TOWARDS THE DEVELOPMENT OF AN INTERNATIONAL GLOBEC SOUTHERN OCEAN PROGRAM

Report of the First Meeting of the International GLOBEC Southern Ocean Planning Group

Center for Coastal Physical Oceanography
Old Dominion University, Norfolk, VA, USA

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PREFACE

The Southern Ocean Marine Ecosystem is, in many respects, unique. It has an inner ring around the Antarctic continent with a sea–ice dominated regime, followed by a very large area that is seasonally iced and deiced and finally, an outer ring of open oceanic water. Because of physical conditions, the surface water is very much isolated from the rest of the world oceans, while intermediate and deep water is in open communication with these. There is generally high primary production in the surface water, particularly close to the ice–edge during the time of ice retreat, but, in general, nutrients in the water are not depleted. What limits primary production is still not understood, but contributing factors are deep mixing, grazing by zooplankton and possibly lack of some micronutrients (e.g. iron). The system sustains a secondary production of enormous proportions, notably of one species of krill, the Antarctic krill (*Euphausia superba*), which has a total estimated biomass of somewhere between 650 and 1000 million tons (which is more than double the biomass of the human population on earth). The system is physically highly variable both seasonally and interannually—yet it is predictable within limits, and it is mature enough for the biota to have adapted to the harsh conditions. Because of these special conditions and the important role of the polar seas in the global climate, the Scientific Steering Committee of the International Global Ocean Ecosystem Dynamics (SSC of GLOBEC International) decided that the Southern Ocean is a key geographical area for studies of the processes that govern and influence secondary production.

The SSC of GLOBEC International gratefully acknowledges the kind invitation to hold a meeting of its Southern Ocean Planning Group at the Center for Coastal Physical Oceanography of the Old Dominion University in Norfolk, Virginia, USA. The meeting was sponsored by U.S. GLOBEC for U.S. participants and by SCOR for many of the international members of the Group. Others were paid for their participation by sources in their own countries. The Meeting took place under excellent conditions and ground service from the host institution.

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1. INTRODUCTION

The Antarctic marine food web is unique in that it is characterized by dependence on a single key species, Antarctic krill, and by dependence of many of the components of this food web on sea–ice during some or all of their life history. These unique characteristics make this ecosystem especially vulnerable to changes in environmental conditions, or to resource exploitation. Predictions of the Antarctic marine food web responses to environmental variability and climate change first require understanding and documentation of the cycles of natural population variability.

The International Global Ocean Ecosystem Dynamics (GLOBEC) programme identified the Southern Ocean as a potential research site. It was recognized that the unique characteristics of the Antarctic marine food web make the Southern Ocean an ideal environment in which to test many of the GLOBEC core hypotheses that consider the effects of variability in the physical environment on population dynamics. In addition to studies relating to the GLOBEC core hypotheses, it was recommended that a Southern Ocean GLOBEC programme include studies of:

1. regional differences in overwintering strategies of Antarctic krill in relation to the physical environment;
2. population dynamics of selected zooplankton species, both sea–ice related and planktonic species;
3. population dynamics of major krill predators, both ice–based and pelagic species; and
4. the effects of UV-B radiation on zooplankton dynamics.

The international GLOBEC Science Steering Committee (SSC) further recommended that a meeting be held to define the scientific rationale and to begin the development of an implementation plan for an international Southern Ocean GLOBEC programme.

This latter recommendation led to a meeting that was held, under the auspices of the international GLOBEC programme, in Norfolk, Virginia, June 15 - 17, 1993. This meeting was attended by 26 scientists who represented 9 nations with interests in Antarctic programmes, and the Intergovernmental Oceanographic Commission (IOC). The goals of this meeting were to define the key questions and framework to be used as a basis for the development of an implementation plan for an international Southern Ocean GLOBEC programme. This report presents a summary of the discussions and recommendations from the meeting. It is anticipated that the recommendations from this meeting will provide the basis for a second meeting which will develop an implementation plan for a Southern Ocean GLOBEC programme.

The following section provides some background information on previous GLOBEC meetings that are relevant to the development of a Southern Ocean programme. In particular the recommendations from a U.S. GLOBEC Southern Ocean meeting held in 1991 are summarized. Section 3 presents a summary of the key questions and recommendations arising from the meeting and section 4 provides the working group reports from which the key questions were extracted. Section 5 lists the international programmes and connections that are important and necessary components of an international Southern Ocean GLOBEC initiative.

2. BACKGROUND

Planning for a GLOBEC-related programme in the Southern Ocean has been ongoing at various levels for about three years. This section provides a brief review of the various meetings and workshops that preceded the workshop held in June 1993.

In May 1991, a workshop was held in La Jolla, CA, with sponsorship from the U.S. GLOBEC programme, which brought together about 40 scientists from 10 countries. The general objective of this workshop was to discuss the important scientific issues that would lead to the development of a GLOBEC-related study in the Southern Ocean. The results of this workshop are published in U.S. GLOBEC Report No. 5.

The discussions at the La Jolla workshop highlighted the importance of the annual formation and retreat of pack ice in influencing the structure and function of the Antarctic marine food web. Observations that include the austral winter and extend over several ice cycles were given high priority as components of a Southern Ocean GLOBEC programme. In particular, observations are needed for Antarctic krill (*Euphausia superba*) and the salp (*Salpa thompsoni*), which were identified at the workshop as key target species. Other suggested target species included a commercially harvested fish species (e.g. *Champsocephalus gunnari*), a non-harvested holopelagic fish species (e.g. *Pleurogramma antarctica*) and a non-harvested nearshore fish species (e.g. *Notothenia neglecta*). The workshop discussions also focused attention on the importance of top predators in the Antarctic marine ecosystem. Hence, several penguin species (e.g. Adelie and Chinstrap penguins), the crab eater seal, and the Antarctic fur seal were recognized to be important and recommendations were made to include these as key species. Benthic communities were also considered to be an important component of an Antarctic GLOBEC programme and recommendations were made to include as target species bivalves, echinoderms and crustaceans that have both pelagic and benthic larval stages.

Considerable attention was given during the workshop to the selection of sites for a Southern Ocean GLOBEC programme. Characteristics that were considered to be important for potential sites included the existence of identifiable populations of the key target species, reliable sea–ice cover and accessibility by ships and from shore-based laboratories. One region that meets these criteria is the area that extends west of the Antarctic Peninsula to the eastern portion of the Bellingshausen Sea. Other areas that were also discussed as potential sites were the southeastern Weddell Sea, the northern part of the Atlantic sector of the Southern Ocean, the Ross Sea, and the Indian Ocean.

