Evolution and Biodiversity in the Antarctic

SCIENCE PLAN

SCAR 2004

Programme Description

A1. Title: Evolution and Biodiversity in the Antarctic: the response of life to change

A2. Submitted by: Life Sciences Scientific Standing Group (LSSSG)

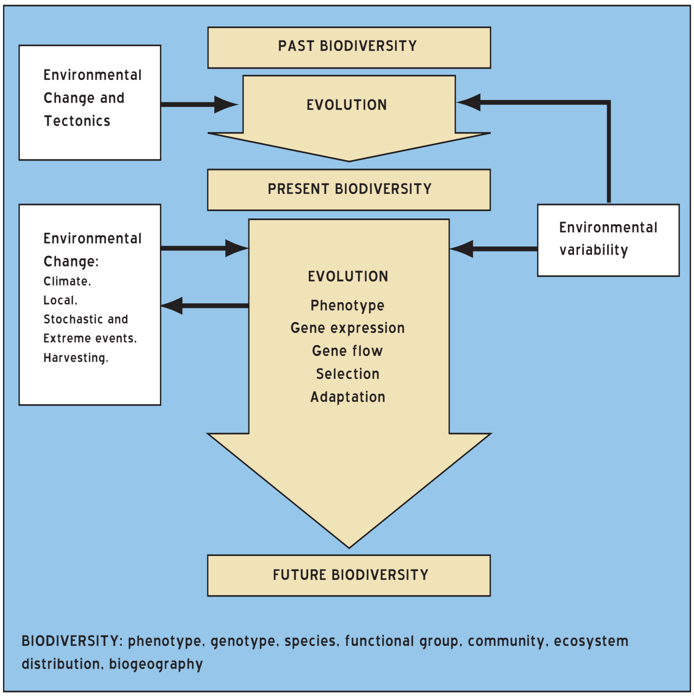
A3. Programme Duration: 8 years, January 1st 2006 – December 31st 2013 Six years of research and meetings and 2 years for synthesis and reporting. Final conference; SCAR Biology Symposium 2013.

A4. Estimated SCAR Funding: Total core programme $120 000 ($15 000/year)
Expected total Supplemental Request: $64 000 ($8 000/year)

A5. Programme Executive Summary

This Scientific Research Programme (SRP) entitled *Evolution and Biodiversity in the Antarctic (EBA): the response of life to change.* EBA will use a suite of modern techniques and an interdisciplinary approach to explore the evolutionary history of selected modern Antarctic biota, examine how modern biological diversity in the Antarctic influences the way present-day ecosystems function, and thereby predict how the biota may respond to future environmental change. For the first time the scientific community will integrate understanding across the major realms of Antarctic biology (marine, terrestrial, freshwater, from molecules to ecosystems) into the cohesive picture that is a prerequisite of Earth System Science. EBA will advance evolutionary and ecological science using model systems and organisms from the Antarctic, facilitating interdisciplinary investigations of systems responses to change. To achieve these goals the broad objectives of this programme are to:

1. Link with geoscientist to establish more clearly the evolutionary history of the Antarctic biota.
2. Compare evolutionary adaptations to the Antarctic environment in a range of organisms and thereby determine general principles.
3. Explore patterns of gene flow within, into and out from the Antarctic, and determine their consequences for population dynamics.
4. Identify patterns and examine diversity of organisms, ecosystems and habitats in the Antarctic, together with the ecological and evolutionary processes that control these.
5. Study the impact of past, current and predicted environmental change on biodiversity and the consequences for Antarctic marine, terrestrial and limnetic ecosystem function.



B. Proposed Details

Programme Plan to date:

The biological community has held six meetings and produced two reports associated with the planning of this SRP:

Meeting 1: Shanghai China, July 2002

Meeting 2: Pontignano Italy

Meeting 3: Cambridge UK January 2003

Meeting 4: Varese Italy July 2003

Meeting 5: Eindhoven April 2004

Meeting 6: Paimpont July 2004

Meeting 7: Bremen July 2004

B 1. Objectives

The overall aim of the EBA programme is to understand the evolution and diversity of life in the Antarctic, to determine how these have influenced the properties and dynamics of present Antarctic and Southern Ocean ecosystems, and to make predictions on how organisms and communities will respond to current and future environmental change.

This programme involves an explicit integration of work on marine, terrestrial and limnetic ecosystems in a manner never before attempted. The science in this programme thus extends over an entire biome on Earth. By comparing the outcome of parallel evolutionary processes over the range of Antarctic environments, fundamental insights can be obtained into evolution and the ways in which life responds to change, from the molecular to the whole organism level and ultimately to biome level. The scientific and political environment of Antarctica offers a unique opportunity to address these globally significant scientific questions in the context of an interdisciplinary approach that is essential for understanding the structure and functioning of the Earth System. Most national programmes individually cannot attempt a study on such a bold scale, whereas the collaborative spirit of the Antarctic science community will provide a mechanism for achieving outstanding scientific success. Specific details and rationale of each of the objectives listed in the Executive Summary are provided below.

