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Coastal and Shelf Ecology of the Antarctic Sea-Ice Zone (CS–EASIZ)
a SCAR Programme of Marine Research for the Coastal and Shelf Ecosystem of Antarctica

Science Plan and Implementation Plan

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COASTAL AND SHELF ECOLOGY
OF THE
ANTARCTIC SEA-ICE ZONE

Science Plan and Implementation Plan

October 1994

EXECUTIVE SUMMARY

This document describes the Science Plan for CS-EASIZ (Coastal and Shelf Ecology of the Antarctic Sea-Ice Zone).

The aim of the CS-EASIZ Programme is to improve our understanding of the structure and dynamics of the Antarctic coastal and shelf ecosystem (ACSE), the most complex and productive ecosystem in Antarctica, and likely the one most sensitive to global environmental change. Particular attention will be paid to those features that make the biology of this ice-dominated ecosystem so distinctive, and to understanding seasonal, inter-annual and long-term changes.

Six key scientific questions have been identified, and for each of these between two and seven research areas recommended. The heart of the CS-EASIZ Programme will be the Core Programme, a series of basic measurements to be undertaken on the ice, water-column and benthic sub-systems of the ACSE. These measurements have been carefully designed to be both simple and relevant, and to encourage participation by a maximum number of the coastal marine research stations around Antarctica.

For those nations wishing to undertake more extensive work, a Wider Programme has been devised as a guide to those areas of coastal marine ecology most in need of attention. This has involved the identification of key organisms, key ecological processes and key biological communities for future research. The Science Plan also discusses the development of new techniques, modelling, diversity studies, physiological work and molecular genetics.

It is proposed that CS-EASIZ will start in the 1994–95 season, and run for ten years. A dedicated cruise has been scheduled for the 1996–97 season, and a timetable of workshops and symposia proposed.

The unique character of CS-EASIZ is its coherent approach to the ecology of the coastal and shelf marine ecosystem, integrating work on the ice, water-column and benthic sub-systems. It will form a potentially major input to the SCAR global change initiative GLOCHANT, interface easily with SO-JGOFS and SO-GLOBEC and relate closely to the international LOICZ Programme.

CS-EASIZ: A SCAR PROGRAMME OF MARINE RESEARCH FOR THE COASTAL AND SHELF ECOSYSTEM OF ANTARCTICA

INTRODUCTION

This document describes the SCAR programme for marine research in the coastal and shelf ecosystem of Antarctica. This programme forms a major component of the SCAR initiative to promote the study of the ecology of the Antarctic sea-ice zone: EASIZ (Ecology of the Antarctic Sea-Ice Zone), and thereby is a key element in the Antarctic contribution to the IGBP.

EASIZ developed at a series of workshops, principally in Trondheim (May, 1990) and Bremerhaven (September 1991). Elements of the EASIZ initiative, and particularly those associated with open ocean biology, were elaborated by the Southern Ocean components of existing or evolving international programmes: SO-JGOFS and SO-GLOBEC. A key feature of the EASIZ initiative, however, was to provide a scientific framework for the integration of the research carried out at the array of coastal marine stations around Antarctica. This is the role undertaken by the SCAR Coastal and Shelf Zone EASIZ Programme (CS-EASIZ) which thereby incorporates much of the heart of the original EASIZ initiative.

The CS-EASIZ Programme was developed at workshops in Cambridge (September 1992), Bremerhaven (September 1993) and Padua (May 1994). SCAR Delegates formally approved the Science and Implementation plans for CS-EASIZ during XXIII SCAR in Rome, Italy, 5-9 September 1994.

Scientific aim of the programme

The overall scientific aim of the EASIZ initiative, as it evolved at the Trondheim workshop, was:

> *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 aim is very general, and applies equally to coastal and open-ocean areas. Within Antarctica the coastal zone has the greatest concentration of biomass, and is the site of most intense production. A more specific rationale for work in the coastal zone of Antarctica is that developed at the Bremerhaven (September 1993) workshop:

> *The aim of the CS-EASIZ Programme is to improve our understanding of the structure and dynamics of the Antarctic coastal and shelf marine ecosystem, the most complex and productive in Antarctica, and likely the most sensitive to global environmental change. Particular attention will be paid to those features that make the biology of this ice-dominated ecosystem so distinctive, and to understanding seasonal, inter-annual, and long-term changes.*

The importance of the Antarctic coastal zone

The Antarctic is a physically extreme and geographically isolated ecosystem which may be particularly sensitive to global change. Antarctica has a very long coastline, roughly 35,000 km. Of this, only 17% is true coast in the sense of exposed rocks or beaches. The remainder is formed either by floating ice-shelf (45%) or rocky coast covered with ice (38%). The Antarctic continental shelf is distinctive in being depressed by the weight of the continental ice; in places the shelf can be 800 metres deep and this increases the distance from the euphotic zone by a factor of x 3 or x 4 compared with continental shelves elsewhere in the world. The overall area of the Antarctic continental shelf is 2.2 x 10^6 km^2, roughly 4-5 times that of the North Sea, and all of this is within the seasonal pack-ice zone. Other factors which make the Antarctic continental shelf distinctive are the proximity or direct contact with shelf ice, the presence of large coastal polynyas, the low riverine input and the large glacial input in the form of cold bottom water, surface melt and glacial debris.

Traditionally, the functioning of the biosphere is largely viewed in terms of the properties of single systems: the atmosphere, the terrestrial and oceanic ecosystems. Those processes occurring at the boundaries such as the interface between the land and oceans, or between ice and water, are easily overlooked. Coastal plains and shallow coastal seas, which comprise about 8% of the surface of the globe, contribute around 25% of global production. A recent review concluded that coastal oceans support roughly half the global oceanic total production; furthermore, when only new production is considered (that is production fuelled by nitrate rather than recycled forms of nitrogen such as ammonia or urea), coastal waters provide almost twice the production of the rest of the oceans. Although current estimates of global production are necessarily imprecise, it is clear that coastal waters are extremely important in global terms and no comprehensive examination of global processes can ignore the coastal zone.

Production data for the Southern Ocean are not yet precise enough for robust comparisons to be made between coastal and open ocean waters, but a number of factors point to coastal (neritic) waters being of major importance to the Southern Ocean marine ecosystem. Maximum summer chlorophyll standing crops are frequently much greater in coastal waters than in open waters, and nutrient levels are often depleted further in coastal waters than in the open ocean. At higher levels in the food web, benthic standing crops on the Antarctic continental shelves are very much greater than in deeper water, and the productive coastal waters are of critical significance to the recruitment of zooplankton such as Antarctic krill, *Euphausia superba*.

Current global circulation models indicate that the Antarctic coastal and shelf system may be particularly sensitive to environmental change. It is relatively free from pollution, and contains areas which have not been subject to harvesting. Its extreme dependence on ice cover, however, makes it particularly sensitive to warming and to secondary effects of warming such as stabilization of the water column. The availability of several baseline data sets for the Antarctic coastal zone offers a unique opportunity to differentiate short term climatological variability from other types of natural variability. The extent to which elevated UV-B radiation resulting from seasonal stratospheric ozone depletion is affecting oceanic processes such as primary production or microbial activity is currently unclear, but is under active investigation.

The Antarctic coastal zone ecosystem is particularly suitable for examining the effects of environmental change because the carbon budget appears to be driven by a limited number of variables, and there is close coupling between sea-ice and other climate-related variables such as temperature, wind, wave and currents. The coupling between benthic and pelagic processes in coastal waters is often tight, and vertical flux of matter is important. Processes important to population dynamics such as dispersal, recruitment and growth rate, also appear to be coupled to sea-ice variability. The coastal areas around Antarctica have been the site of key evolutionary processes, and it is possible that cycles of climate and associated glaciation have been responsible for the high species richness in some Antarctic groups and a large variety of habitats. This makes the Antarctic coastal zone an important area for biological research, especially as there are areas where the basic features of the system are relatively well understood and it is an area where it is logistically feasible to undertake long-term experiments.

How should we define the Antarctic coastal zone?

To develop a clear and unified framework for research it is necessary to set spatial boundaries. The inner boundary of the marine coastal zone is broadly where land meets sea; in the Antarctic context land includes the edge of floating ice-shelves, glacier fronts and ice-covered rock. In functional terms, however, it is essential to take into account the exchange of energy and materials between the marine and terrestrial systems through wind, run-off, glacial processes and biological activity. This means that our definition of the inner boundary must be extended inland to include the supralittoral zone, and seabird colonies or marine mammal aggregations close to the sea.

In terms of physics, a meaningful outer boundary is that defined by 2-3 Rossby radii (roughly 15-50 km in the Southern Ocean) from the coast. This distance scale describes the upper limit for coherent flow within a water body, and this functional definition is more meaningful in terms of biological processes such as larval transport than is a simple geographical or topographical boundary like the shelf-break or a particular isobath. Nevertheless many studies will need to be extended to the limits of immediate glacial impact at the edge of the continental shelf and to include shelf-break processes.

The definition of the Antarctic coastal and shelf ecosystem (ACSE) thus includes the complete continental shelf. It includes all those regions that have been subject to flooding, exposure or glacial scouring during the climatic fluctuations of the past 60 million years, and incorporates much of the area of coastal ice of relevance to the EASIZ initiative. In biological terms it includes all components of the ice, water column and seabed, together with relevant aspects of the near-shore terrestrial ecosystem.

The importance of shore-based research in the Antarctic

The Antarctic has a highly seasonal environment, with large and important differences in biology between summer and winter. A significant impediment to improving our understanding of the open ocean system in the Southern Ocean has been the logistical difficulties associated with undertaking oceanographic research in the austral winter. As a result many of the data available come from summer, and many winter processes are only poorly described and understood.