The Scientific Committee on Oceanic Research (SCOR) decided at its 30th Executive Committee Meeting in November 1991 to launch GLOBEC as an international programme and to establish a Scientific Steering Committee (SSC). SCOR also invited IOC to co–sponsor this as a joint activity and decided to investigate the interest of the International Council for the Exploration of the Sea (ICES) to become a co–sponsor. In March 1992, the IOC Executive Council accepted this invitation to co–sponsor International GLOBEC. Later both ICES and its Pacific counterpart (PICES) accepted co–sponsorship of the programme. The SSC held its first meeting in Ravello, Italy on March 31–April 2, 1991 (GLOBEC Report No. 1). The Southern Ocean was then identified as a research site and the formation of a planning group to over-see the development of an international GLOBEC programme in this region was recommended.

The Scientific Committee on Antarctic Research (SCAR) decided at its 22nd Meeting in June 1992 to co–sponsor the Southern Ocean component of the International GLOBEC and the development of a programme for this region was discussed with the SCAR/SCOR Group of Specialists on Southern Ocean Ecology (GOS-SOE) in September 1992. This group recommended that linkages be established with the Southern Ocean programme that was being developed as part of international GLOBEC. It was further recommended that these linkages be formalized by appointing a member(s) of the GOS-SOE to serve on the GLOBEC Southern Ocean planning group. It was felt that this would foster active participation by SCAR in a Southern Ocean GLOBEC programme.

The final activity that provided the basis for the Southern Ocean Planning Meeting that was held in June 1993, was the meeting of the international GLOBEC Working Group on Population Dynamics and Physical Variability, which took place in February 1993. The report from this workshop (GLOBEC Report No. 2) outlines the important conceptual, measurement and integration issues that must be part of any programme designed to understand and quantify marine animal population variability within the context of a variable physical environment. Many of the recommendations from this workshop provided a focal point for discussions at the Southern Ocean Planning Meeting. The report of the first meeting of the International GLOBEC Sampling and Observational Systems Working Group (SOS-WG), which took place in Paris on April 2, 1993 was not available at the Southern Ocean Planning Meeting.

3. SUMMARY OF MEETING RECOMMENDATIONS

This section provides a summary of the recommendations from the International GLOBEC Southern Ocean Planning Meeting. The working group reports from which these recommendations have been extracted are presented in their entirety in Section 4.

3.1 Population Dynamics and Physical Variability

3.1.1 Zooplankton

The key questions for a zooplankton component of a Southern Ocean GLOBEC programme should focus on:

1. zooplankton overwintering strategies;
2. seasonal and geographical variations in the distribution of Southern Ocean key zooplankton species, especially in relation to the physics of the environment;
3. factors affecting successful reproduction;
4. physical processes influencing larval survival and recruitment to the adult population; and
5. the distribution of Southern Ocean zooplankton in relation sto the distribution of food biomass and reproduction.

These questions are designed to provide a basis from which to develop elements of research programmes and to select core study sites.

Key zooplankton species should represent a diversity of life-history strategies and include species that are of importance to higher predators. The key zooplankton species selected for a Southern Ocean GLOBEC programme are: *Euphausia superba*, *Calanoides acutus*, and *Metridia gerlachei*. However, the scientific basis of a Southern Ocean GLOBEC programme should be broad enough to accommodate research on other zooplankton species as needed. For example, *Salpa thompsoni* could be an important species since it tends to dominate in years and/or locations when *Euphausia superba* is scarce.

3.1.2 Top Predators

The key questions for a top predator component of a Southern Ocean GLOBEC programme should focus on:

1. effects of variability in the physical and biological environments on predator population dynamics;

2. the role of sea–ice in affecting foraging performance, reproductive success and survival of top predators;

3. krill variability and its allocation among several top predator species;

4. the effect of predator foraging activities on altering the distribution and abundance of krill; and

5. the nature of the functional relationships between krill availability and performance and survival of its predators.

These questions are intended to provide a framework for the development of field and laboratory research and numerical modelling initiatives as related to a Southern Ocean GLOBEC top predator research programme.

Target species for a predator programme were selected in terms of their degree of association with ice cover or the ice edge, their dependence on krill, availability of historical data and feasibility of study. Given these criteria, the primary target species are Crabeater seals, Adelie penguins, Snow petrels, Antarctic petrels, fish, and squid. However, it was recognized that other target species may be appropriate in some regions of the Antarctic, such as areas not strongly influenced by pack ice.

3.1.3 Zooplankton/Top Predators

The above questions for zooplankton and top predators require that a Southern Ocean GLOBEC programme study the population dynamics of a variety of organisms that range from small copepods to large seals. This presents severe difficulties in programme design and implementation since the key organisms operate over a wide range of space and time scales. The major components required for a joint zooplankton/top predator study include time-series surveys, process surveys, process studies, laboratory experimental studies and modelling. In terms of joint studies of zooplankton and top predators, it was recommended to implement:

1. <u>time series surveys</u> that focus on collection of data at high temporal resolution that are directed at answering specific questions, e.g. factors influencing zooplankton reproduction;

2. <u>process surveys</u> to address questions relating to the interactions between krill and top predators, e.g. underway sampling of prey with concurrent sampling of predators; and

3. <u>ship-board process studies</u> to address questions concerning mechanisms and processes which do not require high

resolution time–series information over a large geographic area.

The working group provided detailed interaction matrices of the types of sampling approaches that are needed to address the questions posed by the zooplankton and top predator working groups.

3.2 Data Needs

The Historical Data and Data Management working group noted that a large body of historical data exist for the Antarctic that are relevant to the objectives of GLOBEC and are important in planning of GLOBEC activities. It is important to describe the types of data that exist, where they are located and how to access or obtain them. It was also recognized that biological data are collected in a variety of formats, with different devices and different sampling techniques. Thus, the working group recommended that:

1. SCAR be requested to prepare a catalog of national archived biological data and samples;

2. GLOBEC develop a protocol of standard methods for data collection and reporting; and

3. a group be formally tasked by GLOBEC.INT with developing the necessary protocols and with making detailed suggestions for methods of data submission and handling.

3.3 Modelling

Modelling is recognized as an important component of all GLOBEC programmes. Several of the key questions identified for Southern Ocean GLOBEC require modelling approaches or input from model simulations. It was suggested that many of these questions be examined within the context of a conceptual model that would be developed for the Antarctic prior to the development of a field programme. The conceptual model would also provide a framework for the field programme. There are also unique features of the Antarctic ecosystem (e.g. sea–ice, krill swarming) that need to be included in models. The primary recommendations from the working group are that:

1. a conceptual model of the Antarctic physical environment and marine food web be developed;

2. GLOBEC.INT sponsor a workshop on observation, theory, and modeling of krill swarms;

3. existing circulation, ice and biological models of the Southern Ocean be evaluated for use as a point of departure for future modelling efforts; and

4. models of krill allocation among various predator species be developed.