B 2. Scientific background and rationale (and details of objectives)

Nothing in biology makes sense except in the light of evolution

Theodosius Dobzhansky, *American Biology Teacher*, 35: 125-129 (1973)

Evolution is the most fundamental principle of biology, influencing all levels of biological organisation from molecules to ecosystems. It is best studied where its impact can be seen without interference from confounding factors. Evolutionary theory itself developed from insights gained in isolated, island systems, most notably Darwin's experiences in the Galapagos Islands and Wallace's travels through the Indo-West Pacific archipelago. Isolation is also a feature which makes the Antarctic an important natural laboratory for evolutionary work. The extreme nature of the physical environment allows us to probe evolutionary adaptation in rare detail. Important Antarctic discoveries such as the biosynthesis and evolution of antifreeze compounds in fish and terrestrial and limnetic invertebrates are now part of standard textbooks [1]. The Antarctic is also an important laboratory because we know so much about the tectonic and climatic history that provides the context for evolution [2,3,4]. Finally, the combination of isolation and climate change has lead to a biota rich in endemic taxa, and to a strong contrast between marine and terrestrial and limnetic realms, from apparently simple ecosystems on land to highly diverse marine benthic systems on the continental shelves [5,6] and in the Southern Ocean deep sea [7,8]. An important feature of the EBA science programme is to seek an understanding of the reasons behind these striking differences in one of Earth's major biomes.

The western side of the Antarctic Peninsula is currently subject to one of the fastest rates of regional climate change on the planet. Climate change is having impacts on both marine, and terrestrial, and limnetic systems, and hence will influence future biological diversity. Our current understanding is that many Antarctic species are susceptible to this change [9] with those of the marine environment being particularly vulnerable [10]. The critical examination of Antarctic ecosystems undergoing change allows EBA to provide a major contribution to the understanding of evolutionary processes that are of relevance to all life on Earth.

The history of the Antarctic biota

Over geological time environmental conditions and habitats in the Antarctic have changed dramatically. The fossil record, stretching back over 500 million years provides a broad outline of evolutionary history of the continent and its biota. Fossil evidence of Antarctic forests in the Cretaceous and Palaeogene poses interesting questions as to what adaptations in plants and animals evolved to cope with seasonal winter darkness, and the short summer season with continuous light.

After separation of the southern continents from Antarctica during the Cretaceous and Tertiary the earliest cold water marine faunas emerged some 35 million years ago. Since then, the shallow water marine fauna around Antarctica has been subjected to a steady decrease in seawater temperature, and an increasing influence of sea-ice. Conditions on land since the isolation of the Antarctic have fluctuated between cold and warm periods, but superimposed by an overall cooling since the Mesozoic, and terrestrial and limnetic biota, ice-cover and land availability have changed accordingly. However, some small areas of habitat now supporting terrestrial and limnetic biotas have been continuously available for periods of time ranging from the several million to only a few thousand years.

The study of biotic history is thus linked intimately to tectonic, climatic and palaeobiological studies and to biogeographic comparisons with other fragments of Gondwana. Critical to this work will therefore be research on land, freshwater, marine continental shelf and deep seas because all these environments are integral to the history of life since the break-up of Gondwana. Moreover, strong integration with other science programmes investigating climate and tectonic history are an essential feature of the work because intimate feedback between the living and abiotic environments have modulated both.

On shorter time-scales, the Antarctic biota has also experienced cycles of global environmental change driven by periodic glaciations, on which recent anthropogenic global warming and increased UV radiation resulting from ozone depletion have been superimposed [9]. Regional scale and short-term climatic variations appear to have been more frequent and intense in recent years. Environmental change can affect every aspect of an organism's biology, from cellular physiology and biochemistry to population dynamics and food-web dynamics [11, 12]. All organisms are susceptible to environmental change, but small and non-motile organisms are particularly vulnerable. Such organisms must alter their physiology and biochemistry to cope with environmental change. These responses may be a consequence either of genotypic (genetic) change or phenotypic (physiological) plasticity or both, with the time-scale of the former generally being longer [13].

B 2.1. What is the evolutionary history of Antarctic organisms?

How have past changes shaped modern biological diversity? Previous palaeobiological work in the Antarctic and other fragments of Gondwana has established many of the broad features of the evolutionary history of the Antarctic biota. For example, in the marine realm we now know that a shallow-water fauna has existed throughout its history. Palaeobiologists have established the broad history of cool-temperature and cold marine biotas that have evolved in a mid to high latitude setting. These faunas have typically been of lower diversity than contemporary faunas at lower latitudes [14]. This poses the fundamental question, still unresolved, as to whether evolutionary processes differ between warmer and colder habitats (for example whether speciation or extinction rates might be higher in tropical or polar regions) [15,16].

The high diversity of the marine continental shelf fauna of Antarctica [17,18] has been variously explained in terms of a relatively homogenous physical environment, periodic disturbance by icebergs and the glacial history[19]. In particular periodic extensions of the Antarctic icesheet as far as the continental shelf edge will have fragmented the habitat and also driven many species down the continental slope. This is a classic mechanism for driving speciation and this so-called climate diversity pump, a variation of standard vicariance speciation models, has probably been a major evolutionary driver in the history of the Antarctic biota. Fluctuations in the size of the Antarctic icesheet are driven by orbital (Milankovitch) variability, first documented in Antarctica in the Eocene, and have continued through the Pleistocene to the present day.

