landforms and ice barriers) affects many physical processes at a variety of scales (eg island wakes, eddies, transport via internal waves, tidal bores, "squirts", "jets", meanders and fronts). These and similar coastal zone processes are very different from pack-ice zone processes.

Finally, study of the coastal zone benthic and demersal system requires both scuba diving and ship-based research. Because the water column is relatively isothermal, deep shelf species can be retrieved for laboratory study and even translocated into shallow water. This can enhance resolution of physiological and ecological processes.

Primary production
High standing crops and rates of primary productivity compared with the pelagic region characterize the coastal and shelf zone. Shallow polar systems usually include large amounts of production from benthic macro- and microalgae in addition to production from ice algae and phytoplankton. Coastal blooms have ecological consequences that distinguish them from oceanic blooms. One of the most important is that much of the algae sinks to the

benthos rather than being consumed in the water column. This makes an important contribution to the benthic herbivores and serves as a source of carbon which is resuspended and transported in winter storms. Similarly macroalgal debris, dissolved organics, nutrients and minerals are resuspended and transported. These processes can result in substantial regional effects on the benthos including the sequestration of carbon into the shelf sediments.

Primary Consumption
There are many important differences between the grazers in the pack-ice and the coastal and shelf zone. The species are different and many have different life history adaptations presumably resulting from the seasonal differences in the ice. The benthos is much more tightly coupled to primary production via suspension and detritus feeders, which are abundant and large. Decomposition processes and rates may differ importantly from those in more temperate systems.

Secondary Consumption
Demersal fish, benthic invertebrates (particularly sponges, echino-derms, coelenterates and crustaceans) have especially important community roles and are very suitable for experimental study. The summer presence of colonies of penguins and seals in the coastal zone results in patchy regions of intense predation and localized nutrient inputs.

Processes
Study of biochemical and physiological adaptations using modern techniques and equipment are more amenable to year-round research at shore stations than during ship-based operations. In addition, growth rates of marked individuals is feasible in coastal systems where they can be studied by diving or recapture. The ecological processes can be studied with year-round field pro-grammes in the coastal zone. Thus benthic, water column and sea-ice communities can receive much more intensive research in the coastal zone from shore stations than is possible in the pack-ice system. Not only are the communities composed of different species, their organization and dynamics are more complicated because there are many types of disturbances (for example, anchor ice and icebergs on the benthos) which result in opportunities to study successional processes (recruitment, competition, differential survivorship, etc.). It was emphasized that this type of research should not be restricted to shore based stations. In all cases ship surveys and at-sea research are vital components covering the entire shelf area.

Fluxes and Interactions
New primary production and sedimentation may be higher in the coastal and shelf zone than elsewhere. The role of the benthos in this process is virtually unknown and needs research. Indeed,the quantity and quality of organic flux to the benthos is highly variable in the coastal zone, as seen in both McMurdo Sound and the Weddell Sea. It is clear that oceanographic processes driving advection at several scales (benthic boundary layer interactions to large gyres) need study. All of the questions listed in the Trondheim report are particularly relevant to the coastal and shelf zone. Their resolution demands much better coordination between ship and shore-based research. At a smaller scale, the transport of carbon and nutrients between the land and sea by birds and seals can have pronounced small scale consequences. In the low Antarctic soil-water-sea water cycles may be locally important.

Palaeoenvironmental Records
The sedimentary record offers much palaeoenvironmental information in both coastal and pack-ice regions. Because they are subject to more intensive and variable sedimentation, coastal regions offer finer scale resolution, especially of more recent events.

Monitoring
Because shore-based ecological programmes have been conducted for several decades, there are many potential sources of valuable long-term monitoring data. In addition, old study sites can be revisited and evaluated for subsequent changes.

Standard measurements of meteorology, sea ice, water column and benthos could readily made at all shore-based stations.

Monitoring of anthropogenic effects is also essential near shore stations.