3.4 Sampling and Observations Systems

The working group reviewed the availability of satellite remote sensing and non-satellite remote sensing capabilities for the Southern Ocean. The working group also noted the technologies that need development or enhancement for application to sampling Southern Ocean zooplankton and top predator populations. Recommendations were made for the:

1. development of a new satellite dedicated to wildlife telemetry studies;

2. incorporation of data compression algorithms developed for other systems; and

3. development of data loggers for deployment on mammals and birds that use GPS and low earth orbiting satellites.

3.5 International Connections

The Meeting stressed the need for close contacts with several international organizations and programmes in order to gain as much as possible from cooperation and to avoid duplication of work. Among organizations, SCAR and CCAMLR and their subgroups were mentioned in particular and among programs, WOCE (World Ocean Circulation Experiment) and JGOFS (Joint Global Ocean Flux Study) were mentioned as being of particular importance to GLOBEC.

3.6 Future Activities

The Meeting participants decided to hold a second meeting of the International GLOBEC Southern Ocean Planning Group, preferably in May 1994. One possible meeting place could be Cambridge, United Kingdom. The main purpose of the next meeting will be to write an implementation plan for Southern Ocean GLOBEC.

4. REPORTS OF WORKING GROUPS

4.1 Population Dynamics and Physical Variability

Zooplankton Working Group

(M. Huntley, chair, A. Clarke, rapporteur, B. Battaglia, S. Kim, J. Stromberg)

4.1.1 Overall Aims

The overall goal of GLOBEC is that stated in the Core Programme (GLOBEC Report No. 1):

> "To understand the effects of physical processes in predator-prey interactions and population dynamics of zooplankton, and their relation to ocean ecosystems in the context of the global climate system and anthropogenic change"

The aims for the Southern Ocean as decided at the La Jolla GLOBEC workshop (U.S. GLOBEC Report No. 5) were reexamined and agreed to be:

1. regional differences in overwintering strategies of the Antarctic krill (*Euphausia superba*) in relation to physical environment;

2. a detailed study of population dynamics of related zooplankton species, both sea–ice related and planktonic species;

3. population dynamics of major krill predators, ice–based (such as Adelie Penguins, crabeater seals) and more pelagic species (e.g. chinstrap penguins, Antarctic fur seals and the fish, *Pleurogramma*) (Efforts should also be made to include the much neglected squids.); and

4. studies of the effects of UV-B radiation on zooplankton dynamics.

4.1.2 Zooplankton Questions

The aims for Southern Ocean GLOBEC programme in relation to zooplankton were discussed in detail. It was recognised that the zooplankton consist of a wide diversity of organisms of differing size, life-history and abundance, and hence the essential first step was to define the zooplankton science questions. From these would emerge requirements or recommendations for key species and core sites. The agreed science questions were:

1. By what means do Southern Ocean zooplankton survive the winter, and how does this vary geographically?

2. What is the seasonal and geographical variation in the distribution of key Southern Ocean zooplankton species, particularly in relation to the physics of the environment?

3. What factors influence successful reproduction in Southern Ocean zooplankton?

4. What physical processes influence the subsequent survival of larvae and recruitment to the adult population?

5. How is the distribution of Southern Ocean zooplankton related to the distribution of food biomass and reproduction?

These five questions address only the first two of the La Jolla Southern Ocean aims. The third aim is concerned essentially with predators of zooplankton and was considered in detail by a separate working group. The final aim (that involving the effects of UV-B radiation) was not considered in the meeting.

These questions do not specifically address the subject of global change. The subject is nevertheless important and is referred to specifically in the overall GLOBEC aim, but it was felt that this aspect was best studied through remote sensing and suitable monitoring studies.

It was recognised that to gain a full understanding of the population dynamics of zooplankton, it is absolutely critical to obtain winter data. This requires ship-board work in winter, but shore bases can make an important input through year-round studies of suitable coastal zooplankton.

The role of physics in influencing biology was deemed to include regional circulation, mesoscale structures and dynamics and the role of sea–ice. Although it is desirable to tackle complex biological questions in an area where the physics is simple, it was recognised that in many areas of the Southern Ocean, the physics is insufficiently understood to decide whether the area is simple or complex.

Work on spawning, larval survival and recruitment to the adult population is at the heart of population dynamics. To resolve these questions will require a close collaboration between modelling, experimental and observational work.

Tackling these questions will require a range of techniques and approaches, including time-series surveys, process studies at sea and experimental studies in laboratories.

4.1.3 Key Species

Since it is not feasible to study all members of the zooplankton community at once, it is necessary to select some key species on which to focus research. These should represent a diversity of life-history strategies and also include species of direct importance to higher predators. The key species chosen were:

Euphausia superba (a key prey species in the Southern Ocean)

Calanoides acutus (an important herbivorous copepod with a typical overwintering strategy, and one with a substantial body of previous research)

Metridia gerlachei (an important predatory copepod with reproduction throughout the year)

Limiting GLOBEC work entirely to these species was recognised as being too restrictive; for example, it would prevent work on important species of the continental shelf (such as *Euphausia crystallorophias*) or of the Antarctic Circumpolar Current (such as *Rhincalanus gigas*). It was thus agreed that SO GLOBEC work should also encompass work on the seven other species identified as target species by the La Jolla workshop, namely:

Euphausia crystallorophias

Thysanoessa macrura

Salpa thompsoni

Calanus propinquus

Rhincalanus gigas

Themisto gaudichaudii

Sagitta gazellae

Salpa thompsoni was considered an important species in the light of its propensity to dominate in years and/or locations where *Euphausia superba* is scarce. *Euphausia crystallorophias* is a neritic euphausid characteristic of the continental margins and is an important target species for work in the Indian Ocean sector. *Calanus propinquus* is an important copepod with a life history and physiology in distinct contrast to that of *Calanoides acutus*, and *Rhincalanus gigas* is a key component of the ecosystem in the more northerly ice-free waters. Finally the amphipod *Themisto gaudichaudii* and the chaetognath *Sagitta gazellae* are important predators.