The periodic extensions and contractions of the icesheet will have influenced speciation processes by limiting gene flow between isolated populations. Recently powerful insights into the evolutionary history of the Antarctic biota have been gained from modern molecular techniques. These have allowed divergence times between taxa to be dated, radiations such as those of the notothenioid fishes [20] to be related to climatic or tectonic events, and have also revealed a number of cryptic species hinting at a vast reservoir of undetected diversity (see [21,22]). It is clear that the rapidly developing suite of molecular techniques offer enormous potential for potent insights into the evolutionary history of the Antarctic biota. Combining these approaches with our increasingly detailed understanding of the tectonic, climatic and glacial evolution of Gondwana offers a uniquely powerful opportunity to advance our understanding of how evolutionary processes are related to the physical setting.

The EBA programme cannot of itself undertake work on the tectonic, climatic or glacial history of the Antarctic. For this we must rely on other work both within and outside SCAR and cross-disciplinary meetings will thus be important for transfer of ideas and information. Molecular analyses of the Antarctic biota will, however, form a key component of the EBA programme. Key scientific areas will include:

1. Cryptic species: to what extent may we have underestimated the diversity of the Antarctic biota?
2. Radiations: when did the key radiations of the Antarctic taxa take place?
3. Impact of glaciation: what are the evolutionary links between continental shelf and slope or deep-sea species?
4. Phylogeography: how is the Antarctic biota geographically structured and related to that elsewhere?

B 2.2. Evolutionary adaptation to the Antarctic environment

The Antarctic is an extreme environment, both on land and in the sea. Studies of organisms living at extremes have been, and are central to developing our understanding of how life adapts to its environment, and work on Antarctic organisms has made a distinguished contribution to this work.

Two areas will form the basis of EBA work on evolutionary adaptation: organismal level ecophysiology and molecular studies (genomics and proteomics). Ecophysiology (including reproductive biology) has a long and proud history within SCAR biology, across marine and terrestrial and limnetic biomes. This work has been instrumental in developing our fundamental understanding of how organisms cope with environmental challenges on both long (evolutionary) and the shorter time scales relevant to understanding the impacts of climate change (see [23, 11]). Ecophysiology will therefore continue as a major theme in the EBA programme, but strengthened by the insights and understanding to be gained from molecular techniques.

Important in this work are the very different environmental challenges set by marine and terrestrial and limnetic habitats in the Antarctic. In the marine realm the challenge is for organisms to function at the lowest seawater temperature on earth, but where seasonal variations are small (see [24]). Similarly on islands close to the Antarctic Polar Frontal Zone air temperatures are extremely equable. In contrast on continental Antarctica, terrestrial and limnetic organisms must face enormous daily fluctuations in temperature, very low winter minima, extensive periods of freeze/thaw and long periods of low water availability [25]. Another important ecological factor shaping Antarctic ecosystems is the marked seasonality in ice and snow cover, light regime and thus primary production. This resource limitation, especially at the lower trophic levels, has a strong impact on life cycle strategies and ecophysiological adaptations. Ecophysiological studies will be important in defining the limits to organism performance, trade-offs in reproductive and physiological activity, the energetic costs of coping with environmental challenges, and the consequences of these for population dynamics [26]. Molecular studies will be important for elucidating the mechanisms underpinning the organismal level response, and the genetic mechanisms behind these [28]. This combination is critical as neither ecophysiology nor molecular studies in isolation can provide a complete picture of evolutionary adaptation. The Antarctic biology community is unusual in having strong teams in both disciplines.

Key scientific areas to be investigated include:

1. Limits to organism performance: to what extent does adaptation to the Antarctic environment constrain physiological performance?
2. What are the physiological and genomic adaptations that allow organisms to survive in the Antarctic? Are these special to the Antarctic or simply variants of more general adaptations exhibited by organisms elsewhere?
3. How well are Antarctic organisms able to cope with daily, seasonal and longer-term environmental changes?

B 2.3. Patterns of geneflow within, into and out of the Antarctic, and consequences for population dynamics

Isolation has been and remains a major factor in the evolution of Antarctic organisms. The Antarctic is isolated from the rest of the globe by the deep oceans separating it from other continents and by circulation patterns in the atmosphere and oceans. There are also barriers between populations within the Antarctic, in both terrestrial and limnetic and in marine environments. In the terrestrial and limnetic realms these barriers include ice sheets and oceans between land oases, and also atmospheric circulation patterns. In the marine environment barriers include deep water trenches between continental shelves, and isolating mechanisms such as oceanographic fronts and gyres.

This element of the EBA programme seeks to understand the extent of isolation of populations of Antarctic organisms both between the Antarctic and elsewhere and between populations within the Antarctic. In isolated populations evolution occurs through three major processes: genetic drift, mutation and natural selection. Gene flow between populations interrupts within-population evolutionary processes by diluting the effects of the above processes (review in 28). Theoretically gene flow can be active e.g. migration, or passive e.g. transport of propagules, through processes such as ocean currents, on birds and wind [29]. Propagules are also transported by humans[30].

Understanding gene flow and associated population processes provides valuable insight into both fundamental and applied aspects of evolutionary biology in the Antarctic and within the biosphere. Antarctic ecosystems are experiencing increasing rates of environmental change driven mainly by global climate change, and also through major extraction industries both past and present (sealing, whaling and fisheries). It is of fundamental importance to global conservation and management strategies to understand the impact that this environmental change has on gene flow and hence the evolutionary control of the diversity of living organisms [31].

