WP	**11**
Agenda Item:	2.3.4
Person Responsible:	

EXCOM 2013

Barcelona, Spain 22/23rd July 2013

Antarctic Thresholds - Ecosystem Resilience and Adaptation (AnT-ERA)

Executive Summary

Title: Antarctic Thresholds - Ecosystem Resilience and Adaptation (AnT-ERA)

Author: Julian Gutt

Introduction/ Background: (Summary)

Stresses on Antarctic ecosystems result from global climate change, including extreme events, and from other human impacts. Consequently, Antarctic ecosystems are changing, some at a rapid pace while others are relatively stable. A cascade of responses from molecular through organismic to the community level are expected.

The differences in biological complexity and evolutionary histories between the polar regions and the rest of the planet suggest that stresses on polar ecosystem function may have fundamentally different outcomes from those at lower latitudes. Polar ecosystem processes are therefore key to informing wider ecological debate about the nature of stability and potential changes across the biosphere.

The main goal of AnT-ERA is to **facilitate the science required to examine changes in biological *processes*, from the molecular to the ecosystem level, in Antarctic and Sub-Antarctic marine, freshwater and terrestrial ecosystems**. Tolerance limits as well as thresholds, resistance and resilience to environmental change will be determined.

AnT-ERA will be classified into 3 overlapping themes: (1) molecular and physiological performance, (2) population processes, (3) ecosystem functions and services.

Recommendations:

As a SCAR program AnT-ERA lives from the contributions of the scientific community, the national programs and closely linked third party funded projects. Thus, we need full support in promoting AnT-ERA through the SCAR Delegates.

Justification:

Exchange of experience and ideas within a truly global scientific community.
Exchange of experience and ideas independent of competition for research funds.

Expected major Outcomes and Milestones:

Integration of early career scientists and new national programs.
Support of scientific publications, especially reviews.
Dissemination of results.
Communication between and coordination of research activities including trans-disciplinary projects.
Action recommendations especially in the context of natural variability and anthropogenic environmental change.
Contributions to overarching reports, especially "Antarctic Climate Change and the Environment".
Presentations at influential Antarctic-specific symposia.
Presentation of results to the broader scientific community.
Leading of, and participating in, major workshops, which support both the development of long-term observation networks (weather, ocean, lakes and streams or terrestrial) and an integration of ecological information into interdisciplinary models.

Providing mini-grants for early career scientists, members of newly emerging national programmes and contributors to reviews for traveling.

Planned achievements:

The following events mark potential milestones in communication within the AnT-ERA community and will provide a platform for exchange with a broader scientific world:

2012 Begin implementation of specific science, management and outreach plans

2013 Kick-off AnT-ERA workshop at the XI Biology Symposium, Barcelona

2014 Mini joint AnT-ERA – ICED workshop at the XXXIII SCAR and Open Science Conference

2015 AnT-ERA workshop: capacity building to train the next generation of specialists for biological process studies

2016 Joint AnT-ERA - AntEco - AntClim21 Syntheses-workshop at the XXXIV SCAR and Open Science Conference

2017 Meeting to structure and draft reviews for each scientific level

2019 Meeting to plan the future of AnT-ERA

2020 Final workshop (SCAR OSC).

Partners: (within and outside of SCAR)

AntClim21, EGBAMM, AntEco, IASC, APECS, IWC, ICED, ATCM, SOOS, CCAMLR, SPRP, INDEEP, ANTOS, GACS, EcoFinders

Budget Implications: (What funds are requested or other commitments by SCAR?)

$ 20,000 per year

Chief offers and SC:

LLOYD PECK, British Antarctic Survey, UK; CINZIA VERDE, Institute of Protein Biochemistry, National Research Council, Italy; BYRON ADAMS, Brigham Young University, USA; DIANA WALL, Natural Resources Ecology Laboratory, Colorado State University, USA; AKINORI TAKAHASHI, National Institute of Polar Research, Japan; VONDA CUMMINGS, The National Institute of Water and Atmospheric Research (NIWA), New Zealand; CRAIG SMITH, Department of Oceanography, University of Hawaii at Manoa, USA; ENRIQUE ISLA, Institut de Ciències del Mar-CSIC, Barcelona, Spain; IRENE SCHLOSS, Dirección Nacional del Antartico, Argentina & Institut des sciences de la mer de Rimouski, Canada; JOSÉ XAVIER, Institute of Marine Research, Department of Life Sciences, University of Coimbra, Portugal;

Liaison officer to PS SSG, especially AntClim21: T. Bracegirdle (British Antarctic Survey, BAS); to IASC: R. Gradinger (School of Fisheries and Ocean Science, Fairbanks, Alaska); to ICED: E. Murphy (BAS); to ANTOS: D. Wall. APECS representative: C. Suckling (BAS) & T. McIntyre (AWI).