4.2 Population Dynamics and Physical Variability

Top Predator Working Group

(J. Croxall, chair, J. Bengtson, rapporteur, D. Costa, S. Jacobs (part), G. Laurence (part), Y. Naito, P. Penhale (part))

We reviewed the nature and content of potential studies of birds, mammals and fish in relation to the aims of SO GLOBEC. (Fish and squid were considered in general terms but no specialists were present. Subsequent comments from Dr. I. Everson and Dr. P. Rodhouse are incorporated but further elaboration of research approaches and priorities for these groups are required.) We took particular account of: a) the increasing focus of the overall study onto species and processes intimately associated with the pack–ice zone; b) the need to concentrate on Antarctic krill because of its unique role amongst zooplankton as a key prey for a wide range of predator species; c) the need to ensure that the various predator studies are conducted at spatial and temporal scales congruent with the research into the physical and biological environment; d) the requirement that many of the key process studies must be conducted simultaneously on predators and prey; e) the requirement that both process and survey studies need to be underpinned by the continuation and enhancement of existing studies monitoring trends and variation in population parameters and in aspects of foraging and reproductive performance of predators; f) the need to conduct SO GLOBEC studies over several years, at all seasons of the year and especially to include work in the sea–ice zone in winter.

4.2.1 Target Species

The target species were defined in terms of: degree of association with ice-cover/ice–edge; degree of dependence on krill; availability of data from existing and historical studies; and feasibility of study.

Primary

Crabeater seal

Adelie penguin

Snow petrel

Antarctic petrel

Fish

Squid

Psychroteuthis glacialis

Moroteuthis knipoviitchi

Secondary

Leopard seal

Chinstrap penguin

Cape petrel

Antarctic fulmar

Fish

Squid

Kondakovia longimana

Alluroteuthis antarcticus

To the extent that complementary studies in areas where the influence of pack-ice is less direct are feasible, the following target species are recommended: Antarctic fur seal, macaroni penguin, black-browed albatross, the fish *Champsocephalus gunnari*, the squid, *Martialia hyadesi* and *Gonatus antarcticus*. We did not consider incorporating any species of whale into the list of target species, even though the minke whale would meet most of our criteria, because the International Whaling Commission is currently starting to develop a programme of research and monitoring on Southern Ocean whales. It is important to maintain close links with their programme.

4.2.2 Key Questions

The fundamental processes involved in predator-prey interactions are those regulating (both proximately and ultimately) the dynamics of prey populations and the responses of the dependent species. For predators, we need to try to understand the relative influences of the direct and indirect effects of the physical and biological environment (e.g. ice and food) and the nature of the functional responses by predators (e.g. in terms of feeding and vital rates). In the case of the krill-predator relationships, the dynamics of krill distribution (e.g. under ice) and swarming behavior is the key to many aspects of these interactions.

The questions below were formulated to try to focus attention on some of these issues and to aid the development of appropriate field and laboratory research, linked to relevant numerical modelling initiatives.

1. How do changes in the physical environment (e.g. ice cover) and biolog-

ical environment (e.g. food availability) influence top predator species':

a) distribution and abundance;

b) reproductive performance and breeding success;

c) juvenile survival;

d) adult survival; and

e) foraging strategies and tactics?

2. How do the presence and characteristics of ice affect foraging performance, reproductive success and survival of top predators?

3. How do changes in krill availability affect allocation of krill among different dependent species?

4. How and to what extent do the presence and foraging activities of predators induce changes in the behaviour, abundance and distribution of krill (e.g. through avoidance behaviour and removal via predation)?

5. What is the nature of the functional relationships between krill availability and the performance and survival of its predators:

   a) what is the relationship between the distribution (vertical and horizontal) and abundance of krill and its availability to different predators;

   b) how do fluctuations in krill availability affect foraging performance, reproductive success and survival of dependent species; and

   c) which life history stages of predators are most sensitive to changes in prey availability or in the physical environment?

4.2.3 Programme Elements

We reviewed the components of relevant top predators research that should be given priority within SO GLOBEC. What follows is inevitably a brief and preliminary review because defining methods and approaches for studying the dynamic interactions between top predators and their prey has received much less attention than, for instance, the population dynamics of either zooplankton prey or top predators taken separately.

Particularly for this reason the development of outline research programme elements to address each of the key questions will require substantial work by appropriate krill and top predator scientists working together.

Information on the status of current research activities in the fields below are presented in Table 4.2.1. This is a draft version and the group recommended that WG-CEMP, the SCAR Group of Specialists on Seals and the SCAR Bird Biology Subcommittee be asked to review and amend them as soon as possible.

4.2.3.1 Definable Populations

We viewed this as comprising two elements.

1. Definition of Unit Populations

This requires studies, using newly developed molecular techniques, of genetic variation within and between breeding units of target species. Definition of population units for crabeater seals and fish are particularly important.

2. Surveys of Population Distribution and Abundance

Some target species, especially seabirds, can be surveyed, at least locally, by land-based surveys from shore stations. There are quite extensive existing studies of this kind. For other species, ship, aircraft and satellite based work will be essential. Remotely-operated vehicles, especially airborne platforms, could provide invaluable assistance for studies of seals (and possibly seabirds) also.

4.2.3.2 Population Dynamics

For seabirds and fur seals, population age structure, fecundity rates, productivity and survival rates (both juvenile and adult) are studied basically by annual capture-mark-recapture studies of individually identified animals. Offspring production, in relation to breeding population size, is studied widely throughout the region but there are many fewer detailed demographic studies of target species and even fewer that have annual data over more than 10 years.

For ice breeding seals, age structure and vital rates are determined by examination of teeth and reproductive tracts taken from samples of the population. For commercial fish, regular surveys to estimate stock size, population structure, reproductive status and diet are undertaken in support of CCAMLR. Studies on squid are restricted to determining distribution and trophic relationships. In general for fish and squid, age structure and vital rates are determined by examination of otoliths/statoliths and maturity status of the reproductive system taken from samples of the population.

Long-term marking of individuals is not as straightforward in most top predators as it is for flying birds. The use of passive induction transponders offers very significant advantages over flipper tags for penguins but further technological development is required, particularly of recognition systems to detect tagged individuals, to make maximum effective use of this new technology.

4.2.3.3 Processes and Mechanisms

4.2.3.3.1 Foraging Ecology

This comprises studies of:

1. Diet composition—including seasonal, interannual and geographical variations in the nature of the prey, including their size, sex and age, where feasible. Diet research is chiefly based on analysis of stomach (and sometimes faecal) samples (increasingly involving lavage methods for seabirds and seals). Serological techniques have provided important confirmation of visual diet observations in squid. Determination of age, size and sex of prey relies extensively on relationships between structures relatively resistant to digestion (e.g. otoliths, statoliths, beaks, mandibles, eyeballs, carapaces) and whole animals. Better, and standardised, relationships are needed for many taxa. Diet studies other than during the summer months are rare and need to be a particular focus of future work.

2. Foraging habitat and area—the physical structure and physical and biological characteristics of the location selected by top predators for feeding activities and how these vary at temporal scales ranging from diel to annual. Once almost entirely dependent either on direct visual observations (seabirds, seals) or net-haul samples with concurrent oceanographic

data (fish, squid), the use of satellite telemetry is nowadays revolutionising data acquisition in this field, especially for seabirds and seals. Acquisition of congruent data on the nature of the ice and water habitats is essential and, using conventional methods, more difficult for seabirds and seals than for fish and squid.