A key question in Antarctic biology is whether climate change will result in either relaxation of selection pressure on genomes, or tighter constraints and ultimately extinction of populations and species. With regard to sustainable fisheries management it is essential to understand population and stock structure and the extent of exchange of genetic information via transfer of individuals or propagules between populations. It is not understood for instance the extent to which the Antarctic krill population is structured, and this is a serious limitation to management of the fishery. Studies in this area will provide valuable information for CCAMLR management activities.

To determine patterns of gene flow requires the use of molecular techniques with the target molecules (proteins or DNA) and analytical protocol dependent upon the question being asked. Field samples of the organism need to be collected over suitable spatial and temporal scales, and returned to a laboratory, either in the Antarctic or outside, for molecular analysis. For interpretation these data need to be combined with studies of life history, population dynamics and dispersal. Collaboration with modellers and those working on oceanic and atmospheric dynamics will also be integral to success.

Key scientific areas to be tackled by this objective of the EBA programme include:

1. Baseline population structure: how are populations of Antarctic organisms structured, what are their dynamics, and how do these differ from organisms elsewhere?
2. Dispersal: how are organisms being transported to, within and out from the Antarctic? This will include examining the role of humans as vectors.
3. Genetic structure of populations: is the genetic structure of populations of Antarctic organisms different from those elsewhere, and to what extent do these population structures reflect past evolutionary history?
4. To what extent do populations of Antarctic organisms exist as a metapopulation?
5. What is the role of advective processes in the gene flow and population structure of Southern Ocean organisms?

B 2.4. Patterns and diversity of organisms, ecosystems and habitats in the Antarctic, and controlling processes.

What is the present biodiversity in the Antarctic?

Present patterns of biodiversity and distribution are a consequence of factors and processes working on both evolutionary and ecological timescales [32, 33]. In the Antarctic there are a great many ecosystems, from highly complex suspension feeder communities to the strongly impoverished shallow water communities in the sea, and from the rich coastal areas of the subantarctic region to the very simple flora in the nunataks of the high Antarctic plains in the terrestrial and limnetic environment. However within this variety there are significant gradients that can be recognised, such as latitudinal, altitudinal, and depth.

Patterns of biological diversity are greatly different between land and sea in the Antarctic [5]. In the marine realm the concept of the bell-shaped distribution of biodiversity with its peak in the tropics and low values at the poles has been shown to be an oversimplification [34]. We now recognize that patterns of biodiversity in the Southern Hemisphere oceans are very different from those in the North, and the continental shelves of the Southern Ocean in particular have been shown to support a remarkably diverse fauna. This fundamental revision of our view of global patterns of marine diversity has been a result, almost exclusively from the work of SCAR marine ecologists. Of particular importance has been the recognition of taxa whose diversity decreases away from the Antarctic [35]; for example some groups of amphipods [36], isopods [37] and pycnogonids (sea spiders)[18].

In strong contrast terrestrial communities are relatively impoverished, partly the result of eradication of almost all biota at previous glacial maxima although recent work (including molecular diversity studies) has importantly, identified long-term refugia [38]. Most terrestrial assemblages decrease sharply in diversity with latitude, for example in the insect order Diptera (true flies) has many representatives on the sub-Antarctic islands but only one species reaches high latitudes [25].

In marine, terrestrial, as well as limnetic systems some groups are very poorly represented, or even absent altogether. Examples on land include reptiles, amphibians, some insect groups and almost all higher plants. Examples in the sea include reptant decapods, stomatopods and many groups of fish. In contrast some marine groups are markedly species rich, examples including amphipods, isopods, polychaetes and pycnogonids. On land, even the most dominant groups are represented by relatively few species. In both realms a remarkably high proportion of taxa are endemic, reflecting a long period of evolutionary history in relative isolation (e.g. [38, 18]).

Although most Antarctic biotic communities are recognisably related to those elsewhere, a few specific communities are unique to the Antarctic. Among these are the under-ice communities [39] and the epifaunal communities in the high Antarctic [40]. The total lack of macroalgae in regions off the large ice shelves in the high Antarctic Weddell Sea contrasts with the rich macroalgae communities in the subantarctic regions [41, 42]. Typical elements of the Southern Ocean system also include the marine top predators such as seals and penguins, with few species but playing a dominant role in the ecosystem [43]. In the terrestrial and limnetic ecosystems the diversified vegetation of the subantarctic islands is replaced by moss and lichen communities in coastal maritime and continental Antarctica, and by endolithic communities in the high Antarctic. The terrestrial and limnetic fauna is characterised by the dominance of decomposers while herbivores and predators are few in the native fauna [44].

Although studies of biological diversity typically concentrate on species richness, other aspects of diversity are important. These include variety of life forms, trophic guilds and life histories. In the marine realm considerable progress has been made in these areas during the EASIZ programme elucidating, for example trophic diversity in amphipods and fish, and a range of population dynamics in fish and invertebrates. On land the RiSCC programme has elucidated the diversity of morphology and life history in both plants and invertebrates. Together these studies have overturned previous conceptions that the Antarctic environment only allowed the existence of a limited range of strategies; rather it is now clear that a great many strategies are possible and this contributes to the distinctive biological diversity of the Antarctic.