Implementation plan:

See appendix

Appendix to the short report for the SCAR EXCOM meeting 2013

Antarctic Thresholds - Ecosystem Resilience and Adaptation (AnT-ERA)

Implementation plan

Abstract

Stresses on Antarctic ecosystems result from global climate change, including extreme events, and from other human impacts. Consequently, Antarctic ecosystems are changing, some at a rapid pace while others are relatively stable. A cascade of responses from molecular through organismic to the community level are expected.

The differences in biological complexity and evolutionary histories between the polar regions and the rest of the planet suggest that stresses on polar ecosystem function may have fundamentally different outcomes from those at lower latitudes. Polar ecosystem processes are therefore key to informing wider ecological debate about the nature of stability and potential changes across the biosphere.

The main goal of AnT-ERA is to **facilitate the science required to examine changes in biological *processes*, from the molecular to the ecosystem level, in Antarctic and Sub-Antarctic marine, freshwater and terrestrial ecosystems**. Tolerance limits as well as thresholds, resistance and resilience to environmental change will be determined.

Three key questions have been identified.

> *(1) How are Antarctic organisms adapted to current and future environmental conditions and what is the genetic basis for their life history, organism plasticity and physiology?*
>
> *(2) How does environmental change affect population performance and species interactions; e.g., how do species traits impact community stability, key ecosystem processes, and the identities of ecological winners and losers?*
>
> *(3) What are the likely consequences of a changing environment for key ecosystem functions and services?*

AnT-ERA will combine cutting edge bottom-up and top-down approaches *in situ*, in the laboratory (e.g. via 'omics') and *in silico* (e.g. modelling and database mining).

AnT-ERA is fundamentally based on preceding international projects, as well as national programmes that accumulate experience, and will particularly support newly emerging national programmes and early career scientists. AnT-ERA does not only appreciate, but it lives from appropriate contributions from, and cooperation within, the entire scientific community.

Introduction

The overarching objective of AnT-ERA is to define and facilitate the science required to determine the vulnerability and resilience of Antarctic biological systems to change and stress. As a consequence, AnT-ERA will assess the likelihood of crossing biological thresholds, i.e., determine how close we are to the ecological cliff.

The latest report of the Intergovernmental Panel on Climate Change[1] concluded "*Warming of the climate system is unequivocal...*" Current and projected climate changes are unprecedented in magnitude and rate and pose major threats to ecosystem functioning, services, and integrity. Areas along the Antarctic Peninsula are warming faster than anywhere on Earth (except the Arctic) while in other Antarctic areas temperatures are relatively unchanged, in part due to the ozone hole[2,3]. The many species living in warmed and unchanged areas provide an opportunity to compare the resilience of all levels of biological organisation in all major Antarctic environments, terrestrial, freshwater, and marine pelagic and benthic. Such "natural experimental conditions" exist in very few places on Earth. Because polar ecosystems are rapidly changing, it is pressing that we learn what vulnerabilities exist and where the tipping points are so that within the next 10 years we can inform global climate-change policy. Otherwise, a unique opportunity may be lost.

AnT-ERA will focus on current biological ***processes*** that may reflect a cascade of responses to environmental forcing - from molecular and physiological to those at the organismic and ecosystem levels. AnT-ERA will be classified into three overlapping general themes:

(1) Assessment of when, where, and with what impact climate change affects **molecular and physiological performance,** and which performances will allow coping with change or be forced across critical thresholds.

(2) Identification of interactions between drivers and **population processes** (resulting, for example, from species traits) for a predictive understanding of population resilience under future environmental conditions.

(3) Examination of **ecosystem functions** that are potentially sensitive to climate-forced changes, and critical to the maintenance of biogeochemical cycles and **ecosystem services**, including carbon storage, maintenance of biocomplexity, nutrient regeneration, and biomass production.

This focus will complement that of the proposed "State of the Antarctic Ecosystem" (AntEco) programme, which will provide an evolutionary context to AnT-ERA. Most climate-relevant aspects will be studied in cooperation with SCAR's new physical programme "Antarctic Climate Change in the 21st Century" (AntClim21). AnT-ERA will contribute significantly to the realization of SCAR's strategic plan, especially encouraging excellence in research, which addresses topics of regional and global importance as well as emerging frontiers in Antarctic science. AnT-ERA will also provide important scientific knowledge to experts in science and policy and to all levels of society.

Ecological threshold is a situation in which changes in external conditions cause rapid, non-linear change in ecosystems and their health. When an ecosystem flips from one state to another the term **tipping point** can also be used.