3. Foraging behaviour—this comprises all aspects of a) how predators catch prey, including defining the functional morphology of feeding structures (e.g. squid), the methods used, the conditions and circumstances involved (e.g. in terms of the physical (including optical) properties of their environment); b) when predators catch prey (time of day, etc.); c) how often and how much prey is caught. For all except flighted seabirds, relevant quantitative data have only been acquired with the very recent development of archival and satellite-linked instruments on and inside free ranging animals. A range of sensors recording continuously or intermittently data on pressure (= depth), temperature (external and internal), velocity, and light levels, (and often linked to location and physiological data) are permitting unique insights into foraging behaviours, patterns and performance. Requirements for further developing this type of research include smaller and better instruments (i.e. more efficient with respect to power utilisation), better data compression and storage, more accurate sensors to record existing variables (e.g. to collect data on ambient temperature and conductivity in order to determine water body characteristics) and especially better data transfer to satellite. The complementary data on prey distribution and environmental characteristics need to be collected on equivalently fine scales. Laboratory research on sensory abilities of predators is also required.

4.2.3.3.2 Energetics and Physiology

Many of the changes in the relationship between top predators and their environment are ultimately expressed in terms of changes in energy expenditure and often these are reflected in changes in the physiological condition of the individuals themselves and/or their offspring. Measurement of many activity-specific energy costs of air-breathing free-living animals can be achieved using isotopic techniques. These techniques require recapture of animals; they integrate the cost of activities between consecutive sampling periods and can only be used over a relatively short period. Recent developments in the use of heart-rate as an index of energy expenditure are very promising. However this technique generates very large quantities of data (requiring extreme compression of data for storage and/or transmission) and needs accurate calibration studies (involving use of respirometric and other techniques on live animals in flumes, wind tunnels, etc.).

For seabirds and seals the most widely used measures of condition are still those of mass, or size-corrected mass. Use of electronic weighing platforms is greatly enhancing: a) the range and quality of such data; b) the ability to make regular records from individuals with minimum disturbance; c) the feasibility of estimating body energy stores/reserves; and d) linking such data to simultaneous studies of reproductive performance and survival of both adults and/or offspring.

Sampling populations via collected samples offers a range of additional physiological indices and condition (e.g. blubber thickness, fat and protein reserves, chemical composition, nucleic acid ratios, gonadosomatic and hepatosomatic indices (fish), etc.). Almost none of these techniques have been used successfully on a routine basis on animals captured and released alive. Considerable development, both in laboratory and field, in acquisition and interpretation of data using ultrasound, biological impedance and blood chemistry techniques will be required before these techniques can have widespread use.

4.2.3.3.3 Growth

Various aspects of growth reflect different aspects of interactions between predators and their environment. Growth (in mass and/or morphometrics) of dependent offspring reflects parental performance over the breeding season. Growth rates of juveniles and adults (chiefly accessible via annual or daily growth layers revealed by analysis of sections of teeth otoliths and statoliths) integrate a range of interactions over daily to annual time scales.

4.2.4 Sampling and Observation Systems

A full definition of the sampling and observation systems required to address the predator–prey interaction element of SO GLOBEC will need to await the definition of the research programmes required to address the key questions. However, it may be helpful at this stage to summarise some aspects of likely sampling requirements and to note those methods and sampling systems that are being, or will need to be, developed in order to have effective field programmes. Table 4.2.2 summarises some relevant details and highlights several key requirements in the field of development of new sampling systems.

1. Existing electronic systems deployed on and/or in predators need: a) further miniaturisation; b) better sensors, especially those collecting oceanographic data; c) better data compression and storage; and d) better data transmission systems to satellite. It is likely that further rapid progress will only be achieved via a workshop involving current manufacturers and relevant sensor developers from both predator and oceanographic communities.

2. In the longer term, research relying on satellites will be fully effective only with the availability of satellites dedicated to biological applications.

3. The development of systems to record the frequency, amount and nature of prey ingested is essential to thorough understanding of predator–prey interactions. Relatively simple devices and techniques are in use currently; development of more sophisticated systems is a high priority.

4. The use of remotely-operated vehicles, whether aerial or submersible, is a high priority in this type of research.

4.2.5 Models

The whole study of predator–prey interactions would be greatly enhanced by the development of conceptual models focused on the role of krill and particularly on its aggregation characteristics in relation to its predators. Most, if not all, key questions would be signally advanced by models addressing specific aspects of predator–prey interactions. Research into the allocation of krill amongst dependent species and into the nature of functional relationships between krill availability and predator response both require the development of conceptual models in order to define many aspects of the necessary field research.

4.2.6 Logistics

Only a small proportion of the predator research relevant to SO GLOBEC can be carried out from shore-based stations. The variety and complexity of the ship-based research necessitates: a) very careful planning of interactive studies; b) dedicated time on grid sampling cruises; and c) cruises dedicated to predator–prey research.

4.3 Zooplankton/Predators Working Group

(A. Clarke, chair and rapporteur, J. Bengtson, J. Croxall, M. Huntley)

Following the reports to Plenary of the individual working groups on zooplankton and predators, a joint session was held to discuss two main subjects, types of cruises and sites for research.

4.3.1 Types of Study

The requirement of SO GLOBEC to study the population dynamics of a variety of organisms ranging from small copepods to large seals poses severe difficulties of organisation. These different organisms operate over very different temporal and spatial scales, and hence a cruise design appropriate for one will not provide meaningful data for another. A particular challenge for SO GLOBEC, distinct from GLOBEC operations elsewhere, is the explicit inclusion of top predators within the study.

It was recognised in plenary discussion that a major difficulty was posed by the requirement to study different organisms on a single cruise. A sampling protocol designed solely around, for example, the population dynamics of a fast-growing copepod would not provide any meaningful data on, again for example, adult *Euphausia superba* or predatory behaviour by Cape Petrels, *Daption capense*.

The detailed planning of cruises would need to be undertaken by a separate implementation workshop. Nevertheless the major types of study could be clearly identified. These were:

Time-Series Surveys

Process Surveys

Process Studies

Laboratory Experimental Studies

Modelling

Modelling was covered by a separate working group (see elsewhere in this report), and laboratory work was discussed by the La Jolla workshop (GLOBEC Report No. 5, p. 132–137). Neither were therefore discussed further.

4.3.1.1 Time–Series Surveys

These were seen as cruises where the collection of data at high temporal resolution was of paramount importance. In general they would need to be dedicated to very specific questions and hence their flexibility in terms of ability to address several SO GLOBEC questions simultaneously was limited.