Work to date has concentrated in certain geographical areas, such as the Weddell and Ross Seas, or the Antarctic Peninsula for marine work, and sub-Antarctic islands, the maritime Antarctic and the McMurdo Dry Valleys for terrestrial and limnetic work. Many important areas and habitats remain almost completely unexplored, such as the Amundsen and Bellingshausen seas and many areas of the east Antarctic, including continental nunataks and some ice-free oasis on land. These almost completely unknown areas merit special attention in the EBA programme. Embedded in this objective is the Circum-Antarctic Census of Marine Life (CircAntCML) that will occur during the IPY.

Key scientific areas to be tackled in the EBA programme will include:

1. Spatial and temporal variations in diversity: how does diversity vary from area to area within the Antarctic and within defined time frames? Current knowledge suggests that important comparisons, both on land and in the sea, will be the Antarctic Peninsula versus the high (or continental) Antarctic, and East Antarctica versus West Antarctica. Time-frames would include seasonal to interannual examination of selected sites.
2. Latitudinal or environmental gradients: how does marine, and terrestrial, and limnetic diversity vary along gradients? Important areas to study here will be the Antarctic Peninsula and Victoria Land. Comparison with the Magellan area will be critical to this work.
3. Evolutionary radiations: how recent are the key evolutionary radiations in the Antarctic?
4. Unknown areas: what is the pattern of diversity and assemblage faunal composition in unexplored but important areas such as the deep-sea and inland nunataks and isolated islands?
5. Relations with elsewhere: how does diversity in key Antarctic groups compare with other Southern Hemisphere landmasses and oceanic islands?

B 2. 5. What is the impact of past, current and predicted future environmental change on biodiversity, and the consequences for Antarctic marine, and terrestrial and limnetic ecosystem function?

The principal physical factors, tectonic and climatic, influencing the evolution of the Antarctic biota have already been discussed, as have the consequences for present day diversity and evolutionary adaptation.

a). How are environmental changes driving evolution now?

Among the ecological factors controlling distribution patterns and biodiversity of the modern Antarctic biota, the most important are temperature, water availability in the terrestrial and limnetic ecosystem [25] , and ice cover, oxygen, light, UVB and wind in the marine systems [43]. These factors are not constant, and all of them vary over a range of temporal scales from less than daily, through seasonal to interannual. The past two decades have seen a revolution in our view of variability in Antarctic systems, with the recognition that interannual variability is of fundamental importance to the dynamics of Antarctic ecosystems. Particularly important are subdecadal variations associated with ENSO, the Antarctic Oscillation and the circum-Antarctic progression of atmospheric and oceanographic variability manifest as the Antarctic Circumpolar Wave [45]. Variability on this scale is important because it is of the same order as population dynamics and hence Antarctic organisms have been selected to cope with good and bad seasons within their lifespan. The system may, however, be disrupted if the pattern of environmental variability changes (for example through a change in the relative frequency of good and bad years, or of the extreme values).

Studies of sediment cores have also revealed variability on longer time scales, typically hundreds of years. It is possible that the Antarctic environment varies on timescales even longer, merging into that driven by Milankovitch orbital variability. These huge ranges of temporal scales of variability set a significant challenge to ecologists attempting to determine the effects of long-term secular environmental change. These difficulties are exacerbated by the way in which a combination of biotic properties and abiotic factors control processes which shape diversity and distribution patterns. For example, increased iceberg calving may lead to heavy iceberg scour of continental shelves all around the Antarctic which would result in temporal extinction of communities and generates processes of recolonisation and succession, which would produce distinct diversity patterns [46]. In accordance with ecological theory (the intermediate disturbance hypothesis) this disturbance has been shown in the Antarctic to increase diversity on a regional scale [47]. Life histories and dispersal capacity also greatly influence the colonisation abilities both in marine and terrestrial systems [25]. The study of these processes is currently providing important information on the resistance and recoverability of Antarctic communities under present environmental conditions [17]. The challenge now is to determine how changes to the physical drivers will effect the ecology of the Antarctic system.

b). The future

The most important anthropogenic changes currently affecting the Antarctic are accelerated global warming and increased levels of UVB, with further threats from fishing, and the introduction of alien species [47]. In contrast to these widespread phenomena, pollution, and visitor pressure are causing only local effects on Antarctic diversity. Many of these changes have complex and interacting effects. For example an impact on the lowest or highest level in a food web can propagate through to affect other taxa indirectly. Thus UV impact on primary producers may affect consumers, and the removal of great whales has resulted in a very different trophic structure in the Southern Ocean. The recent explosive increase in the population of the Antarctic fur seal has led to extensive damage to vegetation and soil erosion.

The EBA programme will provide SCAR and the international scientific community with the best estimate possible of the possible consequences for the Antarctic of continued environmental change.

Key scientific areas to be tackled in the EBA programme will include:

1. What are the likely outcomes of interactions between introduced and indigenous species in selected environments given a climate of environmental change?
2. The nature of and extent to which interactions between changing abiotic conditions (temperature, UVB, water availability) change biotic responses (through synergy or interference) relative to single variable effects.
3. Modelling of interactions between environmental change and organism responses to facilitate predictions of change in the Antarctic biota.
4. Application of research findings for the development of conservation policy in the region in the face of changing environments and patterns of human use.

B 2.6. Integrating the study

The five main broad objectives outlined above are each clearly focused on a specific area of science. Each objective will provide useful outcomes however further value will arise from the connectivity between objectives. Furthermore, an explicit aspect of the EBA programme is to compare and where possible integrate results from the marine, terrestrial, and limnetic environments. This is a new venture for SCAR, for previous biology programme have always confined themselves to either the oceanic (BIOMASS, EASIZ, EVOLANTA [primarily]) or terrestrial and limnetic (BIOTAS, RiSCC) realms. Although land and sea are very different in terms of the relationship between physical forcing and biological response, there are important insights to be gained by intelligent comparisons. The differences, are of course, even more marked in the Antarctic than elsewhere because of the very different glacial history of the two realms.

The EBA programme is explicitly interdisciplinary in that it brings together a wide range of biological disciplines to tackle a series of sharply focused questions. These disciplines include molecular biology, taxonomy, biogeography, autecology, cellular and organismal-level ecophysiology, and community ecology. However many of the subjects to be tackled by the EBA programme will also require collaboration with other scientists, including palaeobiologists, oceanographers, geophysicists, glaciologists and modellers. This makes the EBA programme multidisciplinary to an extent that has only rarely, if ever, been achieved in SCAR to date. This multidisciplinary approach will allow the EBA programme to tackle a series of important science areas, including:

1. Links between tectonics, climate evolution, glacial processes and evolution.
   In particular, we plan to continue to refine our understanding of how the present biota evolved, and why current patterns of biological diversity are what they are. For example, palaeobiological data can be used to assess the age of Antarctic habitats and species. These results can then be combined with molecular estimates of divergence time to provide a powerful two-pronged approach to understand Antarctic biotic evolution (as was used very successfully to determine the history of the notothenioid radiation by the ESF funded Network on the Biology of Antarctic Fishes). Palaeobiological data can also determine the nature and origin of latitudinal diversity gradients. Essential to this will be the interactions with SCAR's ACE and AGCS programmes.
2. Links between the physical environment and gene flow.
   Models of oceanic and atmospheric circulation can be used to predict transport of propagules into (and out from) the Antarctic. Such models can also be used to elucidate advective processes in the Southern Ocean and their impact on gene flow and population dynamics. In the marine realm we will seek interactions with scientists working with the CCAMLR framework to inhance progress on his topic.
3. EBA will have strong links with the SALE programme. The biological component of SALE and the EBA objectives are strongly compatible.
4. Links with northern polar studies. Comparison of southern with northern polar processes can elucidate the significant evolutionary pressures and provide insight into gene selection.

B 3. Programme Rationale/ Justification

The largest challenge facing humankind is the management of the Earth System to ensure a sustainable human future. To this end, understanding of the functioning of the Earth System in the context of both natural and anthropogenic change is essential. The Antarctic, the Southern Ocean, and their biota are an instrumental part of the Earth System, not only influencing the pace and nature of environmental change, but also responding to it in an integrated system of biologically modulated teleconnections.

An important part of managing for a sustainable human future must include a thorough and profound knowledge of the way in which life has both evolved and the ways in which it is likely to change. Such knowledge can only be obtained by an integrated, interdisciplinary investigation of the structure and functioning of living systems. The Antarctic offers an immensely valuable regionally focussed approach to harness a wide range of international resources, both physical and intellectual. Its ecosystems offer examples of how both structure and function has evolved, and the likely responses of such species and ecosystems to change induced by a wide variety of both natural and anthropogenic processes, as well as the ways in which their responses feed back to influence these processes. In consequence, a programme that integrates research across a wide variety of fields, from functional genomics and molecular systematics, to ecosystem science and modelling, and which draws on and contributes information to a wide rage of related fields, such as climate modelling and tectonics, is required. The SCAR Evolution and Biodiversity in the Antarctic is just such a programme. Its major intention is to provide a platform for the kinds of interactions amongst disciplines and researchers that are essential to understand the evolution within, and responses and contributions of biodiversity to the earth system. In so doing, it will fill a major void in understanding of the role of biodiversity in the Earth System by providing the Antarctic context. No other programme has this as its major goal, nor has the human resources, expertise, and capability of doing so. As such, it is the premier route of contributing a major part of the information required to comprehend the functioning of the Earth System, which will enhance our ability to achieve a sustainable future for all life.

The programme is particularly opportune. Never before has there been such global interest in understanding the full complexity of the Earth System and its responses to change. The tools for comprehending interactions between organisms and their environments are also advanced to the stage where obtaining and managing information from the functional genomic to broad-scale spatial levels are reasonable straightforward, allowing integration of information across all levels in the ecological and genealogical hierarchies. Several international programmes, both within and outside SCAR have also laid the groundwork for the kinds of novel, interdisciplinary science being proposed here, and an equivalent number of proposed or recently initiated programmes will add considerable value to it. These include programmes such as Diversitas, Census of Marine Life, IMBER, CliC, EPICA, and many others that can provide the background to and information required for full integration of the work proposed here. This programme is also timely given increasing concerns expressed by the Antarctic Treaty System regarding the likely responses of Antarctic environments to natural and anthropogenic disturbances at a range of scales, and the request for information regarding ways in which these responses can be distinguished and mitigated to ensure long-term conservation of Antarctic environments and their biodiversity. Finally, by contributing a time-limited, burst of activity, that will leave a legacy of spatially explicit biodiversity information and tools for its exploration, the programme is in an excellent position to contribute to and raise the profile of Antarctic science in the context of the proposed International Polar Year.

B 4. Methodology and Implementation plan

B 4.1. Implementation

The structure of this programme will be based around a series of five major unifying key questions that are addressed across the realms of terrestrial, limnetic and marine environments. The programme will operate along the lines of a matrix of the key questions vs selected environments. A major marine focus will occur during the IPY. Each year the programme will run a series of workshops. There will be three types of workshops: a) defined themes, fostering cross-discipline interaction including joint workshops with the other SCAR programs, particularly ACE and AGCS; b) discipline based; c) environmental based. The workshop timetable will be defined at the EBA workshop during the SCAR Biology Symposium in Curitiba in 2005.

Additional to the workshops will be national and international field programmes. Such programs will be wide ranging, including subantarctic islands, inland to the most remote nunataks as well as northward to the Magallanes, and stretching across the Southern Ocean down to the deep ocean as well as the shelves. This wide range will need significant support from COMNAP and national programs. Already many nations have pledge support for the Census of Antarctic Marine Life (CAML) and co-ordination and securing of funds for this detailed study has already begun.

B 4.2. Timeline

- 2004: Delegates approve of EBA
- 2005: Planning phase including a) Planning meeting in Cambridge in March to draft an implimentation plan; b) SCAR Biology Symposium Theme – Evolution and Biodiversity in the Antarctic; c) International workshop on EBA where objective sub-committees will be appointed and specific milestone detailed; d) detailed planning of workshop structure and themes; e) IPY advanced planning, database construction and integration
- Year 1: 2006 Start of programme and continuation of workshops (one interdisciplinary with SCAR29). Participation in the Northern Hemisphere RiSCC major expedition
- Years 2 & 3: 2007-09 Major, time-limited push for Census of Antarctic Marine Life (CAML), IPY activities and workshops
- Year 4: 2009 First reporting of findings at the SCAR Biology symposium
- Year 5: 2010 Ongoing marine and terrestrial work, SCAR 31 interdisciplinary and other workshops
- Year 6: Last year of field work, with workshops including syntheses of marine/terrestrial system findings
- Year 7 & 8: Reporting years. Final reporting at SCAR Biology Symposium, 2013

B 4.3. Methodology

The EBA programme is wide-ranging and multidisciplinary. Because of this, and space constraints, it is not feasible to list specific methodologies in detail. However a few general points are worth emphasising.

1. The programme will utilise state-of-the-art enabling technologies in molecular biology, ecophysiology, microbiology, taxonomy and organismal biology all of which are established and proven at the highest level in various national groups contributing to the EBA community.
2. The programme will liaise with the relevant physical, geological and historical disciplines to ensure regular interaction and use of the most recent data and insights in interpreting the biological results.
3. The programme will necessarily involve fieldwork and laboratory work, both in the Antarctic and in home institutions. In particular, the study of latitudinal gradients requires extensive international collaboration (as was achieved for the recent Victoria Land Transect study, which involved close collaboration between scientists from New Zealand, Italy and the USA, the IBMANT collaboration between European and Latin American countries on evolutionary connections between the Antarctic and South America, and ICEFISH 2004 a sub-Antarctic cruise with scientists from eight countries).
4. Exploration of some areas will require new technologies (for example benthic landers or remotely operated vehicles for the deep-sea, autonomous underwater vehicles for work beneath ice shelves). Remote-controlled small aircraft for spectral sensing of terrestrial and limnetic environments.
5. Importance will be attached to issues pertaining spatial and temporal scales in studies of gene flow, population dynamics, disturbance ecology and biological diversity.

B 4.4 Relationship with IPY

The International Polar Year activities will overlap with the timing of the EBA programme. Although the EBA and IPY activities were conceived in parallel, the IPY Initial Outline Science Plan (April 2004) indicates that the EBA will be able to make a significant contribution to IPY activities. By undertaking a time-limited, focussed initiative elucidating the spatial distribution of marine and terrestrial diversity, the EBA will leave a legacy of biodiversity information and the tools with which to explore it that is a hallmark of an IPY programme. Specifically the EBA will be in a position to contribute substantially to IPY Themes 1b, 2a-e, 4a-b, though with the major focus on 4b.

B 5. Programme management and governance

The EBA programme will be managed by a small Scientific Programme Group. This group will be selected to include expertise in a range of habitats, organisms and scientific disciplines. The SPG will work by electronic mail but will also meet once a year. An important aspect will be liaison with other scientific disciplines. This will be achieved by a series of multidisplinary workshops focused on specific topics. SIx steering groups will be formed to support each of the objectives as well as the Census of Antarctic Marine Life. EBA will schedule workshops to monitor the progress of the programme in an effective and democratic fashion.

We will work closely with JCADM with regard to data management and will rely heavily on marine data being integrated into MarBIN and terrestrial data integrated into the RiSCC Biodiversity database as well as relevant data centres and databases.

B 6. Deliverables

The main output from the EBA programme will be a significant step forward in our understanding of the Antarctic biota and its evolution. We anticipate that there will also be important contributions to fundamental understanding in a number of disciplines.