Coastal marine stations therefore have a crucial role to play in improving the understanding of not just the coastal marine ecosystem, but of the Southern Ocean marine ecosystem as a whole. They allow biological work to be undertaken throughout the year, thus providing the critical winter data, and allow year-round access to habitats such as sea ice. They also provide a platform for sophisticated biological and physiological work. The network of coastal marine stations that has developed around Antarctica is therefore central to the science it is proposed to undertake. Oceanographic work is undoubtedly critical to a full understanding of processes operating in the coastal zone, particularly for placing shore-based work in its larger-scale context. Few nations, however, can make long-term commitments for regular oceanographic work over the time-scale required for the CS-EASIZ Programme. For this reason, work undertaken at shore stations will be central to CS-EASIZ.

THE KEY SCIENTIFIC QUESTIONS

The EASIZ workshops in Trondheim and Bremerhaven detailed a series of areas where data were required urgently, ranging from sea-ice physics through water-column topics to benthic biota and the sedimentary record. This list can be consolidated into six key biological questions of importance to the ACSE. These are:

1. *What is the role of ice in the Antarctic coastal marine ecosystem?*
2. *How do communities of Antarctic marine organisms differ from those elsewhere?*
3. *What physical chemical and biological factors determine patterns of production, sedimentation and recycling, and the major elemental budgets, of the Antarctic coastal and shelf ecosystem?*
4. *How are marine organisms adapted to the low temperature and seasonal changes in the physico-chemical parameters characteristic of the Antarctic coastal and shelf ecosystem?*

5. *What is the nature and importance of the interaction between land (including shelf ice) and sea in the Antarctic coastal zone?*
6. *How are the biological communities of the Antarctic coastal and shelf ecosystem directly affected by human activities?*

Each of these six questions is discussed in more detail below.

1. What is the role of ice in the Antarctic coastal marine ecosystem?

The Antarctic is characterized by many and varied forms of ice. These include land-based or floating ice shelves, glaciers, icebergs, sea ice, fast ice and anchor ice. The proximity of ice-shelves, glacier fronts and fast-flowing ice streams has a major impact on the ACSE. Melting icebergs can deposit rocks ranging in size up to large boulders onto the seabed, and thus provide isolated patches of hard substratum. Probably of greater significance, however, are the vast quantities of coarse sediment that fall to the sea floor from the melting of land-derived ice. Present data from the Arctic suggest that at times, ice-flow velocities can increase markedly with corresponding increases in the amount of coarse sediment deposited on the seabed (Heinrich events). These can have major impacts on benthic communities.

The sea ice of the Southern Ocean is not a barren, hostile area; it is an extensive habitat for many specially adapted organisms living within the internal structure and on the surfaces of the sea ice, and large populations of seals and penguins moving between the aquatic and ice habitats. A major ecological role of the sea ice in the coastal ecosystem is as an important site of primary production, while it also functions as a filter to the transmission of light, and a barrier to the exchange of heat, gases and momentum between atmosphere and ocean.

In the ACSE there are several types of sea ice and their associated biological communities differ from those in the water column. Ice microbiota contain important primary and secondary producers, which grow in spring through to autumn in the fast-ice areas. Many invertebrates feed directly on ice organisms, but a major fraction of these organisms sinks and provides food for water-column and benthic animals.

The following areas of research are considered to be of particular importance:

- The ecological importance and dynamics of ice shelves, sea ice and polynyas
- The structural features and physico-chemical characteristics of sea ice (including ice platelets and melt-water) that determine the nature, quantity and production of organisms associated with sea ice
- Sedimentation rates of organic matter produced within sea ice
- Life-cycles and trophic interactions of organisms living in association with sea ice
- The effects of seasonal and interannual variations in sea ice on the population dynamics of organisms dependent upon or associated with that ice
- The significance of ice-transported terrigenous sediment and boulders.
- The impact of anchor ice, iceberg and glacial scour on benthic communities

2. How do communities of Antarctic marine organisms differ from those elsewhere?

Like other marine coastal ecosystems, the ACSE has pelagic and benthic communities integrated by their dependence on primary production in the photic zone. However, the ACSE differs markedly from more temperate systems primarily in the importance of the sea ice in controlling production and community structure. In addition, these communities must also be adapted to the cold, stable temperature regime, extreme seasonality of primary production, the deeper Antarctic continental shelf, and much lower material input from rivers. The dynamics of populations and communities in the ACSE are not particularly well known at more than short time scales, but interesting generalizations have been made that may distinguish these communities from those in more temperate areas. For example, some Antarctic macrobenthic communities are composed of very long-lived individuals with low growth rates for many species. Recovery of such communities from episodic perturbations may take centuries. However, in shallow habitats where different sources of disturbance are common, other organisms have life histories and other adaptations to such disturbances.

Many of the processes involved in producing patchiness (in both space and time) are poorly understood. However, it is known that some major events in the environment occur on cycles with periods of several years or longer. Knowledge of these processes and events will be crucial to our understanding of changes in the environment caused by global changes (including those induced by human activities) in contrast to other factors, such as El Niño Southern Oscillation (ENSO) events. Keeping in mind that we are dealing with communities and species encompassing bacteria to whales, careful consideration must be made of the proper temporal and spatial scales for these studies.

The following areas of research are considered to be of particular importance:

- Identifying those species, communities and processes in the ACSE that may be most sensitive to environmental change, and which are amenable to long-term study.
- Determining those factors (temperature, disturbance, geomorphology, advection, sedimentation, resuspension) that control the distribution of species and communities at different spatial and temporal scales.
- Ascertaining the influence of physical seasonality (light, ice conditions, meltwater, weather) on the life histories of species and the dynamics of populations and communities in the ACSE.

- Determining those factors contributing to, or disrupting, the resilience and persistence of Antarctic communities.

3. What physical, chemical and biological factors determine patterns of production, sedimentation and recycling, and the major elemental budgets, of the Antarctic coastal and shelf ecosystem?

The patterns and rates of flow of both dissolved and particulate organic matter in the ACSE need to be examined. Although of limited size, these systems are thought to contribute a significant proportion of the total production of organic matter in the Southern Ocean. The coastal systems are also thought to have higher flux rates of total organic matter than the open ocean, particularly because a high proportion of the production is new production.

In the ACSE there are various sources of organic matter, including both pelagic and sea-ice algae, benthic micro- and macroalgae. Minor contributions come from macroalgal matter on land and other input from terrestrial sources.

There also are numerous and complex pathways for the flow of organic matter. To analyse these complex relations, future research should centre on the relative significance of the different sources, sinks and remineralization process of organic matter. In addition, the spatial and temporal variability of food web structure and the flow of organic matter through key species or key functional groups need to be addressed.

In this context it is necessary to consider the Antarctic coastal and shelf ecosystem as comprising three different but intimately linked sub-systems: the ice, pelagic and benthic systems.

Important areas for research are:

- Geographical and temporal differences in the role of the three sub-systems (ice, pelagic and benthic).
- The relative amounts of production in the ice, pelagic and benthic systems, and the degree of coupling between them.
- The relative importance of various loss processes (vertical flux, advection, respiration) together with geographical and temporal (both seasonal and interannual) variation in those processes.
- The effects of large-scale and long-term hydrographic variability (including that induced by global change) on production, transport and loss processes.
- The role of polynyas in the feeding ecology of vertebrate predators.
- The importance of the ACSE in the generation and flux to the atmosphere of biogenic gases (eg nitrous oxide, methane and dimethyl sulphide), together with geographical, seasonal and interannual variability in these.

4. How are marine organisms adapted to the low temperature and seasonal changes in physico-chemical parameters characteristic of the ACSE?

The Antarctic marine ecosystem is of fundamental significance to our understanding of physiological and biochemical adaptations to temperature because polar seas represent one extreme of the temperature range occupied by marine organisms. The Southern Ocean is also critical to an understanding of adaptation to a marked seasonal light climate and the role of increased UV radiation as a result of stratospheric ozone depletion.

The evolution of cold adaptation in the Antarctic marine biota has involved the development of unique physiological specializations. In some cases an increase in ambient temperature of only a few degrees centigrade would have lethal effects. The extent to which this is a general phenomenon is, however, unknown and studies of the range of physiological tolerance are therefore needed. These tolerances may dictate whether global climate change results in a shift of range or extinction.

Study of biochemical and physiological adaptations using modern techniques and equipment are more amenable to year-round research at shore stations than by ship-based operations. Although temperature is the most obvious environmental parameter to study in Antarctic marine organisms, adaptation to temperature can involve interaction with adaptations to other factors. Temperature adaptation should not, therefore, be viewed in isolation.

Important areas for investigation are:

- Adaptation of organisms from those habitats subject to extremes of temperature, irradiance, salinity and nutrient concentration.
- Molecular mechanisms of adaptation in Antarctic marine organisms.
- Photoadaptive response mechanisms in Antarctic organisms, including photosynthetic mechanisms, screening pigments, and cellular repair mechanisms.
- Behavioural adaptations of Antarctic marine organisms.
- Energetic responses of Antarctic marine organisms to the seasonal supply of light and food.

5. What is the nature and importance of the interaction between land and sea in the Antarctic coastal and shelf ecosystem?

The land and sea have a direct influence on each other, and their interactions are part of a cyclical process. The influence of the sea on the land (particularly the supralittoral) is through input of salt and minerals, via salt spray, bird guano, macroalgal debris, seal excrement, and precipitation. The magnitude of this influence is not fully known. The influence of the land on the sea, apart from a physical influence, is through the run-off of melt-water and minerals, the latter for the most part from guano. In the absence of significant riverine input, the significance of land-derived nutrients to the well-mixed coastal oceanic system is likely to be small. Nevertheless production in coastal areas is usually greater than in the open ocean and the role of land-derived micro-nutrients, such as iron, in enhancing production is unknown.

The littoral and supralittoral systems are subject to strong seasonal and diel fluctuations which depend greatly on local circumstances. This will have influence on the community structure, the primary production and the patchiness of the supralittoral, littoral and possibly the planktonic communities. The marine influence on supralittoral communities is relatively large compared with coastal systems elsewhere.