This type of cruise was seen as essential to tackle the following questions:

1. seasonal and geographical variation in zooplankton in response to physical forcing;

2. factors influencing reproduction in zooplankton;

3. the impact of physics on recruitment; and

4. the effect of sea–ice on krill predators.

4.3.1.2 Process Surveys

Process surveys were seen as necessary to address questions relating to the interactions between krill and top predators, which require simultaneous spatio-temporal data in time-series. The general approach would be targeted sampling of prey detected by underway techniques (acoustics) with concurrent sampling of predators. Such an approach would be important in, for example, addressing questions related to the foraging of top predators on aggregations of prey.

4.3.1.3 Process Studies

Ship-board process studies were seen as the most appropriate approach for addressing questions concerning mechanisms and processes which do not require high resolution time-series data over a wide spatial area. The general approach would be one of focused studies involving ships and possibly also shore laboratories.

4.3.2 Relationship of Types of Study to Science Questions

Having identified both the key questions to be studied and the major types of approach to be used in SO GLOBEC, the two working groups attempted to relate these together. The results were two matrices indicating which type of study was most appropriate for each major science question. These matrices are given below, one each for the zooplankton and predator questions. In each matrix a filled circle indicates a major contribution by that type of study, an open circle a less critical contribution.

In each matrix the abbreviations representing types of study are:

TSS: Time-series Survey

PSV: Process Survey

Proc: Process Study

Lab: Laboratory work (either on ship or shore-based)

Mod: Modelling

The questions (1 to 5 for the zooplankton, 1 to 5 for predators) represent the key questions agreed by the individual working groups.

4.3.2.1 Zooplankton Matrix

The zooplankton interaction matrix is shown in Table 4.3.1.

4.3.2.2 Predator Matrix

The predator–prey interactions are shown in Table 4.3.2.

4.3.3. Conclusions

The precise nature and timing of SO GLOBEC cruises will be decided at future implementation meetings. The first of these will be held in 1994, probably in Cambridge.

4.4 Historical Data and Data Management Working Group

(I. Everson, chair, S. Nicol, rapporteur, R. Holt, S. Jacobs, J. Klinck)

1. A large range of historical scientific data exists for the Antarctic region. The task is to define which of these data are relevant to GLOBEC, where they are to be found and how they can be accessed. These historical data are important for GLOBEC for a number of reasons.

    1. They can be influential in the planning process for GLOBEC studies.

    2. Older data can be re-analyzed using modern techniques and used to extend time–series. It should be noted that a recent change in sampling technology does not necessarily make older observations obsolete.

    3. Some older samples and records have never been analyzed. In some cases, it may well be more cost-effective to locate and analyze these than to collect new data.

2. Data and samples exist in a variety of formats and in many cases, it appears that there is not any concerted national or international effort to catalog these data and samples, particularly in the biological field. In many cases, the only way of judging whether data and samples of a particular type exist for a particular area may be to contact the SCAR representative in those countries working in those areas. This group recommends that SCAR be requested to prepare a catalog of national archived biological data and samples.

3. The data and samples that exist will be of different quality and will often have been obtained by different devices using different sampling techniques. Some sources of scientific data and samples are listed in Table 4.4.1. This table is not meant to be exhaustive but merely illustrates the diversity of forms in which the information is available.

4. Future data and samples that are collected under GLOBEC should be collected using standard protocols and should be presented together with the information necessary for their interpretation. The group recommends that GLOBEC develop protocols of standard methods.

4.4.1 Data Management

5. The report from the U.S. GLOBEC Southern Ocean Workshop (GLOBEC Report No. 5, 1991) presented the arguments in favor of timely exchange and use of data. Other international bodies such as JGOFS and WOCE have protocols for the submission and exchange of data and a protocol should also be developed for SO GLOBEC. This should recognize the inherent differences between the different sorts of data that will come out of SO GLOBEC, e.g. hydrographic data vs. biological data, surveys vs. process studies. It should also take into account different national stipulations on the use and submission of data. A decision should be made on whether data would be submitted and stored

centrally or whether data would be made available in a specified format and lists of available data would be published. The WG recommends that a group be formally tasked by GLOBEC.INT with developing the necessary protocols and with making detailed suggestions for methods of data submission and handling.

4.5 Modelling Working Group

(E. Hofmann, chair and rapporteur, C. Lascara, B. Rothschild)

4.5.1 Overview

The modelling working group noted that much effort has already gone into the development of a modelling programme in GLOBEC. Many of the general theoretical and modelling issues that are of interest to GLOBEC are discussed in U.S. and International GLOBEC documents. Additional discussion of general modelling issues specific to the development of a Southern Ocean programme is given in U.S. GLOBEC Report No. 5 (1991). These documents provide a reference for those interested in GLOBEC modelling issues.

The recommendations for modelling studies that arose from the U.S. GLOBEC Southern Ocean Workshop that was held in 1991 focused on the need for modelling prior to a field programme, the need for sea–ice models, and the need for models of aggregation behavior. Our modelling group endorsed these recommendations and took the next step in making more specific recommendations for a Southern Ocean modelling programme. These are discussed in the following sections.

4.5.2 Modelling Issues

The working group recognised the need for general modelling efforts that will result in the development of circulation, biological and physical-biological models. These models should address important issues that are of general interest to a Southern Ocean modelling programme, including issues of how Southern Ocean models could fit into global models, the use of data assimilation techniques for biological data, and the matching of space and time scales between circulation and biological models. However, the working group focused the majority of its discussion on the unique characteristics of the Antarctic that must be included in models.

Circulation models of the Southern Ocean will be affected by inclusion of sea–ice processes, mixed layer dynamics and buoyancy-driven flows. In particular, models of sea–ice processes were considered to be critically important since many of the components of the Antarctic marine food web depend on sea–ice during all or part of their life history.

Two unique aspects of the Antarctic ecosystem which will influence biological modelling studies are the aggregation (swarming) behavior of Antarctic krill (*Euphausia superba*) and the importance of top predators, such as penguins and seals. The working group felt that the understanding and modelling of krill swarming behavior was critical to the understanding of krill population dynamics as well as understanding the population dynamics of the top predators. The working group also discussed the need for resource modelling studies that could be used to determine how krill is allocated among its many predators.

4.5.3 Conceptual Model

The GLOBEC programme endorses the development of modelling studies prior to implementation of field programmes. The working group felt that efforts in this regard could be helped by the existence of a conceptual model that could be used as a framework for the Southern Ocean programme and around which Southern Ocean field programmes could be developed. This conceptual model should consist of modules that describe the physical environment, food resources and top predator effects on a target species, such as Antarctic krill. Other target species, such as copepods, can be used in place of krill.