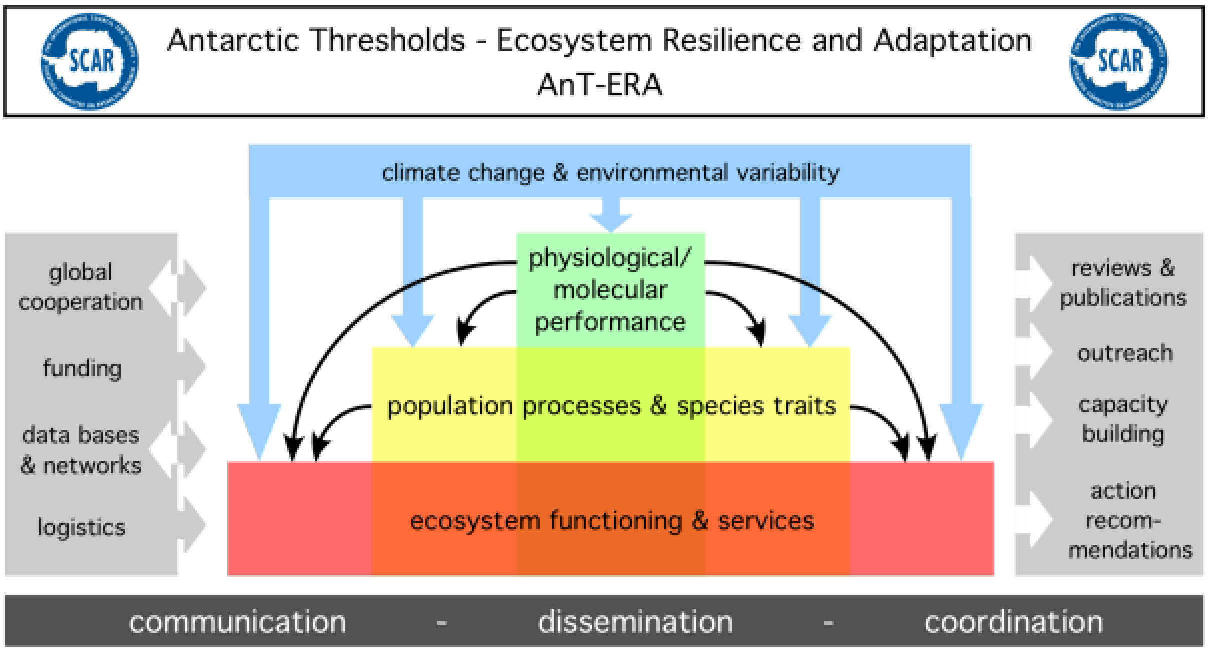
Resilience is the ability of an ecosystem to return to a previous state from which it has been disturbed[4]. It can also be considered as "self-repairing capacity"[5]. **Disturbance** is defined as a discrete event that disrupts ecosystems, communities or populations and changes resources, substrate availability, or the physical environment[6].

Modern biomolecular studies ("omics") analyse *inter alia* at which rates genetic information is translated to metabolically relevant components, e.g. proteins and enzymes. Such turn-over rates allow conclusions on the **adaptation** of organisms to their environment and predictions on the response of **physiological (life) processes** to stress.

Background

Environmental change occurs across broad temporal and spatial scales. Recent climate change is slow compared to daily changes, but is much faster than long-term changes such as glacial cycles. For example, the Antarctic Peninsula is warming very fast: ocean surface temperatures have increased by approximately 2°C, and sea ice extent and persistence have declined markedly since the 1950s[7,8]; in contrast, sea ice extent and persistence is increasing in the Ross Sea sector, but this increase is predicted to slow and then reverse if the ozone hole closes. Currently, organisms across the planet experience a range of environmental change from daily (e.g. tidal) to seasonal and multi-year (e.g. El-Niño, Southern Annular Mode) to medium- and long-term (e.g. Little Ice

Age, mid-Holocene warming, glacial cycles). Terrestrial Antarctic species experience daily and seasonal temperature change that marine species have not experienced in millions of years. Although regions of continental Antarctica are cooling, there has been an increase in warming events, which affect permafrost and the physiologies of their associated terrestrial communities [9,10]. Antarctic species have evolved special adaptations to extreme environments that suggest their responses to climate change may differ from species elsewhere. All Antarctic ecosystems (marine, terrestrial, freshwater, subglacial lakes and cryconites) are vulnerable to environmental, especially climate, changes[3,11-13]. However, the possible responses of organisms to environmental change can vary markedly across process scales, from gene to ecosystem, and spatial scales from nanometre to regional[14,15].



Scheme of AnT-ERA's structure. Scientific themes in the centre in colour, strategic and management issues in grey boxes.

Antarctic organisms include marine species that experience stable temperature regimes[20], whereas some terrestrial species survive regimes with possibly the largest annual temperature amplitudes on Earth[44]. In addition, some Antarctic ecosystems are undergoing very rapid climate change, whereas others appear to be changing very slowly. It is important that we use such environmental differences to assess resilience to changes in temperature, seasonality, and resource supply. As a consequence, AnT-ERA will focus on selected key sites, where detailed studies will elucidate ecosystem response to the full range of environmental variation. These studies will cover three levels of biological organisation, ranging from molecular/organismic through population to ecosystem levels.

Milestones, outcomes, and results

AnT-ERA is designed as a broad scientific programme supporting excellent research and disseminating corresponding novel information to the scientific community, decision makers and the wider public. The essential primary "tools" are publications in journals and papers presented at scientific workshops, symposia and congresses. Deliverables will include:

(i) Primary publications in peer-reviewed journals,

(ii) Reviews and syntheses identifying current state of knowledge and important future research directions,

(iii) Optimized flows of data and information made available through data-bases, web-services and networks as well as advice to decision makers,

(iv) Presentations at influential Antarctic-specific symposia, especially SCAR OSC and Biology Symposia, including AnT-ERA specific sessions,

(v) Presentation of results to the broader scientific community to inform global scale syntheses and future research directions,

(vi) Leading of, and participating in, major workshops, which support both the development of long-term observation networks (weather, ocean, lakes and streams or terrestrial) and an integration of ecological information into interdisciplinary models.

The quality and thus the measurable success of AnT-ERA's scientific output, especially written publications, depend on the usual scientific evaluation of research results, their uniqueness, novelty and their broader disciplinary and cross-disciplinary context and scientific awareness. An important final outcome of AnT-ERA could be a summary of Antarctic ecosystem vulnerabilities to change and potential impacts on ecosystem functioning based on a much improved understanding of ecosystem processes. However, such efforts demand external funds.

The following events mark potential milestones in communication within the AnT-ERA community and will provide a platform for exchange with a broader scientific world:

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Funds

SCAR funds an amount of US $ 20 000 per year for a period of eight years, depending on successful interim evaluations. Decisions about the use of these funds will be made by the SC. Priorities for financial support are:

Year 1-2: 1. travel funds (especially early career), 2. capacity building (especially new emerging Antarctic programmes), 3. outreach.

Year 3-4: 1. capacity building, 2. travel funds.

Year 5-6: 1. support of meetings developing reviews preferably one to two contributions from each level (1-3).

Year 8: 1. support of a final workshop, 2. outreach.

Part of the funds will be spent on requests by mini-grants, following the following structure:

1. Name and affiliation of the applicant,
2. Title and description of the mini-project (max. 12 lines),
3. Relevance to AnT-ERA (max. 8 lines),
4. Exact amount of money requested (max. US $: 1500).

Applications are normally to be submitted the year before its consumption. Reimbursement follows according to SCAR rules.

Steering committee

Chief Officer: JULIAN GUTT is a senior scientist working for the Alfred Wegener Institute (AWI), Germany, and has been involved in polar science since 1984. He has contributed to a variety of international programmes in committees and via his own field research, mainly focussing on benthic systems. Recently he was the chief scientist of an interdisciplinary expedition with R/V Polarstern and PI of a project (to be continued) on the response of the marine ecosystems to the Larsen ice shelf disintegration. He is co-editor and one of the lead-authors of SCAR's ACCE report with its regular updates. In addition to his scientific work at AWI, he is professor at the Oldenburg University (Germany). He has published approx. 72 peer-reviewed scientific articles, 35 with 1st authorship. (www.awi.de/en/research/research_ divisions/biosciences/bentho_pelagic_processes/research_themes/biocomplexity/).

Lead investigators:

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Liaison officer to PS SSG, especially AntClim21: T. Bracegirdle (British Antarctic Survey, BAS); to IASC: R. Gradinger (School of Fisheries and Ocean Science, Fairbanks, Alaska); to ICED: E. Murphy (BAS); to ANTOS: D. Wall. APECS representative: C. Suckling (BAS) & T. McIntyre (AWI).

Theme 1: Physiological limits, biomolecular processes, and thresholds.

Abstract. This theme aims to identify the resistances and tolerances of organisms to environmental change in both their physiological systems (the plasticity of the phenotype) and in their abilities to adapt (genetic change via gene flow and also mutation of new genes), to allow the identification of thresholds for survival and maintenance of function. It will use cutting-edge, next-generation genomic technologies combined with detailed physiological and metabolic analyses to address these issues from microbes to mammals. Examples include: the effects of Antarctic-specific adaptations, such as the loss of haemoglobin in icefish; the widespread permanent expression of heat shock genes and the loss of, or unusual heat-shock response in many species; and the problems low temperature organisms appear to have in making proteins. Efforts will also be made to synthesise studies from many sites and species to allow for the analyses of responses at the assemblage or community level.