Implementation

1. Information is required on existing and historical programmes. The ad hoc group recommended that a questionnaire be developed and circulated to all countries and to the principal research groups conducting Antarctic studies in the coastal and shelf zone. The questionnaire would seek details on both long-term data sets and short-term projects. Input from scientists was regarded as particularly important. The questionnaire would be accompanied by copies of this report and that of the EASIZ Trondheim Workshop. Specific information would be sought on research being undertaken relevant to the EASIZ Trondheim Workshop questions. The information requested would also include names of principle investigators and brief project descriptions.
2. Standardization of methods used in existing and projected research is a major requirement. The *ad hoc* group recommended that the appropriate JGOFS, WOCE and other relevant protocols (e.g. of BIOMASS, CCAMLR, IOC) be adhered to where possible. Other measures which fell outside such guidelines were discussed. Particular emphasis was placed on sea-ice measures. The ad hoc group recommended that at least the following parameters be recorded on a weekly basis: thickness, snow-cover, extent, dates of break-out and formation. Iceberg numbers and size should also be recorded. For the water column parameters recommended were: temperature, salinity, light, UV-β, chlorophyll, CO_2 and currents. Monitoring of anthropogenic effects should include hydrocarbons, faecal coliforms and organochlorines.
3. There is a strong need for multidisciplinary research. Key areas for further development are sea-ice microanalytical chemistry, near-shore physical oceanography, ice physics, sedimentology and remote sensing. Year-round measurements are particularly important.

2. Report of the Southern Ocean JGOFS Group

Southern Ocean JGOFS has a planned study of carbon cycling within the Antarctic marine ecosystem. It has defined a rationale and objectives for the study. These derive from a modification of the overall aims expressed in the JGOFS Science Plan (JGOFS 1990), focussing on those aspects of the Southern Ocean system which have special significance. In particular, it addresses the problems of sea-ice related studies and also takes into account the logistics and scientific framework. Nevertheless, SO-JGOFS is a JGOFS regional study - it works within a defined framework and must produce data which are compatible with other JGOFS studies.

Comparison of EASIZ and SO-JGOFS

JGOFS and its Southern Ocean regional study have well-defined goals, including protocols for measurement, process study philosophy, and schemes for large-scale data collection and model integration. Thus it is comparatively easy to classify the topics covered in the EASIZ Trondheim Workshop report into three groups.

1. *Science topics already covered, at least implicitly, by SO-JGOFS.*
   Oceanic aspects of primary production and fluxes, especially in relation to sea-ice.
2. *Science topics which fall outside the strict remit of JGOFS, but which nevertheless have important implications for JGOFS or related global change research.*
   - Biogenic gases - dimethylsulfide, bromoform compounds, methane, nitrous oxide, etc: refer to SCAR-IGBP and to IGAC
   - UV and biological response: refer to SCAR-IGBP.

- Environmental determinants within sea-ice biota
- Physiology and species composition of sea-ice biota - response to changes
- Theoretical physical (spatio-temporal) framework for sea-ice ecology
- Palaeoenvironment studies.

3. *Science topics in the Antarctic sea-ice zone not covered by JGOFS:*
   - Sea-ice formation:
   - Sea-ice community organization
   - Sea-ice community production
   - Adaptation of sea-ice biota
   - Primary production rates (of ice microalgae)
   - Primary and secondary consumption rates
   - Benthos

Implementation aspects
In the case of Southern Ocean science within JGOFS scientific and logistic planning is already well-advanced. However, SCAR is uniquely placed to act as an interface between the Antarctic marine ecological community and SO-JGOFS and SCAR should be encouraged to co-sponsor the project. Only if this is done can SCAR assume an influential role in this important area. This sponsorship could include:

- planning meetings,
- data evaluation symposia,
- information exchange,
- a feasibility study of appropriate data management (including facilitating access to satellite remote sensing data),
- assistance with administrative costs for the planning group.

3. Report of the Group on Population Dynamics of Marine Animals: BIOMASS/CCAMLR/SO-GLOBEC

BIOMASS
The field research under this programme essentially only addressed the "water column" section of the Trondheim Workshop questions. Within these, it contributed to several questions in each of the sections dealing with primary producers, primary consumers, and secondary and higher consumers.

The main results from the multinational interdisciplinary part of the programme was conducted during FIBEX and SIBEX and was located principally in the Antarctic Peninsula region and subsidiarily in the Indian Ocean sector. Most of the data from these cruises are held in the BIOMASS Data Centre.

CCAMLR
Within the structure of the questions in the Trondheim Workshop, directed research associated with CCAMLR addresses one part only of the question under secondary consumers. This research is chiefly focused within the Integrated Study Regions of CCAMLR Ecosystem Monitoring Programme which are at South Georgia, the Antarctic Peninsula, and Prydz Bay. Some research associated with fisheries also takes place at subantarctic Indian Ocean locations.

SO-GLOBEC
Most of the questions developed at the Trondheim Workshop, and which are not being covered within SO-JGOFS, are capable of being addressed within SO-GLOBEC. Particular strengths of SO-GLOBEC were perceived to be:

a. the emphasis on modelling and the use and development of new technology;
b. the proposal to include a fully representative range of secondary consumers, including those without early life history stages in the plankton (ie seabirds and seals). Seabirds and seals have particularly important trophic roles in Southern Ocean marine systems.