Within each module of the conceptual model are submodules that consider specific processes, for example:

1. Physical Environment

   circulation model (including three-dimensional flow fields and hydrographic structure), sea–ice model (including dynamic and thermodynamic processes), mixed layer model

2. Food Resources

   bio-optical models for pelagic phytoplankton production and sea–ice algal production

   heterotrophic production models, including pelagic and sea–ice components

3. Top Predators

   energy requirements to support steady state populations

   foraging behavior, impact on krill processes

4. Krill (separate into early life stages and older stages that swarm)

   individual processes–energetics

   swarming–mechanisms of formation and maintenance, spatial, and temporal variability

   population dynamics

The working group envisioned that the development of the modules of the conceptual model would be done concurrently by several groups with expertise in particular areas.

4.5.4 Swarming

The working group focused on krill swarming as a topic that is central to the understanding of krill distributions and krill population dynamics. It was felt that a considerable historical data base exists on krill swarm distribution. These data could provide a starting point for the development of fundamental hypotheses about krill swarming behavior and the change in krill swarm distribution and type over seasonal and regional scales. Results from this data analysis could then be used to develop models to consider time and spatial variations in krill swarm distribution. The working group felt that it would be useful for individuals who make measurements of krill swarm distributions to meet with those doing models of krill swarms. This would allow for exchange of information and provide a forum for combining observational, theoretical and modelling studies of krill swarms.

4.5.5 Recommendations

The working group recommended that:

1. a conceptual model of the Antarctic physical environment and marine food web sufficient to provide a framework for a field programme be constructed;

2. the International GLOBEC programme sponsor a workshop on observation, theory and modelling of krill swarms to be held within eighteen months; the product of the workshop would be a book; and

3. existing circulation, ice and biological

models of the Southern Ocean be evaluated within the context of the needs for the development of GLOBEC Southern Ocean modelling studies;

4. GLOBEC modelling programmes maintain close contact with the sampling and observation components of Southern Ocean GLOBEC. This is especially important if data assimilative models are to be developed;

5. models of krill allocation among various predator species be developed; and

6. sea–ice and circulation models that can be interfaced with biological models of the Antarctic marine food web be developed.

4.6 Technology Development Working Group

(V. Marin, chair, D. Costa, rapporteur, J. Comiso, L. Guglielmo, G. Laurence, D. Manahan)

4.6.1 Remote Sensing

Physical Features: A variety of satellites provide or will provide capabilities to measure the following features:

1. Sea Surface topography–from TOPEX and the ERS-1 Altimeter

   Ocean currents from large-scale dynamic topography, and from instrumented drifters

   Quantification of ice–melt fresh water production

   However, for some of these satellites, there is a significant delay in data availability.

2. Sea–ice coverage and sea surface temperature can be obtained as:

Global scale ice cover–

DMSP (SSMI) passive microwave

resolution 30 km, daily maps of globe

Mesoscale–

ERS-1 SAR Ice coverage

5° coverage (100 km) every 3 days (planned coverage)

Cloud independent, resolution 30 m.

AVHRR ice cover and sea surface temperature variations and current movements can be obtained from time–series analysis of these images.

Interference by cloud coverage

1 km temperature and sea–ice resolution, at 1500 km coverage

Possibility of sensing aggregations of birds and seals?

Landsat 6 visible image of sea–ice cover

(rookeries?), etc. at 35 m resolution every 15 days, 800 km coverage. Expensive

SPOT visible–15 m every 15 days, swath width 800 km

3. Ocean Color Scanner–Pigment concentrations can be obtained from:

   MOS1B Japanese system launched, but data availability unknown

SeaWiFS–April 1994, 8 channels likely, data availability–3 days after satellite pass

4 km resolution available with receiver anywhere in world.

1 km resolution available only when receiver is in quadrant of interest

Need to calibrate pigment concentrations for Southern Ocean. GLOBEC could provide major contribution here.

ADEOS–High resolution OCS with high resolution data acquisition accessible anywhere in the world. Has memory capability and 12 channels.

4.6.2 Non-satellite Remote Sensing

Small Autonomous Aircraft:

There is a significant potential for the application of small remotely piloted, or programmed aircraft to carry sensors or cameras over specific areas of interest. These aircraft have been used by the military for pilotless reconnaissance. These could be used for mammal and bird population surveys, determination of fine scale oceanographic features, and sea–ice characteristics.

4.6.3 Problems That Need Attention

Satellite data is often difficult to acquire (Landsat, SPOT) or can only be acquired in near real time if the investigator has access to a dedicated data acquisition and processing facility. In addition, some systems require local receivers to acquire high resolution data of that area. A major contribution of GLOBEC.INT would be to develop a site or sites in the core Southern Ocean study sites which have dedicated satellite data acquisition and processing capabilities that could supply researchers with satellite images and data in real or near real time.

Currently studies of the behavior of mammal and bird behavior while at sea is limited by the data bandwidth of the ARGOS satellite system. The potential exists to acquire data on the diving behavior (swim velocity, depth and feeding rate) that can be correlated with physical features (location, depth, salinity, and temperature). This limitation is based on the limited time available for data uplinks to ARGOS and the small bandwidth available (8 bytes).

4.6.4 Local Level Data and Sample Acquisition Needs

1. Zooplankton Development issues:

Same as other GLOBEC.INT programmes except:

Develop the capability to use newly developed sampling schemes in ice.

2. Zooplankton and Higher Trophic Levels:

Apply genetic techniques to Southern Ocean systems. State-of-the art approaches have yet to be implemented for population genetic studies with higher trophic levels.

3. Higher Trophic Levels:

Population dynamics–

Need further refinement and/or development of PIT tags (transponder identification tags) that can incorporate greater ranges and can be coupled with automatic weighing and counting devices.

Development of data loggers with sensors capable of collecting data (pressure, temperature, salinity) valuable to oceanographers.

Develop data loggers and/or satellite tags that can measure:

swim velocity

animal location

feeding rates (stomach temp, pH, jaw movements, etc.)

Use R.O.V.'s to observe behavior of predator–prey interactions.

Develop capability to place cameras on predators to observe their behavior in relation to prey.

Develop acoustic and/or optical sensing methods to correlate prey abundance with predator behavior.

Develop ability to telemeter behavioral data on top predators by acoustic transmission to moorings coupled to ARGOS satellites or directly to ship. (This includes fish, mammals, and birds.)

4.6.5 Recommendations

1. Develop new satellite dedicated to wildlife telemetry to enable greater data throughout.

2. Incorporate state-of-the-art data compression algorithms designed for other information processing systems.

3. Develop data loggers that can be deployed on mammals and birds that incorporate GPS technology and use LEOS (low earth orbiting satellites) that use hand bandwidth data transmission.