Theme 2: Population processes

Abstract: Population performance and species interactions have important influences on community stability, key ecosystem processes, and the response of ecosystems to change. Understanding interactions between environmental drivers and population processes is thus essential for predicting population resilience and persistence. Using a combination of observational (population dynamics in space and time) and experimental (lab, microcosm, field) approaches, and in collaboration with programmes of other disciplines, studies of populations and species traits will better determine how external drivers affect populations. This will contribute to an improved understanding of ecosystem functioning.

Theme 3: Ecosystem functioning and services

Abstract: Antarctic ecosystems provide globally significant ecosystem services, playing a key role in climate regulation. In some Antarctic and sub-Antarctic marine and terrestrial systems, ongoing climate change is already altering ecosystem functions. An ecosystem approach is urgently required to define baselines and thresholds, and to evaluate subsequent responses to climate change. Key methods to accomplish this task will include technology to identify tipping points - from automated sampling to novel laboratory methods to integrative modelling.

Synergies with other SCAR initiatives, other international involvement and partnerships

SCAR has a key role in achieving AnT-ERA's goals. Most important is that AnT-ERA's focus will complement that of the proposed “State of the Antarctic Ecosystem” (AntEco) programme, which addresses the origins and evolution of current large-scale biological patterns. Clearly, any understanding of adaptation and functioning requires understanding of the evolutionary context. Another important link will be developed with the new “Antarctic Climate in the 21st Century“ (AntClim21) programme of SCAR, since environmental changes are a main driver of biological processes. Joint cruises and field programmes will be organised through the “Council of Managers of National Antarctic Programs” (COMNAP). It is essential to disseminate results and facilitate the fastest progress through the SCAR Biology Symposia and Open Science Conferences. Such networking and cross-linkage opportunities are powerful drivers for progress including standardisation of scientific protocols to create added value for all parties involved. SCAR has an essential role in the management of data and assisting with access to international data portals through its Standing Committee on Antarctic Data Management (SC-ADM). Data management will be supported e.g. by SCAR's biological data network ANTABif (formerly SCAR-MarBIN), see ”Data management plan”. Interactions with scientists from non-biological, but ecologically relevant, disciplines will be greatly facilitated by SCAR support through its SSGs and Expert and Action Groups, such as Birds and Marine Mammals, Continuous Plankton Recorder and Ocean

Acidification. AnT-ERA will provide new results for regular updates to the “Antarctic Climate Change and the Environment” (ACCE) report and through ACCE also to IPCC. As a result, AnT-ERA will also directly contribute to SCAR’s “Standing Committee on the Antarctic Treaty System” (SC-ATS), allowing clear scientific information to be provided to the “Committee for Environmental Protection” (CEP) and the Antarctic Treaty system as a whole. Another partner within the SCAR-community is the "SCAR SO-Continuous Pankton Recorder Survey". AnT-ERA will mentor and encourage new scientists and seek to engage the general public.

Research in Antarctica would continue even without SCAR support, but the testing of major paradigms like ecological resiliencies and tipping points would likely take decades longer, and it may then be too late for inclusion in significant policy and conservation efforts.

Besides close links to other SCAR initiatives, AnT-ERA will contribute with long-term data sets to „Southern Ocean Observing System“ (SOOS) and parallel systems in non-marine environments. AnT-ERA will also contribute to strengthen interactions between SCAR and CCAMLR, the “International Arctic Science Committee” (IASC), and the “Integrating Climate and Ecosystem Dynamics” (ICED) programme. Dissemination of results to stakeholders and society depend on Outreach and Education. This is especially so in the inclusion and engagement of polar early career scientists (APECS) through its fellowship programmes. AnT-ERA will also cooperate with the Southern Ocean Research partnership (SORP), focussing on whales, INDEEP - International network for scientific investigation of deep-sea ecosystems, Global Soil Biodiversity Initiative, EU-Project EcoFinders, Society of Nematologists, Antarctic Nearshore and Terrestrial Observing System (ANTOS), and the "Global Alliance of Continuous Plankton Recorder Surveys" (GACS).

Management and reporting

Management tasks directly follow from the AnT-ERA general objectives, which are (1) to focus, stimulate and coordinate research activities dealing with thresholds and resilience of Antarctic life and (2) disseminate corresponding knowledge. Within (1) there are two objectives. The first is to provide a knowledge platform compiling basic information about any initiatives worldwide dealing with our major goals in order to accelerate the exchange of concepts, data, and experience. The second is to make AnT-ERA the centre of a network of specialists and projects, by attracting the attention of the scientific community and offering advice to new projects. This will facilitate an added value for both single initiatives and collaboration within the overall AnT-ERA approach.

All three themes and all three types of ecosystems, marine, terrestrial and freshwater will be represented in the steering committee. Each member will contribute to the decisions, e.g. on workshops, review articles, development of concepts and general or specific recommendations in this fast moving field of science. Each member of the steering committee will represent part of the wider community of scientists according to the AnT-ERA themes.

Dissemination of scientific results will be supported by the administration of AnT-ERA by maximising the flow of attractive scientific information to a wide public. A newsletter, list of projects and key publications will be compiled and published electronically.

Reporting of scientific activities and high-impact publications is part of a continuous outreach component of AnT-ERA. Such output will be regularly presented in SCAR meetings, on its website to the Delegates and in cross-disciplinary fora. These results will provide a basis for discussion and planning within the meetings of the SSG-LS and during workshops of the SCAR Biology Symposium.

Data management plan

Large amounts of complex data, including genetic but also non-biological environmental data and biological/functional process information will be produced. Long-term data management will follow existing national and international conventions and use established infrastructure, e.g., ANTABif, Polar Information Commons, Antarctic Master Director (AMD), Standing Committee on Antarctic Data Management (SC-ADM) and GenBank. Such data systems not only provide a modern way to accommodate and manage data and to make them widely available but also allow them to be successfully exploited, especially if adequate portals are available[67]. AnT-ERA will act as a meta-information node by dynamically pointing to the relevant data. True data management requires external funds.

Capacity building

"Education and Outreach" activities will be a major component of this programme to ensure the issues facing Antarctic ecosystems and our latest research findings are highlighted in the public domain and perception. Talks to schools, universities and the general public, popular articles and additions to school curricula will be major foci. A specially constructed website (including blogs and videos) will provide a variety of general and detailed information but will mainly concentrate on scientific results of broad and general relevance/interest. Working through SCAR, National Programs and international organizations, AnT-ERA scientists will contribute to the development of policy at national and international levels (e.g. global emission control strategies, biosecurity, tourism, strategic and ecosystem based management of Antarctic marine resources).

This programme will foster the development of the next generation of Antarctic scientists by mentoring, networking and ensuring the presence of APECS members in the steering committee of AnT-ERA. It will also build capacity within the Antarctic community by increasing the accessibility of data describing Antarctic ecosystem processes and encouraging collaboration to increase the use of new tools, methods and technologies. Another cooperation partner for capacity building is the "Polar Educators International" (PEI) network, which brings together educators in, for, and about the polar regions.

Add value for SCAR and the scientific community

Identifying resilience and tipping points in Antarctic ecosystems is a complex challenge. Thus research within AnT-ERA needs a common focus, well-organised coordination and strong cross-disciplinary linkages with other initiatives. This can be best provided by a large interdisciplinary and international organisation such as SCAR. Isolated research activities should be given the opportunity to exchange experience for which SCAR meetings provide an excellent platform. Through SCAR SSG-LS, AnT-ERA can attract the attention of and collaborate with new programmes. AnT-ERA will also build on the legacy of completed initiatives such as GLOBEC, JGOFS, EASIZ and EBA and provide the opportunity to jointly use large facilities. By networking with COMNAP and CCAMLR, SCAR can encourage collaboration and synergism. SCAR can also provide networking and outreach opportunities for AnT-ERA. Through its responsibilities with the Antarctic Treaty system, ICSU and other bodies, SCAR can use AnT-ERA's findings to help modify public policy and attitudes toward the Antarctic. Finally, via its mentoring and networking efforts, SCAR will ensure that AnT-ERA is a vibrant programme through excellence and engagement in Antarctic science.

This implementation plan reflects the proposal submitted in 2012 to SCAR, the response to the official reviews and the comments of the SCAR delegates after approval.

Annex (full description of scientific themes and references)

Theme 1: Physiological limits, biomolecular processes, and thresholds.

Abstract. This theme aims to identify the resistances and tolerances of organisms to environmental change in both their physiological systems (the plasticity of the phenotype) and in their abilities to adapt (genetic change via gene flow and also mutation of new genes), to allow the identification of thresholds for survival and maintenance of function. It will use cutting-edge, next-generation genomic technologies combined with detailed physiological and metabolic analyses to address these issues from microbes to mammals. Examples include: the effects of Antarctic-specific adaptations, such as the loss of haemoglobin in icefish; the widespread permanent expression of heat shock genes and the loss of, or unusual heat-shock response in many species; and the problems low temperature organisms appear to have in making proteins. Efforts will also be made to synthesise studies from many sites and

Background. Evolutionary theory predicts that environments that are stable for thousands of years produce species with low genetic variation[16]. As a result, many Antarctic species have a diminished capacity to respond to abrupt environmental change because they have lost alleles, genes and/or metabolic pathways that enable them to tolerate a wide range of environmental stress, e.g., icefish have lost the ability to produce haemoglobin[17]. Some fish and terrestrial invertebrates spend energy to synthesize antifreeze compounds[18], and have a low capacity to cope with warming; increasing numbers of marine species with little tolerance to warming[19,20], but also the opposite is found. Local species extinction is a predictable consequence of the loss of genetic resources required to respond to environmental change[21]. Understanding the physiological limits, the genetic underpinnings of these, and environmental response thresholds of species that play a central role in current ecosystem processes (e.g. krill, nematodes, ice-fish and Antarctic silverfish, macro- and microalgae, lichens) is needed to inform predictive ecological models under scenarios of climate change.

Scientific approach and rational. Within this theme, geneticists, physiologists and systems biologists will investigate which genetic information is involved in mitigating environmental insults and, thus, is directly responsible for a species' resilience and its capacity to respond to change. The extraordinarily successful work on known molecular adaptations to the Antarctic environment, such as development of anti-freeze proteins, loss of red blood pigments and cells, and activity of heat-shock proteins[45], must be continued. The rapid development of new technologies promises to provide further insights into the evolutionary responses and thus thresholds of Antarctic organisms. In addition, next generation molecular tools can be wielded to identify new molecular processes that enable organisms to cope with changing environmental conditions or limit their organismic plasticity. One approach to reach these aims is the direct comparison of populations living within areas of fastest environmental change with populations of the same species in areas of little or no change. Other relevant studies will involve comparing organisms with broad tolerance to environmental extremes (e.g. terrestrial species) with those having restricted capacities to resist change (e.g. marine ectotherms) and comparing closely related species that live in different environmental regimes, e.g. fish from Antarctic and temperate-subantarctic waters.

The above recommendations require comparative studies of genetic characteristics, their expression and physiological flexibility in organisms across wide spatio-temporal scales (including seasonal and climatic oscillations). This calls for coordinated activities between stations, field campaigns, disciplines and international programmes in all major environments. Likewise, coordinated field and station-based campaigns measuring relevant characteristics will be needed for terrestrial, freshwater and marine benthic groups. These analyses are essential for individual-based models (life-history models) and it is important that they be geo-referenced so that they can inform spatial and temporal ecosystem models.

Experimental section and methodologies. Understanding the genetic and physiological processes that constrain how individual organisms mitigate stress provides insight into understanding and predicting changes in the distribution, abundance and functional diversity of ecological communities (informing Themes 2 and 3, below). For example, gene expression and proteomic studies have already revealed the stress proteins and metabolic pathways involved in heat-stress responses and UV-protectants exhibited by some Antarctic terrestrial and marine species[45,62,63]. Although these studies have been important in identifying molecular targets linked to physiological adaptations to environmental stress, emerging technologies for exploring whole transcriptomes and metagenomic responses to stress and comparative approaches will strengthen our ability to identify the ecological amplitude of eukaryotic species and microbial soil communities. Progress in this area will require the use of current and next-generation genomic methods. In addition, we need to combine transcriptomic and proteomic approaches to understand how organisms may translate a changing environment into a molecular response and how this response contributes to organism fitness. Such knowledge forms the baseline for predicting how species and communities might respond to environmental change.

Theme 2: Population processes

Abstract: Population performance and species interactions have important influences on community stability, key ecosystem processes, and the response of ecosystems to change. Understanding interactions between environmental drivers and population processes is thus essential for predicting population resilience and persistence. Using a combination of observational (population dynamics in space and time) and experimental (lab, microcosm, field) approaches, and in collaboration with programmes of other disciplines, studies of populations and species traits will better determine how external drivers affect populations. This will contribute to an improved understanding of ecosystem functioning.

Background. Biotic and abiotic drivers can determine population performance such as range shifts, competitiveness, speciation and extinction. These drivers work through different species traits and processes, for example, growth, feeding, reproduction, migration, and recruitment. Understanding interactions between drivers and population processes is essential for modelling future population resilience to temperature rise and ocean acidification[22,23]. The latter is expected to become an especially serious problem for polar marine ecosystems due to the shift of the saturation horizon to the ocean's surface. Indirect effects mediated through the food web add further levels of complexity. Impacts on population processes in lower trophic levels can be amplified through food webs, e.g. from krill, salps and copepods up to apex predators[24-27]. Top-down effects are also likely; for example, cooling in the Dry Valleys has led to a rapid decline of the key carbon cycling invertebrate, a soil nematode. The unprecedented changes in flora and fauna may include both the entry or range expansion of destructive invasive species, e.g., king crabs[28-31] on the Antarctic shelf and the loss of endemic species. Either event will impact Antarctic ecosystems[32,33].