Specific output will include the following:

- Primary literature publications
- Conference proceedings (These would be particularly valuable where the symposium tackles a multidisciplinary theme in a focused manner)
- Input to databases (national/international e.g. GenBank, OBIS, GBIF)
- Advisory reports to ATCM and its instruments CEP, CCAMLR, COMNAP

- Input to, and feedback from international programmes (IPY, CoML, CAML, ACE, AGGS, APIS, CLIVAR, SO-GLOBEC, CLiC, ANDEEP, IBMANT, CPR, LGP, ICEFISH)
- Interactions with other SCAR programmes (ACE, AGCS, SALE)
- Trained PhD graduates
- Capacity development of students from developing Antarctic nations
- Outreach via National Programmes and in coordination with proposed SCAR Outreach Committee

B 7. Biennial milestones

- Programme Reports (detailing deliverables and success factors) and publications from workshops
- Four yearly SCAR biology conference proceedings

B 8. Success factors

The main success factor will be a significant improvement of our understanding of the Antarctic and its place in the Earth system. More specific items would include:

- Number of completed post-graduate degrees associated with the programme
- Number of papers citing EBA
- Citation profile indicating value of EBA science to the global science community
- The number of national programmes involved in EBA
- The number of scientists working in EBA

B 9. References Cited

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C. Supporting Information

C 1. Special Programme Group

Dana Bergstrom (Australia, terrestrial) Angelika Brandt (Germany, Marine)

Guido di Prisco (Italy, marine) Ad Huiskes (Netherlands, CO LSSSG)

C 2. SCAR Role

SCAR is the major organization coordinating research in the Antarctic and Southern Ocean region. With SCAR's support the EBA will facilitate a level of interdisciplinary interaction, in support of the integrated approach required for understanding the earth system, that will not be possible without the extensive network of representation that is SCAR, both in terms of its members and links to other organizations. Moreover, by feeding information back through SCAR, the EBA will enhance SCAR's ability to address key issues raised within the Antarctic Treaty System.

Furthermore SCAR and particularly the new SCAR platform of open science meetings will provide an opportunity for us to inform non- biological disciplines and of the ultimate necessity of the programme and their essential contribution towards understanding the impact of climate change on Antarctic ecosystems

C 3. National and International Involvement

It is anticipated that the majority of the SCAR nations will participate in this programme, that it will act as a major route for capacity building in new SCAR members and those with a comparatively reduced logistic and financial resource base, and that it will contribute to a wide variety of international programme, including potentially programme of the IGBP, WCRP, IPY, and other such as Diversitas, Census of Marine Life, and GBIF.

C 4. Indicative budget

Year and Item	Amount	Year and Item	Amount
2005		**2006**	
EBA – manual	1 000	SPG Meeting	5 000
Terrestrial database	9 000	Terrestrial database	2000
MarBIN	5 000	MarBin	5 000
Workshops	5 000	Workshops	10 000
EBA-CAML Office	2 000	EBA-CAML Office	2 000
Total	**22 000**	**Total**	**24 000**
2007		**2008**	
SPG Meeting	5 000	SPG Meeting	5 000
Terrestrial Database	1 000	Terrestrial DB	2 000
MarBIN	5 000	MarBIN	5 000
Workshops	10 000	Workshops	10 000
EBA-CAML Office	2 000	EBA-CAML Office	2 000
Total	**23 000**	**Total**	**24 000**

ANNEX 1 – ACRONYMS USED IN THIS DOCUMENT

ACE - Antarctic Climate Evolution – an international research programme studying the climate and glacial history of Antarctica (SCAR programme)

AGGCS - Antarctica and the Global Cliamte System (SCAR programme)

ANDEEP- Antarctic benthic deep-sea biodiversity International Programme

APIS - Antarctic Pack Ice Seals Programme (SCAR programme)

ATCM - Antarctic Treaty Consultative Meeting

BIOMASS - Biological Investigations of Marine Systems and Stocks programme (past SCAR programme)

BIOTAS - Biological Investigations of Terrestrial Antarctic Systems (past SCAR programme)

CAML - Census for Antarctic Marine Life

CCAMLR - Committee for the Conservation of Antarctic Marine Living Resources

CEP - Committee for Environmental Protection

CLiC - Climate and Cryosphere Project – part of the World Climate Programme

CLIVAR –International research programme of climate variability and predictability climate change.

CoML - Census of Marine Life

COMNAP - Council of Managers of National Antarctic Programs

CPR- Continuous Plankton Recorder Programme

Diversitas - an international programme of biodiversity science

EASIZ - Ecology of the Antarctic Sea Ice Zone (SCAR WG Biology) or Coastal-Shelf Easiz Programme on Sea-Ice Ecology (recent SCAR programme)

EPICA - European Project for Ice Coring in Antarctica

EVOLANTA - Evolutionary Biology of Antarctic Organisms (recent SCAR programme)

GBIF - The Global Biodiversity Information Facility

GenBank (R)- is a nucleic acid database produced by the National Institute of Health USA

IBMANT - Interactions Between the Magellan Region and the Antarctic – International Programme

ICEFISH 2004 – International Collaborative Expedition to collect and study Fish Indigenous to sub-Antarctic Habitats

IMBER - Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) Project

IPY- International Polar Year

LGP- Latitudinal Gradient Programme – New Zealand based programme around the Ross Sea

OBIS - The Ocean Biogeographic Information System

RiSCC - Regional Sensitivity to Climate Change in Antarctic Terrestrial Ecosystems (recent SCAR programme)

SALE - Subglacial Antarctic Lake Exploration Project

SO-GLOBEC - Southern Ocean Global Ocean Ecosystem Dynamics