Key areas for research are:

- The magnitude of nutrient and material fluxes from land to sea, and vice versa.
- The sensitivity of those processes to climatic variability and long-term change.

6. How are the biological communities of the Antarctic coastal and shelf ecosystem directly affected by human activities?

In the Antarctic, anthropogenic impact may occur locally or, to a lesser degree, on a larger scale. Local impacts include those from past and present fishing and scientific endeavours as well as current shipping activities. The last have increased significantly over the past decade and will continue to increase as a result of both enhanced scientific effort and tourism. Larger scale anthropogenic activity results from mainly atmospheric transport of specific pollutants to Antarctica and Southern Ocean waters, global climate change and seasonal ozone depletion.

The main concerns for local pollution are from human sewage and oil spills. Routine sampling, perhaps enhanced during the summer season, may be required to monitor both types of pollution. Evaluation of existing data sets, standardization of methods and planning of appropriate data management need to be undertaken. The generally low levels of these compounds within the Antarctic marine ecosystem make this a unique environment for use as a yardstick against which we can ascertain future global pollution.

Undertaking impact studies *per se* is not within the remit of CS-EASIZ, for these are covered potentially by activities such as those organized by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and SCAR Group of Specialists on Environmental Affairs and Conservation (GOSEAC). There is a recognized need, however, for marine scientists to respond to major scientific issues concerned with the well-being of the environment within which they work. In particular there is a pressing need to furnish scientific advice to both SCAR GOSEAC and CCAMLR concerning the proper evaluation of human impact on the Antarctic coastal and shelf marine ecosystem. CS-EASIZ will therefore have a critical scientific role in Antarctic environmental issues through the provision of scientific advice and background data, against which to assess the extent of perceived human impact. It is essential that any environmental sampling or monitoring in the ACSE proposed by SCAR GOSEAC or CCAMLR be aligned with CS-EASIZ research.

Specific CS-EASIZ recommendations are:

- To identify those species, communities and processes within the ACSE that are sensitive to human impact, and which are amenable to long-term study.
- To facilitate liaison between biologists undertaking CS-EASIZ research with those environmental scientists and managers within SCAR and other appropriate agencies.

THE CS-EASIZ CORE PROGRAMME

Philosophy

The scientific questions and research topics outlined above do not in themselves form a programme of scientific research. In order to provide a coherent package of work that will allow the major biological processes of the ACSE to be compared between different regions it is necessary to develop a suite of core measurements. These should provide basic data on all subsystems of the ecosystem (that is the ice, water column and benthos) and on the major links between them. The core measurements thus form a basic skeleton to which can be added more detailed or sophisticated work examining particular communities or processes. The core measurements are designed to be undertaken regularly; they are thus quite distinct from the detailed process studies, observational work or sophisticated experimental work to be undertaken within the wider CS-EASIZ Programme.

For the core programme to be successful it must be both simple and relevant. The data it provides must be of high quality, but also able to be obtained by relatively unsophisticated means. Finally, it is critical that techniques used are comparable between research stations or the value of comparative studies around the Antarctic continent will be lost. Careful attention to analytical protocol, internal calibration and comparability between different research techniques is vital to the success of the core programme.

THE CORE MEASUREMENTS

1. Ice measurements

Sea ice is perhaps the most important seasonally variable environmental parameter in the Antarctic coastal and shelf ecosystem. The annual formation and loss of surface ice is a major influence on the structure and function of the ACSE and is the central linking theme in the EASIZ Programme. Sea-ice thickness is also believed to be a key parameter in its sensitivity to global warming. For the core programme, monthly measurements should be made of the following parameters:

Type of ice:
ice should be described using the standard classification (see Appendix).

Thickness:
by drilling a core, or cutting a hole; the thickness of ice and overlying snow should be measured separately and if feasible the presence and thickness of underlying platelets should also be measured.

Coverage of ice:
percentage ice cover together with the size of any polynya present.

Air temperature:
at most stations these data will be provided by routine synoptic meteorological measurements. Weekly averages are most suitable.

In addition the timing of formation and melt- or break-out of the winter ice cover should be recorded. Essential background data for these parameters include a map of the local area to show the extent of the winter ice, and the position of sampling points. Geographical Information System (GIS) techniques should be used where these are available, and the map should include bathymetry.

2. Ice biology

There are striking geographical differences around Antarctica in the timing and extent of the growth of communities associated with sea ice. Although study of the ice-associated community is of central importance to the EASIZ initiative, for a core measurement only the routine measurement of sea ice chlorophyll is appropriate.

Sea ice chlorophyll:
the concentration of chlorophyll in the lower part of the monthly ice-core should be determined using the standard JGOFS protocols for sea-ice analysis. Data should be reported as mg chlorophyll per unit volume of sea ice (see Appendix).

3. Water-column measurements

The biology of the water column is of critical importance to the EASIZ Programme. It receives the sea-ice community at melt, it is the site of primary production, it is the medium through which particulate material passes to the benthos, and it supports an important community of grazers and predators. It is not possible fully to understand the benthic environment without knowledge of the overlying water column. Of particular relevance to the patterns of recruitment to benthic communities is the pelagic larval phase of those species whose life-cycle includes a free-swimming larval stage.

The suite of core water-column parameters has been designed to provide a maximum amount of basic information that links the three critical sub-systems of the ACSE: ice, water-column and benthos. The proposed parameters are:

Seawater temperature:
for shallow and well-mixed water columns temperature can be measured at any depth; for deeper or stratified water columns then the depth of measurement should be 10 metres below the ice, and also close to the seabed if this is possible. Temperature should be measured to ±0.01°C using a calibrated reversing thermometer, or a CTD if this is available. Weekly measurements are ideal, and both the depth of measurement and total water depth should be recorded. A fixed sampling location should be established.

PAR:
photosynthetically active radiation (PAR) should be measured at the sea surface and 10 metres depth if the relevant equipment is available. Data should ideally be collected weekly.

Zooplankton:
monthly tows to determine zooplankton composition. In order to provide information on the important smaller zooplankton and larvae the net should be of 300 micron mesh and have a solid cod-end. Vertical tows should be made from 100 m to the surface, with a net of 1 m diameter. Samples can be fixed in neutral formal-saline, and preserved Steedman's solution, for later taxonomic examination. Samples should be sorted to species and stage; collaborative work may be needed to undertake this programme.

Chlorophyll:
the standing stock of water-column chlorophyll is a critical core measurement (see Appendix). This should be determined monthly in winter but at least once every two weeks in summer, using standard oceanographic techniques (JGOFS). A fixed station and depth (10 m is suggested) should be used, and size-fractionation is recommended. The most appropriate size fractions are >20, 20–2, and 2–0.2 μm, and if possible the dominant taxa should be reported.

4. Vertical flux

The flux of material from the sea ice or upper waters to the seabed is the fundamental process linking the various components of the ACSE. In addition to the biologically mediated fluxes, in polar regions there can also be a major flux of land-derived sediments released from ice-bergs and from melt-water input.

Although many of these processes can have a significant horizontal (advective) component, the use of sediment traps to monitor vertical flux is a long-established technique in marine biology. Traps can vary from the simple (and hence cheap) to the highly sophisticated. Trap design is important, and can involve the use of baffles, vanes and poisons. The critical factors are to maximize the trapping efficiency by keeping the ratio of trap diameter to length at 1:3, and to avoid lines, buoys or other material above the traps. Export production, an important oceanographic parameter, can only be measured by sediment traps set below the euphotic zone, and hence beyond the depths accessible to SCUBA divers. For any measurement of export production, sophisticated automatic sediment traps are required. Nevertheless, for the purposes of the CS-EASIZ Programme, extremely valuable comparative data can be obtained from simple trap arrays operated over long time periods.

Sediment trap:

traps operated continuously at a site close to the station chosen for seawater temperature and chlorophyll monitoring. The depth needs to be set as deep as possible whilst still allowing clearance by SCUBA divers. Traps should be cleared monthly in winter but weekly in summer and material either preserved or analysed immediately. Core analytical measurements are chlorophyll and phaeophytin, dry mass and ash content.

5. Benthic measurements

In contrast to the impoverished fauna of the Arctic, the benthos of the Antarctic is rich and diverse. Consequently there are few simple core parameters that will provide meaningful data to allow comparison between different areas. However, one biological process that is of fundamental importance to community structure and function, and that appears to have distinctive features in polar regions, is recruitment. Studies at several sites around Antarctica have revealed very low rates of colonization of settlement panels, and one study from McMurdo Sound has indicated large interannual variations in settlement. Established protocols exist for monitoring recruitment to hard substrata and although soft bottom habitats have proved less tractable to long-term monitoring, workable protocols exist for these also. Soft sediments can be cored and the cores screened for newly settled juveniles. Recruitment monitoring is therefore proposed as the most important core programme for the benthos.

Settlement panels:

panels of area at least $0.2m^2$ exposed for one year and recovered at the end of the austral summer. Panels should be replicated (at least three) and can either be photographed or preserved (ideally both) for more detailed examination.

Cores:

species composition, abundance and biomass should be measured regularly with cores taken directly, or taken from undisturbed grab samples.

One core should be analysed for grain size distribution using standard techniques, and two cores used for the determination of organic matter (loss on ignition: ash-free dry mass) in the top 1 cm. Monthly determinations should be undertaken to follow seasonal variations in organic content.

6. Vertebrate measurements

Fish are an important component of both the water-column and benthic environments, where they are major predators. Fish populations are less easily surveyed but well-established techniques include line and net fishing. Marine mammals and seabirds are also important components of the ACSE, and can influence biological processes in a number of ways. Most populations are highly dispersed for most of the year but concentrate on land or ice for breeding and/or moulting. At these times their impact on the system is highly focused, and their populations can be assessed most easily.

Protocols for the routine estimation of population parameters in fish, penguins, other seabirds and seals are given in the Appendix.

THE WIDER PROGRAMME

The Core Programme has been designed to provide a central set of measurements which should allow the basic features of the ACSE to be compared between different areas. These measurements, however, only cover a small part of the science proposed for the SCAR CS-EASIZ Programme.

In one sense, almost any biology or oceanography undertaken in the near-shore or shelf areas of the Antarctic is a contribution to our understanding of the ACSE. Central to the philosophy of the CS-EASIZ Programme, however, is a focused approach to facilitate the integration of previously diffuse research projects. The aim is to provide a coherent integrated framework and thereby provide an impetus to research in particular areas or directions which are currently seen as important or critical areas to improve our knowledge. The Wider Programme will necessarily involve a range of approaches and techniques, and not all will be possible at every site. Nor will it be possible for any one nation or research station to undertake more than a fraction of the programme described below. In this section, therefore, guidelines are provided for wider aspects of research to be undertaken alongside the core programme.

The role of ice

The role of ice in the ACSE is diverse and variable. In some areas the formation of anchor ice has a major impact on the benthic fauna. There is some evidence that long term (sub-decadal) variation in oceanographic parameters may influence the intensity of anchor-ice formation and so long-term studies of anchor-ice incidence and impact would be valuable. In the intertidal zone scour by brash ice or grounded floes has a major ecological impact, and iceberg grounding is an important process causing density-independent mortality in benthic communities. Studies of the incidence and effect of iceberg impact, coupled with studies of subsequent recolonization and succession, would be most valuable.

Of obvious relevance to studies of the ecological importance of iceberg impact is knowledge of calving rates from glaciers or ice-shelves, and the rate of deposition of land-derived debris. These topics are under active consideration by glaciological programmes in Antarctica, and hence are outside the immediate scope of CS-EASIZ.

The annual formation and melt of surface ice is a major process in the ACSE, and central to the scientific aims of the EASIZ initiative. Although regular measurements of ice thickness and snow cover form part of the core programme, extra data would be valuable. These could include description of roughness, pressure ridges, leads and both small and large polynyas. Data such as these could be obtained from supply or research vessels in addition to observations from shore stations. More detailed observations of pack or fast ice could include temperature profiles within the ice, and the thickness and extent of the subsurface platelet layer throughout the season. The structure of the ice–water interface may be of vital importance to the life cycle of many invertebrates in providing both food and a refuge from predation. An example of a standard form for recording ice variables is given in the Appendix.

The core programme includes regular simple measurements of chlorophyll concentration in the ice close to the ice–water interface. More detailed studies could include a full description of the microbial and meiofaunal communities associated with the ice. It would then be of interest to see the extent to which species found within the sea-ice community contributed to any subsequent water-column bloom. An important scientific problem is to estimate the extent of primary production within the sea ice community. This question has so far resisted definitive solution, essentially because of the extreme technical difficulty of making measurements without destroying the structural integrity of the community under investigation. These difficulties have similarly prevented reliable estimates of the extent to which this primary production is recycled within the sea-ice microbial community or available to water-column grazers. The structure of the ice habitat is of profound significance to the sea-ice community, and the physical environment can be extreme in terms of temperature, salinity and nutrient concentration. These problems are of interest to all biological oceanographers concerned with polar regions. The ability to work year-round from shore stations, however, make these problems amenable to investigation within the CS-EASIZ Programme in a way that they are not from oceanographic cruises.

A sediment trap programme is included as part of the core programme, but this includes only a very basic array of measurements. A great deal more information could be obtained by extending the analyses made on the trapped material. In this way the sediment trap programme becomes central to CS-EASIZ in that it contributes important data to several key topics. A wider programme of sediment trap work should include analysis for the full range of pigments by HPLC, assay for C, N, P, and opal (biogenic silica), and examination by optical and electron microscopy. Such a programme would allow a distinction, for example, between land-derived debris, diatom flux and marine snow derived from sea ice. Sea ice may also be important as a potential source of food for invertebrate grazers, which in turn form a food source for both invertebrate and vertebrate predators. Although the role of the sea-ice microbial community as a food source for grazers is still much debated, it is clearly important to some species in some areas at some times. It may even be that the nature, extent and timing of winter sea ice and its associated microbial community is of importance to the year class strength of zooplankton grazers such as *Euphausia superba*. Coastal marine stations offer a valuable opportunity for observations on interactions between water-column species and the sea-ice community to be conducted throughout the winter.

Antarctic communities

Above the waterline, sea ice is an important habitat component for marine mammals and seabirds. It serves both as a safe resting place immediately adjacent to foraging areas, and as an important habitat for potential prey. Such close juxtaposition is a unique feature of the ACSE compared with other marine ecosystems, and may promote a higher efficiency of energy transfer. This will be a topic of research in the SCAR Antarctic pack-ice seals (APIS) Programme, but should be considered in the CS-EASIZ for seabirds and Weddell seals.

The structure and dynamics of the sea-ice microbial community have received considerable attention in the last decade, but still remain poorly understood. The mechanism by which organisms are incorporated into the ice, the activities of individual micro-organisms and interactions between them, and the fate of the community following ice melt all warrant further detailed attention. Such work is crucial to our understanding of the overall productivity of the ACSE, but can be difficult to undertake because of problems in gaining access to sea ice at the time of its formation or break-up. There is also the ever-present difficulty that investigation of the sea-ice microbial community is almost impossible without disrupting the structural integrity of the community itself. Despite these difficulties, investigations of the sea-ice community is seen as of central importance to CS-EASIZ, and an area where the ease of access provided by year-round shore stations is a significant asset.

The water-column protist community is characterized by marked seasonality and a distinct seasonal species succession. These features are particularly important in terms of the balance between new and regenerated production in the water column with significant consequences for sedimentation, biogeochemical cycling and trophodynamics.

The water-column macroinvertebrate community contains fewer species than the benthos, and many of the key species have been well-studied during the *Discovery* Investigations and the SCAR BIOMASS Programme. The SO-GLOBEC Programme has proposed to continue investigation of certain key species, notably *Euphausia superba*, selected copepods and salps. Although it is the larger species that often attract attention in net hauls, and are often easier to work on, the water column in the ACSE contains many small copepods. Together with juvenile stages of larger species and, on occasion, larval stages of benthic macroinvertebrates, these small organisms may exert a significant grazing impact. They are therefore an important area for attention in water-column studies within CS-EASIZ.

Two other groups of water-column organisms which are likely to be extremely significant ecologically, but where difficulties of sampling limit useful work, are squid and gelatinous zooplankton. Cnidarians are often noted as predators under winter ice but studies are few because of their fragile nature. Even simple observational studies, coupled perhaps with photography, could provide valuable data for this important group.

Many of the key topics suggested for work on the benthos require sophisticated observational and experimental ecological work. Basic life-history studies are still required urgently for many groups within the benthos. Ecological studies to date have tended to concentrate on the more easily sampled taxa such as molluscs, crustaceans, echinoderms or demersal fish. Many areas of the Antarctic continental shelf are, however, dominated by dense communities of suspension feeders. Ecological and life history studies of groups such as sponges, corals, octocorals, polychaetes, bryozoans and brachiopods are needed urgently. Such basic natural history studies are of fundamental and lasting importance, particularly in an ecosystem such as the Antarctic where so little basic biology and ecology is documented. These studies allow for comparison with elsewhere, and form an important knowledge base for later generalizations and modelling.

Fish are an important component of the coastal and shelf marine communities and play a significant role in linking the benthic and pelagic systems. The detailed biology of only few species is, however, described and further studies are needed. There is also a need for basic biological studies of macroalgae and their contribution to the water-column particulate organic matter. The ACSE is unusual in the contribution of glacial debris (of wide size range) to the soft-bottom substrate; this community is also in need of attention for in places it is dominated by taxa rare elsewhere (for example sipunculids).

Particular features of interest include the influence of the seasonal supply of light and food on life-history parameters such as growth, reproduction, larval type and energetics. The wide latitudinal gradient available within the ACSE, particularly along the Antarctic Peninsula, offers a valuable opportunity for comparative studies of within-taxon variation in these parameters. The geographical distribution of coastal research stations makes this a particularly important aspect of the CS-EASIZ Programme.

Elucidating those factors that control the distribution of different benthic communities will require sophisticated ecological experimentation on time and spatial scales appropriate to the question being investigated. This aspect of Southern Ocean ecology has received little attention and in many areas there is still ignorance of the relative balance between physical and biological processes in structuring communities. Such work is badly needed, and is again best carried out from shore-based marine stations.

Although there have been many studies of surface and epipelagic predators (especially birds and seals) there is much less knowledge about the trophic levels immediately below these predators. As many of these predators are considered to be good indicators of environmental change, it is important that the CS-EASIZ Programme involves studies to elucidate those processes underlying or driving the population dynamics of these surface predators. This clearly includes an improved knowledge of those squid and fish that are taken by the predators.

Diversity studies in the Antarctic Coastal and Shelf Ecosystem

It is often remarked that the fauna of the Southern Ocean is very poorly known in comparison with those elsewhere. This is not really true. Although a few groups are only poorly known, many are well-described. For example, a recent study of molluscs collected from previously unsampled areas of the Weddell Sea revealed very few new species. As with all areas of the world, continued careful taxonomic work is necessary (especially for the more obscure and physically small taxa), but a recent survey showed that the Southern Ocean fauna is better known than is often realised. The more extreme estimates of our ignorance are probably misleading.

The large amount of collecting done by the early pioneering biologists working in the Southern Ocean means that there is now a good working picture of the broad patterns of distribution around Antarctica. There is thus relatively little scientific value in simply accumulating more lists of species for different areas. What is needed are careful diversity studies, based on precise quantitative data and directly comparable sampling and analytical techniques.

Thorough studies of the biological diversity of specified areas of the ACSE would therefore make a valuable contribution to CS-EASIZ. These should concentrate on specific and defined habitats (for example soft-bottom communities at a certain depth) and involve as full an evaluation of the total species list as possible. The data collected should include date, the specific site (with coordinates), depth, habitat and full information on the number of each species together with biological information such as size, sex or maturity.

Such thorough studies are very labour-intensive and take a great deal of time. They are, however, badly needed for the Antarctic, for to date there have been very few evaluations of biodiversity in polar marine communities. Such studies would also provide much-needed quantitative data on community biomass.

The ice, water-column and benthic sub-systems

Geographical differences in the relative importance of the three sub-systems (ice, water-column and benthos) will become apparent once the CS-EASIZ Programme is underway. Temporal differences will be revealed only when data from several years are available.

Recommendations for work on the ice, water-column and benthic subsystems have been made in the previous section.

The proposed work on sea-ice communities and on the water column will relate in important ways to work either planned or currently underway in the open ocean (within the SO-JGOFS and SO-GLOBEC programmes). Coupled with remotely-sensed information on wider geographical patterns of sea ice and some aspects of biological oceanography now becoming available from satellites, these interactions should provide important insights into the operation not only of the ACSE but the Southern Ocean ecosystem as a whole.

Proposals have been made above for a wider programme of sediment trapping. One further area of potential importance in understanding the link between the ice, pelagic and benthic components of the ACSE is the role of sediment metabolism. The sediments of the Antarctic continental shelves are unusual in containing a high percentage of land-derived material of a wide range of grain size. These sediments contain an active microbial and meiofaunal community which can receive a substantial input of organic material following the spring or summer bloom. The importance of disturbance by macroinfauna and remineralization processes in the sediment in returning carbon, nitrogen, phosphorus, and sulphur to the water column and atmosphere is currently only poorly known. Present evidence suggests that these processes are both active and important. The proposed core programme of sediment sampling will provide valuable preliminary background data, but it would be greatly enhanced by a wider programme. Studies of the microbial flora and the meiofauna in recycling processes are of critical importance in understanding the role of the benthic component within the ACSE.

Regional and mesoscale studies

Those processes within the ACSE that induce variability observed at CS-EASIZ shore stations operate at a variety of spatial and temporal scales. This means that local studies at shore stations need to be complemented by meso-scale or regional scale surveys within the Antarctic coastal zone. These will refine understanding of the functional links between the small-scale effects observed at individual stations with the larger scale physical or biota processes which drive them. The larger scale surveys can include oceanographic work from vessels or moored arrays, and emphasize the close links between CS-EASIZ and other programmes such as SO-JGOFS and LOICZ.

Adaptation

Studies of adaptation are necessarily largely experimental. The programme of core observations will provide important data on the environmental challenges which are faced by polar organisms. Understanding how organisms have evolved to cope with these challenges, however, will require sophisticated experimentation.

Important research programmes looking at a variety of aspects of molecular and physiological adaptation to the polar environment have long been underway in many laboratories. One aim which has not yet received widespread attention, however, is that of the range of physiological tolerance in polar marine organisms. Tolerance experiments are often short term, although in the longer term it is the temperature range of growth, reproduction and survival that is important; these studies are, however, difficult and time-consuming to undertake.

It is widely believed that polar organisms are stenothermal, that is they are relatively intolerant of changes in temperature. It is undoubtedly true that this is so in some marine organisms, and this may be related in subtle and important ways to the way in which they are adapted to low temperature. It is not clear, however, the extent to which this may be regarded as a general result for polar organisms. Since the range of physiological tolerance is of critical importance to how organisms may respond to global change, this is an area which could benefit from further data.

The basic approach is to subject organisms to small changes in temperature and determine the overall range to which they can undergo acclimation. It is important to select an appropriate physiological measure with which to assess performance. Oxygen consumption has often been used in the past but this is not ideal because it integrates too many disparate physiological processes. A better approach would utilize measures based on processes involved in the maintenance of cellular or physiological homeostasis (heart or ventilatory rate, ionic or acid-base regulation). The value of such experiments depends critically on tight temperature control, sufficient replication of measurements, and a sensible choice of physiological measure.

The behavioural aspects of adaptation are important. For example, some populations of the Antarctic limpet *Nacella concinna* are known to undergo seasonal migrations to and from the intertidal zone in order avoid the impact of winter ice. It would be very valuable to expand this work to cover the more general aspects of marine invertebrate behavioural responses to ice. For work on vertebrates, appropriate technology already exists in the form of sophisticated time–depth recorders and related devices, many of which are now available commercially. Protocols for deployment and interpretation of data are being developed within CEMP.

The ability in micro and macroalgae to minimize photoinhibition and to limit cell damage by the synthesis of protective UV-absorbing pigments may be crucial to survival in some habitats. Further data are needed urgently to assess the possible impact of anthropogenic changes in UV flux in the ACSE region.

Land–sea interactions

In this area active research proposals for work in Antarctica already exist (for example the RASCALS Programme at Jubany station) or are underway. The proposed core programme will provide important background data but areas where further data would be valuable include the impact of seabird colonies and marine mammal aggregations on nutrient dynamics in the waters close to shore, the role of marine nutrients in the growth of plants in the supralittoral region, and the role of decomposition of macroalgae cast ashore in littoral nutrient fluxes. The sea also influences the land significantly through the formation of aerosols.

The impact of the land on the coastal marine ecosystem involves the transport of land-derived sediment up to large boulders ('drop-stones') in ice, and the influence of local geology and geomorphology is important in this impact.

Human impact

Aspects of human impact in the ACSE will be covered in initiatives mounted by SCAR GOSEAC, CCAMLR and other groups. Nevertheless scientists participating in the CS-EASIZ Programme can make a fundamental contribution to environmental matters within the ACSE and, where feasible, should do so. CS-EASIZ research will necessarily be driven by key biological questions but there is important scope for such work also to address the effects of human impact. For example, CS-EASIZ studies of biological processes or key species might be expanded to include examination of the effects of pollutant materials.

Although studies of the impact of shore-based stations from effluents and other waste is an obvious topic for research, one important aspect of human impact in need of scientific attention is the effect of sampling programmes on the local environment. This might include the impact of dredging, trawling or other netting techniques, or the effect of bottom gear such as fish traps or moored arrays. Whilst not yet an area of major concern in the ACSE, this aspect of human impact could benefit from scientific input when sampling regimes are designed.

KEY ORGANISMS

Within the ACSE there are many species with important ecological roles. Several of these species, particularly the vertebrate predators, are already the subject of existing research or monitoring programmes. Of particular relevance to CS-EASIZ are the emperor and Adélie penguins, snow petrel, Weddell seal and the fish *Pleurogramma antarcticum*. This list includes some that are either actual, or are closely allied to, species selected for monitoring by CCAMLR within its Ecosystem Monitoring Programme (CEMP), and several of whose populations are either depleted or recovering from such depletion.

In the water column there are also species which have been selected for special attention by SO-GLOBEC. These include the two most important species of krill, *Euphausia superba* and *E. crystallorophias*, several copepods, and salps. The microzooplankton is also important, as are the very small species of copepod, juvenile and larval stages at times. At present, however, too little is kinown about the species composition of this community to make sensible recommendations for key organisms to tackle. The same problem applies equally to the sea-ice microbial community.

The criteria for selection of key benthic organisms were that they should be relatively abundant, be easily identified, have a wide distribution, and should (if possible) have measurable growth parameters. They should come from a variety of ecological groups, and should include those both close to and more removed from immediate dependence on primary production. Examples of suitable species are:

Macroalgae

A suitable dominant species at the site under study (eg *Desmarestia*, *Himantothallus*, *Iridaea* or *Phyllophora*).

Grazers

Nacella concinna	(limpet)
Paramoera walkeri	(amphipod, grazing the ice community in winter)
Sterechinus neumayeri	(echinoid)

Suspension Feeders

Laternula elliptica	(infaunal bivalve)
Adamussium colbecki	(epifaunal bivalve)
Liothyrella uva	(brachiopod)

Also a suitable dominant sponge (such as *Rosella* or *Homaxinella*) where these occur.

Scavengers/Omnivores

Odontaster validus	(cushion-star)
Waldeckia obesa	(amphipod)
Chorismus antarcticus	(caridean shrimp)

Deposit Feeders

Yoldia eightsi	(nuculanid infaunal bivalve)

Also a suitable polychaete worm.

Carnivores

Parborlasia corrugatus	(nemertean)
Acodontaster conspicuus	(asteroid)
Trematomus bernachii	(high latitude demersal fish)
Notothenia coriiceps	(low latitude demersal fish)

This list includes many of the common species of the shallow waters of the ACSE. Many of them have, therefore, been studied already at some sites. Comparative studies of the biology of these species from new areas will thus add valuable information to help understand geographical or latitudinal differences in biology. Importance should, however, be attached to studies of less well-known but related (either taxonomically or ecologically) organisms.

KEY COMMUNITIES

The development of the CS-EASIZ science programme revealed clearly that there were a number of biological communities, study of which was particularly important to the understanding of the structure and function of the ACSE. These were:

Supralittoral communities

These communities are also subject to intense physical disturbance as well as a severe seasonality in factors such as light, temperature and nutrient availability. This community may also be particularly subject to UV stress, and is also directly impacted by changes in the numbers and activity of vertebrates. Supralittoral communities are specifically included in the RASCALS Programme and also come within the remit of the SCAR BIOTAS (Biological Investigations of Terrestrial Antarctic Systems) Programme.

Intertidal communities

Where they exist at all, these communities are subject to intense physical disturbance by ice. Contrary to expectation, the intertidal region can contain quite a few species, often confined to crevices or the undersides of stones and boulders. The species composition and seasonal dynamics of this community may offer insights into community function in highly disturbed habitats. The life-history patterns of the constituent species will also be of theoretical interest since they combine the need for rapid completion of the life-history within an environment that would appear to dictate slow growth.

Sea-ice communities

The sea-ice community has long been recognized as fundamental to the structure and function of the ACSE. Practical difficulties, however, mean that there are still significant gaps in our knowledge of the composition, dynamics and energetics of this community. Studies of the sea-ice community are a prime focus of the CS-EASIZ Programme.

Microplankton community

Open-ocean studies both in Antarctica and elsewhere have shown the importance of microbial processes in the nutrient dynamics of the sea. The microbial loop is known to be important in the Southern Ocean, although at times it is dominated by the short summer pulse of diatom-based new production. Shore-based studies offer the advantage of longer time series (for example year-round seasonal studies) than is often the case with oceanographic cruises. The microzooplankton community is thus important for study in the CS-EASIZ Programme.

Macroalgal communities

Macroalgal communities are a significant component of the shallower waters of Antarctica, where they are subject to severe disturbance by ice, and are also influenced by variations in incident light climate. Macroalgae are important structural elements within the near-shore benthos, providing a substratum and habitat for a diverse community of invertebrates. They can also contribute substantially locally to the primary production. Studies of regional and temporal variation in these macroalgal communities are urgently needed, as these will give valuable insight into the effects of ice in the shallow waters of Antarctica. Ecophysiological studies of the macroalgae themselves are also badly needed.

Hard-bottom communities

Hard-bottom communities vary regionally in Antarctica, but have been little studied. Wherever undisturbed hard-bottom communities exist, long-term studies can make a major contribution to the CS-EASIZ Programme. Solitary sessile invertebrates and macroalgae can be tagged and followed over many years to provide information on regional differences in demographic patterns. Many areas are dominated by clonal or colonial invertebrates such as sponges, ascidians, cnidarians and bryozoans. These are very important components of the sessile benthos and are best studied photographically.

Sessile suspension feeders

It has been recognized since the earliest oceanographic expeditions that large parts of the Antarctic continental shelf are dominated by rich and diverse communities of suspension feeders. These have, however, been little studied to date. The direct link between these communities and both production and advection processes in the overlying water column mean that benthic suspension feeding communities have a high priority for study within CS-EASIZ.

Soft-bottom communities

Soft-bottom communities have long been known to be major sites of recycling processes in shallow seas. They are particularly important in returning N, P and S to the ecosystem. These communities have been little studied in Antarctica. Some data now indicate that microbial and meiofaunal communities in the soft sediments of the Antarctic continental shelf are very active in remineralization processes. Studies of these communities are thus important in closing the loop started by primary production and the vertical flux of biological material to the seabed. The species composition and dynamics of these communities are also of great interest in comparison with Arctic sediments. Both are subject to physical disturbance by ice-related processes, but the Antarctic lacks the biological disturbance by marine mammals so important in areas of the Arctic.

Top predator communities

The ACSE contains substantial populations of avian and mammalian top predators. These organisms crop the top of what can be quite short food chains. Their populations are also changing, possibly in some cases as a result of human activities. The potential impact of these predators on the ACSE makes them an important community for study within the CS-EASIZ Programme, and an area of scientific interaction with the SCAR Antarctic Pack-Ice Seals (APIS) Programme.

KEY PROCESSES

The marine ecosystem surrounding Antarctica has been isolated for over 30 million years, far longer than any continental ecosystem. During this period the marine ecosystem has cooled from a mild Eocene climate to its present glaciated condition and has been subject to fluctuating sea levels. The system is now, in broad terms, relatively well-described; what is lacking is knowledge of ecological and evolutionary processes. Among the most important are:

- Growth, reproduction and mortality
- Settlement and recruitment/establishment
- Adaptation and life-history evolution
- Those processes influencing the diversity and structure of communities

The last processes include all aspects of primary production, vertical flux and advection, secondary production, remineralization (both in the water column and the benthos) and grazing.

The CS-EASIZ Programme differs from other large scale programmes in the Antarctic by taking a complete ecosystem view. The framework linking the various key communities is those processes which mediate the fluxes of material and nutrients between the various compartments of the ACSE. A knowledge of fluxes is not, however, all that is needed to understand the operation of the ACSE. A knowledge of ecological and evolutionary processes is also critical. Knowledge of only one set of processes will lead only to an incomplete understanding of the Antarctic coastal and shelf ecosystem.

SOME FINAL CONSIDERATIONS

Modelling

The Antarctic coastal sea-ice zone presents some unique and challenging requirements for modelling studies. The most obvious of these is the need for models that include sea ice. Much of what is known about coastal sea-ice zones shows that many of the species that make up the biological communities characterizing this region have a strong dependence on sea ice for some or all of their life history. Correct representation of interannual variability in the extent of sea-ice cover and its effect on biological populations in models is therefore important. At present thermodynamic models that describe the growth and melting of a uniform ice-field over an annual cycle are reasonably well-developed. Schemes for incorporating thermodynamic sea-ice models into circulation models are also available. What remains to be done is to include the influence of sea ice on biological processes. Some attempts have been made in this area, but the implementation of ice-circulation-biological models is limited by the lack of measurements, especially in winter, that can be used to parameterize ice-biology interactions. Therefore, not only do the models need development but the measurements, on which these models can be based, are also needed.

Much of the available information on Antarctic coastal systems indicates that biological production in these regions is closely tied to the development of the mixed layer. A biological mixed-layer model forms one approach for investigating this dependence. Several mixed-layer methods have been developed and are available. Some attempts have been made to use mixed-layer models with biological models and these have yielded valuable insights into physical-biological interactions. However, the application of these models to investigate processes in coastal Antarctic systems remains to be undertaken. Given the current state of development of biological and mixed-layer models, this is likely to be an area of modelling that could yield interesting and informative results for the ACSE (and hence the Southern Ocean as a whole) in a relatively short time.

The annual variation in light, as well as the spectral quality of the light, is a strong determinant of biological production in high latitude systems. During the past five to ten years, considerable advances have been made in the area of bio-optical modelling. These models consider the attenuation and penetration of light as a function of spectral wavelength and allow the underwater light field to be determined by the physical and biological characteristics of the environment. Given the advances made in the area of bio-optical modelling, it no longer seems sensible to develop biological models that do not include this capability. The existing bio-optical models should be adapted and implemented for high-latitude coastal systems.

Coastal circulation models have matured considerably in the last decade. Some of these models are readily available for general use having been tested in a variety of environments, and some have been coupled with biological models. It would be instructive to adapt and implement some of the existing circulation models for Antarctic coastal systems. Once these are available, then straightforward Lagrangian calculations could be done better to understand and define the general transport patterns and residence times of planktonic organisms. This approach has yielded useful results on population dispersion characteristics in other environments.

At the individual level, the marked seasonality of many aspects of the Southern Ocean ecosystem makes the ACSE an ideal area to develop and test models of life-history of suspension feeders (both pelagic and benthic).

Databases

A central database has become an integral part of almost all modern multi-disciplinary or international programmes. There is, however, no SCAR (or other) funding available to set up or run a central CS-EASIZ database. Data from the CS-EASIZ Programme will therefore be made available (with observer's permission) to all relevant existing or planned databases. In particular data will be directed to the SCAR GLOCHANT database, once this is operational.

Taxonomy, biodiversity and molecular genetics

Many of the programmes outlined in this CS-EASIZ Science Plan rely to a varying extent on an accurate knowledge of the taxonomy of the organisms under study. Population dynamics, distributional or community structure studies are all dependent upon accurate taxonomic knowledge of the organisms involved. For these studies, conventional taxonomic techniques will often be sufficient. For more detailed studies, for example of how organisms react to biotic or abiotic changes in the ecosystem, it may be necessary to gain an understanding of variation at the intraspecific level. Knowledge of the genetic structure of a species at both the population and the individual level may provide insight into the ability of that species to respond to environmental changes. This will require the use of modern genetic techniques for assessing population or individual variation; electrophoresis, DNA fingerprinting or sequencing techniques may all be needed depending on the scientific question to be tackled.

For traditional taxonomy the established informal network of active taxonomists specializing in various groups of Antarctic organisms will continue to prove essential, but it might also form the basis for a more formalized network of *Antarctic Biodiversity Reference Centres*. The present centres of Antarctic taxonomic knowledge are usually individual specialists working within larger establishments. The CS-EASIZ Programme, and Antarctic marine ecology in general, would benefit greatly from the development of computer-assisted identification methods and the establishment of taxonomic databases incorporating geographical, bathymetric, ecological and genetic information. The maintenance of well-documented reference collections is also critical, and should be the concern of all scientists utilizing the expertise of the proposed Resource Centres.

Recently there has been a major proposal, following the Biodiversity Convention that emanated from the 1993 UNCED meeting held in Rio de Janeiro, Brazil, for a global initiative to 'discover, describe and classify the world's biota'. This initiative is named *'Systematics Agenda 2000, Charting the Biosphere'*. Should this initiative receive the national funding to proceed, it has clear and important relevance to Antarctic ecology and the CS-EASIZ Programme in particular.

Historical aspects

All marine environments have been (and continue to be) subject to long-term change, and the coastal and shelf ecosystem of Antarctica is no exception. In addition to the changes in mean temperature, current patterns, sea level and glaciation consequent upon the break-up of Gondwana, the ACSE has been subject to significant variation throughout the Pleistocene. Since the last glacial maximum there have been regional differences in the retreat of ice shelves, ice scour and other glacial activity such as sediment transport, isostasy and sea-level change. These historical changes form an important background to the present ecology of the ACSE.

New technology for research

New technology is required to deal with the special problems of sampling a harsh environment throughout the whole year, particularly in the presence of a dynamic cover of sea-ice and the need for synoptic coverage. Recent advances in allied fields such as chemistry, optics, molecular biology and remote sensing can be expected to facilitate this development. Examples of a few of these problems and possible solutions are presented below.

Year-round environmental sampling requires robust equipment that can log and store data, or telemeter data to satellites. Synoptic coverage of physical and biological features of the ACSE should be possible by continuous underway mapping from ships or remote-operated underwater vehicles (ROVs) that sample water from below the ice cover. A new generation of very high resolution satellite sensors, such as SAR for sea ice and SeaWiFS for ocean colour, provide possibilities for synoptic time series examination of those ACSE surface features of relevance to the objectives of ecological research. The use of fibre optics and microelectrodes to investigate properties of the ice habitat has not yet been reported. Molecular techniques can provide specific probes to identify specific microorganisms in their natural environments. Nucleic acid technologies offer tools for the determination of genetic relatedness and the ability to distinguish closely related taxa. Fluorescent stains increase sensitivity of chemical and cytological analyses over conventional methods for use with conventional microscopes, micro-spectrophotometers and cytofluorographs for flow-through analysis of particles.

A most urgent need is for development of sampling devices to capture living organisms from within and immediately beneath the ice or close to the sea-bed. Techniques for determining the *in situ* distribution and activity of ice microbiota are also badly needed.

Imaging methods

Many benthic communities on both soft and hard bottoms of the Antarctic continental shelf have a complex three-dimensional structure. Together with the patchy distribution of many organisms, and the unusually deep continental shelves around Antarctica, this creates severe difficulties for the use of conventional sampling techniques such as SCUBA, grabs, trawls and dredges. In these cases imaging methods such as underwater photography, video or remotely operated vehicles (ROVs) may be the only appropriate techniques for studying benthic community structure. They may also allow for rapid preliminary surveys, as an initial step before the deployment of more traditional sampling equipment, or for investigating habitats otherwise very difficult to sample (for example beneath ice). This is a rapidly developing field of marine ecology, and it will be important to establish agreed protocols to ensure comparability of results.

LINKS TO OTHER PROGRAMMES

During the early development of the EASIZ initiative close links were established with the JGOFS and GLOBEC communities. As a result the scientific concerns and geographical areas of concern to SO-JGOFS, SO-GLOBEC and CS-EASIZ are complementary. Thus SO-JGOFS concentrates on euphotic zone processes in the deeper water areas beyond the continental shelves, and SO-GLOBEC is concerned primarily with the life cycles and production of fully pelagic macrozooplankton. CS-EASIZ includes aspects of both programmes in an integrated ecological approach to the coastal and shelf ecosystem of Antarctica. This gives CS-EASIZ a character of its own.

The new SCAR global change initiative GLOCHANT includes some biological work, particularly in the sub-projects 1 (Sea ice) and 5 (Biogeochemical cycles). These are based on approaches developed in the early stages of EASIZ. For the coastal zone, CS-EASIZ will, therefore, act as the primary input to these aspects of GLOCHANT. In turn, the core measurements undertaken within CS-EASIZ will follow measurement protocols established by the GLOCHANT sea-ice group, or JGOFS.

There will inevitably be close liaison between CS-EASIZ and both SO-GLOBEC and CCAMLR through the focusing on the same key species in the macrozooplankton, fish and top predator communities. A new research initiative on Antarctic pack-ice seals (APIS) is being coordinated by the SCAR Group of Specialists on Seals. It will overlap and complement the present programme in its ecological orientation and aim of detecting and understanding environmental change. An important difference, however, is that the APIS Programme places strong emphasis on pack-ice species, especially crabeater seals, and thereby encompasses large areas of open ocean and may exclude fast-ice and near-shore processes.

The closest scientific ties, however, will be to the international LOICZ (Land–Ocean Interactions in the Coastal Zone) Programme. LOICZ is one of the Core Projects of the International Geosphere–Biosphere Programme (IGBP), and includes a series of continental margin studies to be undertaken jointly with the JGOFS programme. There are thus very close parallels between CS-EASIZ and LOICZ in both the ecosystems to be investigated, and the processes to be studied. No Atlantic studies are planned for LOICZ and so CS-EASIZ will be in a position to make an important contribution to this aspect of two important IGBP Core Projects.

IMPLEMENTATION PLAN

Implementation of the CS-EASIZ Core Programme will take place at identified Research Stations. Aspects of the Wider Programme can be undertaken at any appropriate site in Antarctica, and through suitably focused ship-borne work. The fieldwork programme will be complemented by a series of workshops and symposia, culminating in a final symposium.

Shore-based work

The existing network of shore stations in Antarctica falls conveniently into three broad geographical regions, namely the Ross Sea region, the Indian Ocean sector and the Antarctic Peninsula region. Within these three regions, several shore stations (Dallmann/Jubany, Syowa, King Sejong, Rothera) have committed to undertake a significant number of CS-EASIZ Core Programmes in due course. The wide geographical and latitudinal spread of the Research Stations contributing to the CS-EASIZ Core Programme will enable latitudinal and geographical trends to be examined.

Ship-borne work

An important feature of the CS-EASIZ Programme will be a CS-EASIZ cruise to the Weddell Sea in January to March 1996. This cruise, on RV *Polarstern*, will undertake a detailed study of a defined research area on the continental shelf of the south-eastern Weddell Sea, and will involve both benthic research and water-column work related to benthic processes. This approach, modelled on the highly successful EPOS (European *Polarstern* Study) Programme in 1989, will be a major fieldwork event within the CS-EASIZ Programme, and will be followed by a dedicated workshop to examine the results.

Formal dedicated cruises are not the only approach to ship-borne CS-EASIZ work. Many nations have on-going oceanographic research, including moored arrays and repeated transect work, which can make a major contribution to the CS-EASIZ Programme at the same time as contributing to other international programmes such as JGOFS, GLOBEC or WOCE.

Workshops

Workshops and Symposia are an essential component of the CS-EASIZ Programme. Workshops will include those devoted to developing standardized techniques where these do not already exist (for example an underwater visual techniques workshop to be held at the Alfred-Wegener-Institut in 1995). Symposia will be held for the presentation and comparison of data from different CS-EASIZ shore stations.

It is not possible to devise a definitive list of workshops, for these will be arranged when needed as the programme progresses. Major review points can however be identified already, and these are:

1994	CS-EASIZ Programme starts, following SCAR approval
1995	Workshop on underwater visual techniques (AWI)
	Workshop on land–sea interactions (Warsaw)
1996	CS-EASIZ Cruise (RV *Polarstern*)
1998	Major Review Symposium, associated with 7th SCAR Biology Symposium, New Zealand
2003	Formal end of CS-EASIZ Programme
2004	CS-EASIZ Final Symposium

Management

The CS-EASIZ Programme will be guided by a small steering committee. The nominated membership for this is:-

Andrew CLARKE (Chair)	British Antarctic Survey, UK
Wolf ARNTZ	Alfred-Wegener-Institute, Germany
Paul DAYTON	Scripps Institution of Oceanography, USA
Mitsuo FUKUCHI	National Institute of Polar Research, Japan
Maria CRISTINA GAMBI	Stazione Zoologica di Napoli, Italy
Harvey MARCHANT	Antarctic Division, Australia

Liaison with other international and Antarctic programmes will be maintained through the SCAR Group of Specialists on Southern Ocean Ecology (GOSSOE).

Contact and exchange between participating nations and individuals will be maintained through a regular newsletter. This will be produced through the SCAR Project Coordination office in Hobart.

LIST OF ACRONYMS AND ABBREVIATIONS

ACSE	Antarctic Coastal and Shelf Ecosystem
APIS	Antarctic Pack-Ice Seals
AWI	Alfred-Wegener-Institut für Polar- und Meeresforschung
BIOMASS	Biological Investigations of Marine Antarctic Systems and Stocks
BIOTAS	Biological Investigations of Terrestrial Antarctic Systems programme
C	Carbon
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CEMP	CCAMLR Ecosystem Monitoring Programme
CRREL	Cold Regions Research and Engineering Laboratory
CS-EASIZ	Coastal and Shelf Ecology of the Antarctic Sea-Ice Zone
CTD	Conductivity, Temperature and Depth
DNA	Dioxyribonucleic Acid
ENSO	El Niño Southern Oscillation
EPOS	European Polarstern Study
GIS	Geographical Information System
GLOBEC	Global Oceans Ecosystems Dynamics Research
GLOCHANT	Group of Specialists on Global Change and the Antarctic
GOSEAC	Group of Specialists on Environmental Affairs and Conservation
GOSSOE	Group of Specialists on Southern Ocean Ecology
HPLC	High Performance Liquid Chromatography
ICES	International Convention for the Exploration of the Seas
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Programme
ISBN	International Standard Book Number
JGOFS	Joint Global Ocean Flux Study
LOICZ	Land-Ocean Interactions in the Coastal Zone programme
N	Nitrogen
P	Phosphorus
PAR	Photosynthetically Active Radiation
PVC	Poly-Vinyl Chloride
RASCALS	Research on Antarctic Shallow and Littoral Systems
ROV	Remote-Operated underwater Vehicle
SAR	Synthetic Aperture Radar
SCAR	Scientific Committee on Antarctic Research
SCUBA	Self-Contained Underwater Breathing Apparatus
SeaWiFS	Sea-viewing Wide-Field-of-View Sensor
SO-GLOBEC	Southern Ocean – GLOBEC
SO-JGOFS	Southern Ocean – JGOFS
TDR	Time-Depth Recorder
UNCED	United Nations Conference on Environment and Development
UV-B	Ultra-Violet B radiation

ICE TERMINOLOGY

New ice: A general term for recently formed ice which includes *frazil ice, grease ice, slush* and *shuga.*

Nilas: A thin elastic crust of ice. Subdivisions are *dark nilas, light nilas.*

Pancake ice: Predominantly circular pieces of ice, with raised rims due to the pieces striking against one another.

Young ice: Ice in the transition stage between *nilas* and *first-year ice*. Subdivisions are *grey ice* and *grey-white ice*.

First-year ice: Sea ice of not more than one winter's growth, developing from *young ice*. Subdivisions are *thin first-year ice/white ice, medium first-year ice, thick first-year ice*.

Old ice: *Sea ice* which has survived at least one summer's melt. Sub-divisions are *second-year ice, multi-year ice.*

Fast ice: *Sea ice* which forms and remains fast along the coast, where it is attached to the shore, to an *ice wall,* to an *ice front,* between shoals or grounded *icebergs.*

Floating ice: Any form of ice floating in water. Forms of floating ice are *pancake ice, floe, ice cake, floeberg, glacier berg, tabular berg, ice island, bergy bit* and *growler.*

Pack ice: Used in a wide sense to include any area of *sea ice, other* than *fast ice,* no matter what form it takes or how it is disposed.

Ice cover: Used to express areal coverage of ice within a large geographical region, eg Baffin Bay, Weddell Sea.

Concentration: Used to express areal density of ice in a given, comparatively small, area. The following descriptive terms imply different concentrations: *compact, consolidated, very close, open* and *very open pack ice; open water, ice-free.*

EXAMPLE ICE DATA SHEET

Station:
Lat:
Long:
Observer:
Date:

Air temp (°C):
Water temp (°C):
Wind velocity (m/sec):
Wind direction:

ICE CONDITIONS

Ice Type
Conc %

Thick cm

Snow cm

Floes 1-7

Comments (colour, rafting, ridges, rot)

A: Open water

B: Grease/slush

C: Pancake

D: Dark nilas

E: Light nilas

F: Grey/grey-white

G: White (1st yr)

H: White (2nd yr)

I: White (multi-yr)

J: Brash ice

Floe sizes: 1 (<1 m); 2 (1–3m); 3 (3–10 m); 4 (10–100 m); 5 (100–1,000 m); 6 (>1 km); 7 (vast)

PLEASE PROVIDE A MAP OF ICE COVER

JGOFS PROTOCOLS FOR SEA-ICE BIOTA
(Based on JGOFS Protocol 25)

Investigations on sea-ice biota become a major component of research programmes dealing with ice associated systems. They are necessary and appropriate when and wherever sea ice covers or influences an area of investigation. There are three major sea-ice associated processes which are inextricably linked to water-column processes. These are:

- Ice formation and growth
- Development and activity of sea-ice communities
- Ice melting

For the purpose of this protocol sea-ice biota are defined as all organisms living within or attached to sea ice in one way or another. They comprise organisms which spend almost their entire life cycle within the ice as well as planktonic forms which have only specific life cycle stages associated with the sea ice.

Principles of measurement

The parameters measured and methods applied should be essentially the same as for water-column measurements, bearing in mind certain methodological adaptations arising from the nature of the samples and specific sea-ice properties. Sea ice needs to be sampled during its various developmental stages from loose grease ice to multi-year congelation ice several metres thick.

In the event of observing new ice formation, sampling of sea ice should begin with this stage as planktonic organisms may become incorporated into the ice in large numbers during ice formation.

Apparatus

Grease ice

Loose ice crystals drifting on the water surface are best sampled from deck using buckets.

Pancake ice

Small ice pancakes can be samples using a crane and metal cage palettes.

Congelation ice

Commercially available three or four inch (7.5 and 10 cm) diameter 1 metre long mechanical corers (eg CRREL ice corers), driven by a small two-stroke motor are used to obtain cores from congelation ice up to several metres thick.

Other equipment:

- Stainless steel butcher's hacksaw
- PVC freezer cans with screw caps (10 cm diameter) for core sections
- One metre PVC pipe (12 cm diameter) cut in half length-wise and mounted on a wooden board for core examination and sectioning after extraction
- Plastic tubing and PVC pipes for archiving cores
- Black PVC foil to cover cores intended for photo- biological work

Sampling

Ice cores are normally drilled vertically through the ice flow. Immediately after drilling, the cores are cut into 10 cm sections. Sections are placed into PVC cans and kept in a cool box until further processing.

Analysis

Almost all analyses of sea ice can be done only after melting the samples. However, melting of sea-ice samples lowers salinity and may involve a rise in temperature. Where samples are required for physiological experiments or species enumeration it may be necessary to melt in large volumes of sterile sea water (10 cm core section in 5 litres of 0.2 μm filtered) to avoid a strong drop in salinity. The melting process should take place in a cold room but should not take longer than 24 hours. Subsamples are analysed for the following parameters, according to water column protocols: chlorophyll a, particulate organic carbon, particulate organic nitrogen, particulate silicate, bacterial numbers, species composition of biota (phyto and zoo). Bulk properties such as total salinity and chlorophyll *a* may be determined in core sections which are simply melted at 4°C.

Procedures for determining salinity, nutrients and other parameters which may not be diluted

Brine can be extracted from sea ice by centrifuging core sections in a cooled centrifuge using specially constructed large centrifuge buckets with an inserted sieve. Alternatively, samples of brine can be obtained by drilling core holes into but not through congelation ice. The holes are carefully cleaned of snow and ice shavings. Brine is allowed to accumulate and is removed with a syringe or hand pump.

Expression of results

Where diluted samples are used, care should be taken to determine dilution factors.

CHLOROPHYLL PROTOCOLS

ZOOPLANKTON PROTOCOLS

Several standardized protocols are available. A good source volume is:

Tidal Estuaries. *Manual of sampling and analytical procedures*. Edited by K J M Kramer, U H Brockman & R M Warwick. Published for the European Commission by A A Balkema, Rotterdam, 1994. (ISBN 90 5410 610 8).

BENTHOS PROTOCOLS

Benthic sampling has long been beset with problems of lack of comparability of sampling gear. These difficulties have been exemplified by the recent increase in interest in diversity studies, where lack of comparability of sampling techniques has made meaningful comparison essentially impossible. There is thus an urgent need within CS-EASIZ to agree on the use of a small number of standardized techniques for benthic sampling. This need is particularly acute for benthic biomass and diversity studies.

General protocols already exist for benthic work in the Arctic, having been developed by ICES and the Baltic Group for benthic biologists. The volume edited by Kramer and others (see above) is an excellent general source reference for benthic protocols.

VERTEBRATE PROTOCOLS

No single technique can provide full data on fish population and community structure. Nevertheless simple routine methods can provide valuable information. Routine plankton hauls for ichthyoplankton (fish larvae) can provide information on species occurrence, seasonal changes and annual variation in fish populations. Estimates of the population size of the adult stages of demersal fish can be made from regular (monthly) deployment of set traps, lines or nets. These methods are, however, selective and so a range of techniques needs to be utilized to provide full information on population size and structure.

In addition to the number of individuals of each species collected by the particular gear, data recorded should include standard length, sex and maturity stage. Wherever possible the full range of biological data recommended by the BIOMASS protocol should be recorded.

Fish:

Monthly population estimates using either traps or lines should provide baseline data for fish community composition and a rough index of population size. The BIOMASS protocols should be followed.

Penguins:

For Adélie, chinstrap, gentoo and macaroni penguins standard methods for determining breeding population size, breeding success, survival, recruitment and diet, together with various measures of condition and reproductive performance (adult mass at arrival, incubation shift duration, foraging trip duration, chick mass at fledging) have been developed by CCAMLR within its Ecosystem Monitoring Programme (CEMP) and are in use at numerous Antarctic sites.

These methods, available from the CCAMLR Secretariat, are for ground-based work at breeding sites. Aerial photography to estimate population size has been extensively used (and methods published), especially with Adélie penguins. Standardization of methods for collecting, interpreting and analysing data on foraging performance (eg using time–depth recorders, TDRs) are under way within CEMP. Many of these protocols and approaches apply to, or could easily be modified for, other penguins, especially the emperor penguin.

Other seabirds:

Snow and Antarctic petrels have already been selected for priority attention within CEMP and standard protocols for monitoring breeding population size, success, survival, diet and aspects of reproductive performance are being developed. These would be readily applicable also to Antarctic fulmars and Cape petrels. Many research studies have been conducted on south polar skuas and standardized approaches to the study of some aspects of their breeding biology and ecology would not be difficult to develop.

Seals:

For Antarctic fur seals the CEMP standard methods for collecting data on the duration of foraging (at sea)/attendance (on shore) cycles and on pup growth are already widely used. Standard procedures for obtaining and analysing data on foraging performance (using TDRs) are currently under review. Estimation of population size, pup production and a variety of indices of maternal condition and reproductive performance is currently being undertaken in studies at South Georgia and the South Shetland Islands. The crabeater seal is also a priority species within CEMP but no standard methods for monitoring purposes have been developed yet.

Estimates of the number of seals in particular areas can be obtained using line-transect counting methods. This is relevant particularly to crabeater, leopard and Weddell seals, but can also be applied to elephant seals; in some circumstances it may also be possible to consider counts of seals from the coast as a special type of line-transect estimate. However, for any line-transect estimate an assessment of the sightability of seals from the transect line must be made. In any circumstances ice conditions, species (plus sex and approximate age, eg pup, juvenile or adult) and distance from the transect must be recorded. In the case of coastal surveys of ice-bound areas, line-transect surveys perpendicular to the coast should be made whenever possible and under the full range of ice conditions. This will allow an assessment to be made of the effects of the coast on seal numbers. Regular (eg weekly) counts of a specific area can be used to assess seasonal trends in abundance and, if continued over successive years, these counts may provide an indication of trends in abundance.

Whales:

Collection of quantitative data is unlikely to be feasible, but records of the occurrence of whales, particularly of the large baleen whales, might be helpful in assessing the recovery of these previously hunted species. Data to be recorded are date, species, number of individuals, age (adult or calf), behaviour, direction of travel, and distance from the observer.

In connection with its monitoring studies, the CEMP also recommends collection of at least four types of environmental data. It has developed suggested standard methods for:

a. sea-ice cover as viewed from the colony;
b. sea ice within the study region;
c. local weather;
d. snow cover in the colony.