In addition, those species which breed on land or ice provide an important and very accessible source of data on fluctuations in population size and other parameters relevant to detecting effects of global change.
It was noted that SO-GLOBEC proposes to concentrate research within the Bellingshausen Sea. This would provide particularly good links with SO-JGOFS field programmes. A Bellingshausen Sea research area is also adjacent (upstream) to the BIOMASS and CCAMLR research areas in the Antarctic Peninsula region. The Bellingshausen Sea, however, is less convenient for using ships of opportunity because it is remote from the routes taken by logistic vessels supplying Antarctic stations.

Another important consideration relevant to the location of SO- GLOBEC studies is the extent to which the results obtained in one area of the Antarctic can be applied to other regions. For example, seabirds and marine mammals in the Indian Ocean sector are much less dependent on Antarctic krill than are the same or similar species in the Antarctic Peninsula/Scotia Sea areas. The composition and dynamics of zooplankton populations and communities are also significantly different between these regions. Therefore studies analogous to those proposed for SO-GLOBEC should be encouraged to be developed in representative areas of the Indian and Pacific Ocean sectors.

A general concern, even for a programme restricted to the Bellingshausen Sea, was how to implement such a wide-ranging programme with such broad goals. The BIOMASS Programme, which was not dissimilar in scientific scope to SO-GLOBEC, needed a very substantial basis of scientific and logistic support to undertake the planning and execution of its field programmes and data management. These operations ultimately addressed a much smaller suite of questions than those proposed by SO-GLOBEC, which will, therefore, require an even more effective organizational structure and greater logistic support.

For SO-GLOBEC to have reasonable prospects of success requires a major coordinated multinational interdisciplinary effort. It was regarded as essential that SCAR support be forthcoming. It was suggested that SCAR could help in four main ways:

a. coordinate national marine research programmes to conduct research in support of SO-GLOBEC objectives in the Bellingshausen Sea;
b. explore the possibilities of developing analogous research programmes in one or more additional sectors of the Antarctic;
c. ensure that data in the BIOMASS Data Centre are available for site and area-specific modelling during the programme preparation phase of SO-GLOBEC;
d. assist in developing the detailed programme description and implementation necessary to carry out SO-GLOBEC.

SCAR's experience in organizing the BIOMASS Programme and in facilitating scientific and logistic interactions between Antarctic operating nations should be especially valuable in this regard.

IMPLEMENTATION OF EASIZ PROGRAMME: IMPLICATIONS FOR SCAR

In reviewing the products of the three ad hoc groups, the Workshop noted that many of the biological objectives within EASIZ (as expressed in the report of the Trondheim Workshop) were being addressed, primarily outside SCAR, in two complementary ways and involving programmes at very different stages of development. One programme (SO-JGOFS) was focussing on climate change and the oceanic carbon cycle. The other proposed programme (SO-GLOBEC) was addressing the biological and physical processes that affect population dynamics of selected Antarctic biota, and that will determine their potential response to global change. Some elements of SO-GLOBEC have also been addressed by BIOMASS and many relating to krill and higher trophic level predators are included in research being undertaken by CCAMLR.

The SO-JGOFS programme is already established and is to a large extent operational. The Workshop noted that the existing SO-JGOFS field programmes concentrate on deep-water processes. The other comments and conclusions of this sub-group's discussions were considered. The Workshop noted that data management initiatives were a particular requirement.

The Workshop *recommended* that SCAR should endorse and co-sponsor the SO-JGOFS activities and take an active role in the development of that programme in the Southern Ocean, including promoting related studies in the coastal and shelf zone.

The SO-GLOBEC programme was currently at an early stage of planning. It was emphasized that this particular programme covered in outline most of the questions contained in the Trondheim report.

The Workshop *recommended*, that SCAR, in conjunction with SCOR, should seek to participate fully in the further planning and implementation operations concerning this programme.

The initiatives proposed for the Antarctic coastal and shelf zone require further development into a comprehensive programme of research on coastal and shelf processes.

The Workshop *recommended* that a task group be established to coordinate existing and projected research relevant to the EASIZ priorities and questions within the Antarctic coastal and shelf zone.

SCAR Report

SCAR Report is an irregular series of publications, started in 1986 to complement SCAR Bulletin. Its purpose is to provide SCAR National Committees and others directly involved in the work of SCAR with the full texts of reports of SCAR Working Group and Group of Specialists meetings, which had become too extensive to be published in the *Bulletin*, and with more comprehensive material from Antarctic Treaty meetings.

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