5. INTERNATIONAL CONNECTIONS

A number of international organizations and programmes were mentioned that have or might have a special interest in GLOBEC–related issues in the Southern Ocean. It would be beneficial for GLOBEC to establish close contacts with these organizations and their programmes to learn from their results and advances and to avoid unnecessary overlap or duplication of work. The limitations in material and personnel resources, as well as in money, will necessitate cooperation wherever such is possible.

Examples of organizations and programmes of particular interest are the following:

1. International Council of Scientific Unions (ICSU) and its special Committees for:

   the Antarctic (SCAR), and

   Global Change (IGBP, International Geosphere–Biosphere Programme)

2. Unesco and its Intergovernmental Oceanographic Commission (IOC) with a Regional Committee for the Southern Ocean (SOC)

3. The Antarctic Treaty and the Commission for the Conservation of the Antarctic Marine Living Resources (CCAMLR)

4. The International Whaling Commission (IWC)

5. The Convention for the Conservation of Antarctic Seals (CCAS)

6. The European Committee for Ocean and Polar Sciences (ECOPS) (of the European Science Foundation and the Commission of the European Community).

Programmes and subgroups of particular interest to GLOBEC:

1. Joint Global Ocean Flux Study (JGOFS, of SCOR and IGBP)

2. Global Ocean Euphotic Zone Study (GOEZS, of IGBP)

3. Land Ocean Interaction in the Coastal Zone (LOICZ, of IGBP)

4. World Ocean Circulation Experiment (WOCE, of SCOR and IOC but now under ICSU, WMO and IOC)

5. Global Ocean Observing System (GOOS, of IOC, ICSU and WMO)

6. Antarctic Coastal and Shelf Zone Processes (of SCAR/SCOR Group of Specialists on Southern Ocean Ecology GOS–SOE)

7. Ecology of the Antarctic Sea–Ice Zone (EASIZ of the SCAR/SCOR GOS-SOE)

8. Group of Specialists on Seals (of SCAR)

9. Bird Biology Subcommittee (of SCAR)

10. Working Group on Krill (of CCAMLR)

11. Working Group on CCAMLR Ecosystem Monitoring Programme (CEMP, of CCAMLR)

12. Working Group on Fish Stock Assessment (of CCAMLR) (the three WGs of CCAMLR report to its Scientific Committee)

APPENDIX 1

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APPENDIX 2

Agenda

Tuesday, June 15

0815 Pick up at hotel–transportation to Crittenton Hall
0900 Welcome, Introductions and Local Logistics: Stromberg and Hofmann
0910 Overview of Meeting Goals/Tasks: Stromberg
0920 Overview of the Cambridge Fizzypop Meeting: Rothschild
0930 Physical processes and the selection of study sites for SO GLOBEC Int: Hofmann
0945 Physiology and distribution: Clarke
1000 Phytoplankton/ice algae and productivity regimes: Smetacek
1015 Fish and krill distribution: Everson
1030 Coffee Break
1045 Marine bird and mammal distribution: Croxall
1100 The proposals of the SCAR Group of Specialists on Seals: Bengtson
1115 Results of the Santiago Meeting on SO GLOBEC: Marin
1130 Recent advances in satellite capabilities: Comiso
1145 Open discussions, working group structure
1200 Lunch–Catered, Room 113, Crittenton Hall
1300 Working Group Meetings
1500 Break
1530 Continue working groups
1700 Adjourn
1730 Reception for all meeting participants–Fireplace Room, Crittenton Hall

Wednesday, June 16

0815 Pick up at hotel–transportation to Crittenton Hall
0900 Plenary session
working group reports
discussion of International Programs and Connections
1030 Break
1045 Continue working groups
1200 Lunch–Catered, Room 113, Crittenton Hall
1300 Continue working groups
1500 Break
1530 Reconvene in plenary session
working group reports
discussion of program logistics and facility needs
1700 Adjourn
1800 Cocktails and Dinner at Town Point Club in downtown Norfolk

Thursday, June 17

0815 Pick up at hotel–transportation to Crittenton Hall
0900 Working Groups/open discussion
discussion of global/climate change programs and connections
1000 Break
1015 working Groups/open discussion
1200 Lunch–Catered, Room 113, Crittenton Hall

1300	working groups/plenary session
1500	Break
1530	working groups/plenary session
1700	Adjourn
1800	Dinner at Hofmann/Klinck house

APPENDIX 3

List of Acronyms

ADEOS	Advanced Earth Observing Satellite
ANARE	Australian National Antarctic Research Expeditions
ARGOS	Satellite Location and Data Collection System
AVHRR	Advanced Very High Resolution Radiometer
BIOMASS	Biological Investigations of Marine Antarctic Systems and Stocks
CCAMLR	Convention for the Conservation of Antarctic Marine Living Resources
CCAS	Convention for the Conservation of Antarctic Seals
CEMP	CCAMLR Ecosystem Monitoring Programme
DMSP	Defense Meteorological Satellite Program
EASIZ	Ecology of the Antarctic Sea–Ice Zone
ECOPS	European Committee for Ocean and Polar Sciences
ERS-1	Earth Resources Satellite-1
GLOBEC	GLOBal ocean ECosystems dynamics
GOEZS	Global Ocean Euphotic Zone Study
GOOS	Global Ocean Observing System
GOS–SOE	Group of Specialists on Southern Ocean Ecology
GPS	Global Positioning System
ICES	International Council for the Exploration of the Sea
ICSU	International Council of Scientific Unions
IGBP	International Geosphere–Biosphere Programme
IOC	Intergovernmental Oceanographic Commission
IWC	International Whaling Commission
JARE	Japanese Antarctic Research Expeditions
JGOFS	Joint Global Ocean Flux Study
LEOS	Low Earth Orbiting Satellites
LOICZ	Land Ocean Interaction in the Coastal Zone
MOS1B	Marine Observation Satellite-1
NASA	National Aeronautics and Space Administration
PICES	Pacific International Council for Exploration of the Sea
ROV	Remotely Operated Vehicle
SAR	Synthetic Aperture Radar
SCAR	Scientific Committee on Antarctic Research
SCOR	Scientific Committee on Oceanic Research
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SOC	Southern Ocean Committee
SOE	Southern Ocean Ecology
SO GLOBEC	Southern Ocean GLOBal ocean ECosystems dynamics
SPOT	Systeme pour l'observation de la Terre
SSMI	Special Sensor for Microwave/Imaging
SSC	Science Steering Committee
SST	Sea Surface Temperature
TOPEX	Ocean Topography Experiment
UNESCO	United Nations Educational Scientific and Cultural Organization
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment