The Census of Antarctic Marine Life (CAML)

Science Statement

Introduction

This Science Statement for the Census of Antarctic Marine Life (CAML) sets the context in which a large and internationally integrated field and laboratory program of study is required. It is not intended to be a work plan – rather, it establishes the main questions that need to be asked about Antarctica's surrounding ocean in order to gain knowledge about its role in provision of ecosystem services to humankind, and how these are likely to be affected by climate and global change. Plans for specific studies are being coordinated by the Scientific Steering Committee of CAML, based on the emerging picture of available ship-time provided by research-active Antarctic nations.

The Southern Ocean surrounding Antarctica covers 35 million km^2 and comprises about 10% of the Earth's oceans. Of the 4.6 million km^2 of continental shelf (<1,000 m), 1.6 million lie underneath permanent ice shelves. The continental slope (1,000–3,000m) comprises 2.3 million km^2, while the abyssal plain (>3,000 m) covers 28 million km^2 (Clarke and Johnston 2003). During winter, sea ice extends to over 20 million km^2; in summer the area decreases to 7 million (Gloersen *et al.* 1992). The relationship between ice and sea is the most significant driver of the circulation of the Earth's great ocean currents which pump nutrient and oxygen-rich water thousands of kilometres into the northern hemisphere to fertilise surface waters. As the water completes its return circulation to Antarctica it rises to the surface and nourishes plant and animal plankton, krill and the huge biomass of whales, seals, penguins and sea birds that are uniquely Antarctic.

Prior to 40 million years ago Antarctica was an integral part of the super-continent Gondwana, sharing common boundaries with Australia, Africa, South America, India and New Zealand. When Gondwana broke apart and its components drifted northwards a significant current, the Antarctic Circumpolar Current System (ACCS), established a strong flow of water from west to east, cutting Antarctica off from more northern influences. The biggest ocean current in the world, the ACCS moves 145 million m^3 of water per second, greater than the combined flow of all the rivers in the world. It mixes waters of the Indian, Atlantic and Pacific oceans and, in its deeper layers, provides the contiguity of Antarctic's marine ecosystem within the global ocean system.

The Southern Ocean around Antarctica is a key component of the Earth's ocean system; a detailed knowledge of its past, present and future status is of *global significance.*

Antarctica's evolutionary history of isolation may explain the rich and diverse speciation observed in many groups of organisms living on the sea floor (benthic fauna) or above it (benthopelagic fauna) (e.g. fish of the family Notothenioidei; crustacea of the orders Amphipoda and Isopoda; molluscs of the order Gastropoda). While the bioevolution of some organisms in shallow waters has been studied, little is known about the deep-sea forms. Nevertheless this is now changing with the ANDEEP (Brandt *et al.* 2004) and related studies of abyssal benthos in the Southern Ocean. Antarctica may be an evolutionary incubator for some animal groups. The long time available for evolution to have occurred, probably explains the high degree of endemism seen in Antarctic communities, approaching 90% in groups such as sponges, some crustaceans and some mollusc families.

Such generalisations apply only to the benthic fauna of the near-shore continental shelf as this is the only part of the Southern Ocean biota about which much is known. It is not clear whether the biological properties frequently stated as characteristic of the Antarctic fauna, such as gigantism, late maturity, decreased number of offspring, long life-spans, also apply to organisms living in deeper waters.

The Antarctic ocean environment is changing. In 1995 the Intergovernmental Panel on Climate Change (IPCC) noted that the most rapid climate change was likely to be seen in the polar regions. One of the locations of greatest warming, and the only region of anomalous warming which is almost solely marine, is the water to the west of the Antarctic Peninsula (King 1994). There is a growing body of evidence to suggest that the maximum extent of winter sea ice in the Antarctic is also declining (Curran *et al.* 2003; Atkinson *et al.* 2004), though there is no evidence that the mass of ice on the continent is diminishing. The collapse of the Larsen B ice shelf in 2003 may be a portent of further degradation of the Antarctic cryosphere. There is evidence of substantial and sustained temperature rise in the sub-Antarctic, with Heard and Signy Islands showing temperature rises of at least 0.8 ºC in the past 50 years (Rudell and Allison 1998; Quayle *et al.* 2002). Photographic records from Signy Island suggest that ice cover has decreased by 45% since the 1950s, and similar records from Heard Island indicate a reduction of over 38%. By way of global comparison it is well recorded that sea ice in the Arctic is declining at a fast rate (Parkinson *et al.* 1999).

Observations such as these suggest that the Southern Ocean may be the most vulnerable part of the global marine system. This vulnerability has the potential to disrupt the world's ocean circulation causing dramatic biological and economic impacts. The global marine ecosystem provides significant benefits to humankind in the form of food, biological products, atmospheric carbon absorption, as well as recreational, spiritual and aesthetic resources. The services provided to humanity by the marine ecosystem which we enjoy today must be maintained and protected for the benefit of future generations, and the well-being of the whole planet.

In many international fora the need for improved understanding about biodiversity has been repeatedly and strongly emphasised. Knowledge about how human societies and biodiversity interact underlies many international environmental instruments (e.g. the

Convention on Biological Diversity 1993; Global Biodiversity Assessment UNEP 1995; Millennium Assessment "*Biodiversity and human well-being"* UNEP 2005). In many parts of the world, humankind has made a strong impact on the natural environment. However, in the oceans surrounding Antarctica this is restricted to fishing (finfish and krill), the taking of whales as permitted by the International Whaling Commission, a growing tourism industry, and the conduct of science. The integrated nature of the global ocean circulation and the probable future effects of climate change on it provide the strongest and most urgent reasons for a structured assessment of the ocean's biodiversity to be undertaken as a reliable benchmark against which future change can reliably be assessed. There are a number of international research programs planned for the International Polar Year (IPY) and beyond which will depend for their success upon the baseline established by CAML.

As part of its "*Evolution and Biodiversity in Antarctica*" program the Scientific Committee on Antarctic Research (SCAR) has proposed that a Census of Antarctic Marine Life be undertaken as a major activity during the IPY. Funds for coordination activities have been successfully obtained from the Alfred P Sloan Foundation of New York, USA, enabling SCAR's Scientific Steering Committee for CAML to develop this Science Statement and coordinate the project. CAML is one of 14 field programs being conducted under the ten-year international umbrella program "Census of Marine Life" which aims to describe the state of the world's oceans in terms of their former biodiversity, their present biodiversity, and their likely future biodiversity.

The CAML is an ambitious 5-year project that will focus interest on the ice-bound oceans of Antarctica preceeding, and during, the IPY in 2007/08. Its philosophy is to integrate knowledge across all regions, biomes, habitats and fields of study. The project will utilise currently unworked taxonomic collections, in addition to purpose-designed field studies, in fulfilling its objectives. It will make use of techniques of modern molecular biology to solve evolutionary and ecological questions, and will transmit its understanding of the great Southern Ocean to the wider public though a website (www.caml.aq) and active public outreach program. Plans for a preliminary synthesis of the results of the fieldwork during the IPY will be generated at a CAML workshop in mid-2008. While papers will continue to be published for many years, the main synthesis will occur within about 18 months of the completion of the fieldwork, as part of the autumn 2010 schedule to produce the first Census of Marine Life.

Research on the biodiversity of Antarctic ecosystems in CAML relies on understanding the functionality of the biological systems, integrated with their physical environment. Only by studying the organisms and how they are adapted to their environment, can we gain knowledge of the past, present and future inhabitants of the waters around Antarctica. The concept of "functional biodiversity" or how the organisms survive in the harsh Antarctic conditions, or will survive in a changing Antarctica, is central to our investigations in all ocean realms.

Baseline information on biodiversity and the role of bio-physical processes in its maintenance will provide fundamental building blocks in understanding how the Antarctic marine ecosystem will respond to future regional and global climate change. A feature of CAML will be that all sampling in every biome will be conducted according to a set of agreed protocols, ensuring uniform data analysis and interpretation. Some of these sampling protocols have been agreed already, others are under development. Data management protocols are currently being developed through CAML's sister program SCAR-Marine Biodiversity Information Network (SCAR-MarBIN), fully interoperable with the Ocean Biodiversity Information System (OBIS). The integrated database offers the capacity to query data using powerful relational structures – a central feature of the CAML project. New questions can be asked and the relevant data assembled, joining data from diverse sources for analysis. These two key elements of CAML will ensure that all data collected are maximally available for broad-scale analysis and interpretation. The protocols may have broader relevance to studies of biodiversity beyond the geographical range of the CAML project.

Polar marine biodiversity

The observation that many groups of marine organisms in Antarctica are taxonomically diverse has contributed to a major change in the view of polar marine ecosystems. The paradigm of high marine biodiversity in the tropics and low biodiversity towards the poles (Poore and Wilson 1993) is being abandoned in favour of an asymmetric distribution of taxonomic richness in the two hemispheres (Gray 2001; Rex *et al.* 1993). What is emerging is an understanding that regional and historical processes strongly influence community structure and perceived species richness (Ricklefs 1987). Evidence shows marked asymmetry between latitudinal gradients in the two hemispheres with higher species richness in the Antarctic than in the younger Arctic marine ecosystems at equivalent latitudes (Brandt 2000).

In analysing the evidence for and against the existence of a latitudinal cline in species diversity in Antarctic waters Clarke and Johnston (2003) argue that while ecological factors might exert some influence in patterns of occurrence and distribution, and have done so in the past, historical processes are probably most likely to have shaped the present patterns. In contrast, there is great interest in the similarity between species that harbour bi-polar distributions. Many of the polar planktonic algae and bacteria are more closely related to each other than to other mid and low-latitude species. One study conducted recently comparing Arctic and Antarctic sea ice bacteria found many of the species to be highly related between both locations (Brinkmeyer *et al.* 2003).

Genetic insights

Molecular biotechnologies have been applied to some uniquely Antarctic questions, notably to address the phylogenetic history, and radiation, of the Nototheniodiei. This group of teleost fishes has adapted to the cold conditions of the Southern Ocean most dramatically, with many species able to survive in conditions that would kill more northerly teleosts (Near *et al.* 2003). Over the course of their evolution they have acquired genes through change-of-function mutations that produce antifreeze glycoproteins. Clark *et al.* (2004) point out that cold-adapted notothenoid fishes have lost capabilities normally associated with vertebrate life, such as the presence of myoglobin in the heart muscle and the loss of the usual respiratory protein haemoglobin in the blood circulatory system of icefishes (Channichthyidae). They conclude that such new understanding has potential application for the development of innovative treatments for blood-related disorders in humans. The application of molecular and genomic techniques to Antarctic biodiversity can resolve long-standing evolutionary questions (Committee on Frontiers in Polar Biology (CFPB) 2004; Clark *et al.* 2004), as well as providing information on the species richness of micro-organisms which have, to date, been the overlooked species of marine biodiversity.

Molecular biotechnologies are capable of resolving many problems regarding endemism, cryptic species and species distribution. While some studies have been conducted already, CAML provides an opportunity for systematic genomic analysis, allowing answers to currently intractable questions (CFPB 2004). Antarctic marine invertebrates have long been thought to have a wide bathymetric distribution with species being found from shallow water to depths of thousands of metres. With recent advances in technology we can determine the genotype of the smallest organisms (e.g. protists, larvae) and filter large volumes of sea water (e.g. with Continuous Plankton Recorders) to investigate their distribution and abundance. Recent DNA sequencing has shown that, for some isopods and several groups of bivalves, what were previously considered as single species are in fact clusters of very similar species with different geographical or depth distributions (Held 2003; Linse 2003). This not only means that conventional thinking about wide depth distribution is wrong but also that the diversity of these groups has been considerably underestimated.

The Benthic Zone

More is known about the Antarctic benthos than most other zones. Many benthic organisms are large and the taxonomy of a number of groups is quite well known, however our knowledge is insufficient to understand their functional biodiversity in the ocean ecosystem. Nevertheless further intensive study of Antarctic benthos is important for a number of reasons:

- As the Antarctic is undergoing very rapid change compared to most parts of the globe a baseline against which to measure future change is urgently required.
- At present Antarctic benthic ecosystems are amongst the least disturbed on earth. Understanding processes in such systems will help understand the workings of benthic ecosystems in general.
- Answering questions about the impact of commercial trawling on the structure of benthic communities, and what ecosystem services might we be losing.
- Benthic communities are involved in biogeochemical cycling of many chemical compounds between the sea floor and the water column. If the benthos changes, how will these cycles change?
- We do not know the role of Antarctic waters in the exchange of benthic species between the world's oceans. The Southern Ocean links the world's oceans and is thought to have a role in spreading benthic species. Changes to ocean circulation, brought about by climate change, may radically alter global benthic biodiversity.

- Arctic benthic assemblages reacted differently to Pleistocene glacial cycles in comparison to their Antarctic benthic counterparts. Understanding how this has occurred will help understand both evolutionary change and benthic species migration.

The benthic biodiversity component of CAML will investigate these problems by addressing the questions:

1. Which species – or groups of species – hold the key to ecosystem function? What is the distribution and abundance of key benthic species?
2. What are the critical ecological processes and historical factors affecting benthic diversity? Is Arctic diversity subject to similar, or different processes? To what extent are the Arctic and Antarctic ice-oceans the same?
3. How will benthic communities respond to climate change, particularly warming of Antarctic waters?
4. What is the role of the Southern Ocean in driving marine speciation to the north? Is the Southern Ocean a speciation 'hotspot', and if so, why is it?

To address these questions sampling will occur in a range of depths, from shallow to deep water locations. As far as it is practicable logistically, sampling will cover representative habitat types, such as areas of turbid waters; areas where there is strong down-slope water transport; canyons; regions of strong bottom currents; regions close to ice shelves; and regions recently covered by permanent ice.

The Pelagic Zone

The pelagic system interacts most directly with the atmosphere and with the extensive sea ice cover that forms during the dark season. The pelagic system in the Southern Ocean has borne the brunt of human impact in the region; directly though over-harvesting of marine mammals and finfish (and potentially krill) and indirectly by the increasing winter temperatures and declining sea ice extent, observed most strongly in the Antarctic Peninsula. Life histories of all pelagic species from microbes to whales are tied to the advance and retreat of sea ice.

In turn, most of the top predators (penguins, seals, and whales) are absolutely dependent on the intermediate trophic levels of the pelagic zone, the krill, squid, and pelagic fishes, for their forage. Thus, the pelagic zone is both a critical element in the Antarctic ecosystem and a highly sensitive one. Critical, because the pelagic zone sequesters carbon in the form of the lower trophic level fuel that drives the marine system; sensitive, because the pelagic biota has been keyed through evolutionary time to a predictable relationship between sea ice and photoperiod that may now be changing. The most significant questions to be addressed in CAML are:

- What effect is the warming west of the Antarctic Peninsula, having on the species composition, distribution, and abundance of pelagic organisms, including micro-organisms?

- What are the broad consequences on the structure of the pelagic community of decades of exploitation-driven ecological change? How is the pelagic zone responding to whale and seal recovery, and to changes in the by-catch of fisheries?
- Is species composition consistent within the various oceanographic zones of the Antarctic region, such that we can predict species composition in areas not sampled or monitored in the future?
- How will the pelagic community respond to global warming? Will we be able to model and predict the effects of global warming on pelagic ecosystem structure?
- How are communities of calcifying micro-organisms such as the tintinnids, and calcifying zooplankton such as the pteropods, responding and adapting to ocean acidification?
- How are pelagic communities responding to increased surface UV irradiance due to ozone thinning?

Sampling will be conducted according to agreed protocols used by all vessels, with a view to maximizing international participation and data acquisition. Protocols will include those used in international programmes (e.g. in CCAMLR science; IWC science), and in national programmes (e.g. by national fisheries authorities). Tourist vessels, as well as national program research vessels, will be used as sampling platforms. Pre-existing data and biological collections will be assembled for SCAR-MarBIN/OBIS.

As far as it is practicable logistically, sampling will be undertaken in currently under-sampled regions such as the Bellingshausen and Amundsen Seas. The legacy of CAML will be as complete a picture as possible of Antarctic pelagic biogeography, the mechanisms that result in the observed ecosystem structure, and how that structure will respond to global change.

Top Predators

Many species of top predators in the Antarctic are the focus of conservation activities, due to excessive exploitation by humankind for oil, meat, fur, and other products. Many have high conservation value (e.g. Wandering albatross, Southern Giant and White chinned petrels, Black-browed albatross, penguins, Southern right, humpback, blue, sei and fin whales). Predictable models for critical habitats will provide a tool for wise management in the face of increasing human presence in the Southern Ocean.

Refined, *at-sea* methods coupled with emerging tag technologies will contribute to a new Southern Ocean observation system and provide an integrated GIS database, a component of the OBIS sea-mapping program SEAMAP. The legacy of CAML will be an integrated database of animal movements, critical habitats and oceanographic environmental data, leading to an understanding of predator-prey interactions in the context of biodiversity in Antarctica. Animal-borne video and data recorders provide unique opportunities to observe underwater behaviour and reconstruct three dimensional movements. Their utilisation in this part of CAML will provide not only fine scale information on individual diving patterns and performance, but will also be of a great impact for the Education and

Outreach Program. Data collected by top predators beneath the permanent ice shelf in Antarctica offer a unique opportunity to sample a previously unavailable habitat.

Air-breathing marine predators have evolved diverse life history patterns to accommodate the extreme fluctuations in the physical and biological environment of the Southern Ocean. Because they are long-lived, top predators must be able to withstand variations in food resources over large spatial and temporal scales. A basic understanding of the foraging behaviour and habitat utilization of pelagic predators requires knowledge of this spatial and temporal variation, coupled with information of how organisms respond to these changes. Recent advances in satellite-linked data logging now make it possible for detailed information on the foraging behaviour of top predators to be correlated in real-time with their physical and chemical environment enabling a quantum leap in our understanding of the mechanisms controlling their movements at sea, foraging behaviour and, ultimately, reproductive success. In addition, technological advances enable top predators to be used as highly cost-effective platforms from which to collect bio-physical data on a scale relevant to the processes that govern biodiversity in the Southern Ocean.

CAML's studies on top predators offer a unique opportunity to extend the type of international cooperation exemplified by international treaties such as the Convention of the Conservation of Antarctic Marine Living Resources, the Antarctic Treaty, the Agreement on Conservation of Albatross and Petrels and the International Whaling Commission. CAML will build on science initiatives developed in the southern hemisphere such as the BirdLife International's petrel and albatross global tracking database, the multinational Southern Ocean TOP elephant seal project developed by Australia, France UK and the USA, the Antarctic Pack Ice Seal survey, and Southern Ocean GLOBEC.

The two largest questions to be addressed for top predators during the work of the CAML are:

- How does bio-physical coupling in the marine environment drive the biological diversity, distribution and abundance of top predators in the Southern Ocean?
- What key functional components of the marine environment are the principle drivers of top predator distribution and abundance?

These fundamental questions will be addressed through the following series of interrelated hypotheses:

1. Multi-species aggregations of top predators are associated with specific bio-physical meso-scale processes that are predictable and observable with existing methodology.
2. Top predators form "foraging guilds", associations that feed on similar prey that are associated with specific oceanographic features. Guilds will associate with different oceanographic features and will have different species compositions. Species with catholic diets will be more fluid in space and time, in whichever guild they join. What spatial and temporal changes in the bio-physical process in these frontal zones affect the composition and integrity of the foraging guilds?

3. How do top predators locate and select profitable areas in the open ocean? Are there specific cues (temperature, salinity, chemical, light level, water clarity) used to track and locate their prey? Are there specific foraging strategies that top predators use to locate prey associated with these different oceanographic features? Does this change with age, gender, season, meta-population and region?

Integrated observations and interpretation of remotely sensed data (obtained from bio-loggers and tags) together with observational and oceanographic data will provide an ocean-wide picture of the distribution and abundance of top predators in relation to bio-physical variability, and thus greatly assist with the development of conservation measures.

In all realms of the Southern Ocean, CAML will integrate studies of the diversity, abundance and distribution of marine life. Studies of the biodiversity of marine organisms – ranging in size from microbes to mammals – will bring a better understanding of how life has evolved in the marine environment of the Antarctic. By promoting collaboration between different research disciplines and international programs, CAML will provide a legacy of knowledge for future generations.

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