Scientific approach and rational. An intended outcome of this theme is to predict better how external drivers affect populations, such as their growth or decline, expansion or contraction. These studies will develop improved population scenarios as an input for the ecosystem functioning approach (Theme 3). To achieve this, observational (population dynamics in space and time) and experimental (lab, microcosm, field) approaches are required along with increased collaboration within SCAR (e.g., between disciplines) and beyond, e.g., between SCAR and the "Commission for the Conservations of Antarctic Marine Living Resources" (CCAMLR). For example, it is not yet clear to what extent population changes in penguins are caused by changes in krill biomass associated with ocean warming[26], increased snow accumulation that prevents successful reproduction[46], or recovery of trophic competitors[47]. These scenarios may produce different population projections in relation to future changes in climate. Similarly, how are vegetation dynamics differentially influenced by changes of snow distribution, soil warming, and surface disturbance caused by permafrost degradation? A large, joint effort is needed to develop more robust predictions for these important questions.

Long-term observation of populations is essential for this understanding but this has been established only for a limited number of species and locations, e.g., some bird and seal colonies[27,37,48], terrestrial invertebrates[49], stream diatoms[50], and coastal benthic invertebrates[51]. While population changes may correlate with environmental variables[52], these correlations do not necessarily indicate causal relationships. Behavioural changes can buffer environmental impacts on population processes[53], and may be used as sensitive indicators of environment fluctuations[54].

Microevolutionary adaptation to the polar environment may add spatial variability to population response to environmental change. Even within Antarctic regions, populations of the same species can respond differently to change, due to isolation of gene pools[15,55].

As we are discovering, not all regions of Antarctica are responding in the same way to climate forcing. Concern exists that warming will result in the invasion of such durophagous predators as King crabs on the continental shelf. Since shelf communities have not experienced crab predation for millions of years, these voracious invaders could inflict radical damage[31,56]. Some resident species may also experience "explosive" growth, such as deep-sea holothurians[57] under favourable food conditions and *Homaxinella* sponges, which thrive on naturally disturbed seabeds[58]. Interspecies relationships may also be altered by a changed environment[51]. Complete population performance of macro- and microalgae depends significantly on the light regime. As a consequence, studies of their response to increased sedimentation rates and turbidity are of high relevance to understand ecosystem changes[59]. Knowledge of the airborne invasion by micoorganisms into Antarctica will allow conclusions on corresponding shifts in functional diversity of terrestrial habitats[60].

Experimental section and methodologies. Observational and experimental studies are required to predict the response of populations to environmental change. (i) Observation of key population processes (e.g. feeding, reproduction, dispersal) across natural environmental gradients in space and time will illuminate population performance under current and past conditions[64]. Interspecific comparisons will show which specific traits are important in determining resilience and which species are more or less sensitive to change[52]. (ii) Manipulation and comparative experiments at different scales (lab, mesocosm, field) will be useful tools to determine population resilience capacity as well as the significance of inter- and intraspecific interactions. Both observations and experiments will contribute to the development of scenarios of future Antarctic life. There are several examples of how data on populations of a single species can be used to determine their response to change. One example involves use of the diving behaviour of elephant seals as a proxy for their local feeding conditions[65]. Through analysis of numerous existing and future diving profiles, a relatively complete image of temporal changes and regional differences can be provided. As a consequence of ecological limits, the resilience and thresholds of populations can be determined for this species, and maybe in the future for other endotherms. Another example, in a 'natural experiment', is the study of opposite population trajectories of Adelie penguins in the Ross Sea region, where sea ice and coastal polynyas have been expanding, versus the Antarctic Peninsula, where sea ice is in retreat.

Theme 3: Ecosystem functioning and services

Abstract: Antarctic ecosystems provide globally significant ecosystem services, playing a key role in climate regulation. In some Antarctic and sub-Antarctic marine and terrestrial systems, ongoing climate change is already altering ecosystem functions. An ecosystem approach is urgently required to define baselines and thresholds, and to evaluate subsequent responses to climate change. Key methods to accomplish this task will include technology to identify tipping points - from automated sampling to novel laboratory methods to integrative modelling.

Background. Antarctic ecosystems play a key role in climate regulation and provide globally significant ecosystem services. Environmental changes may alter the production and transfer of energy and materials through marine and terrestrial food webs, as well as the sequestration of carbon in the deep ocean. For example, ecosystem processes in most parts of the Southern Ocean are closely linked to sea-ice dynamics, and sea-ice cover is predicted to decline by 25% in the next century[34]. While primary production is typically high at the sea-ice edge and in polynyas[35], the responses of primary production to changes in sea-ice extent and duration are poorly understood[26]. Alterations in phytoplankton community structure are expected to have cascading effects on secondary production and export of organic carbon to the ocean's interior. In addition, recent observations of krill aggregations and Humpback whale foraging in West Antarctic Peninsula fjords[36] may be related to sea-ice loss on the open shelf. In the large off-shore pelagic system, a recovery from whaling of Humpback whale stocks of ~10% per year and an explosion in Fur seal populations contrasts with an enormous decrease in food resources, the krill stock, especially in the Atlantic sector of the Southern Ocean[24,37]. As another example of potentially climate sensitive ecosystem services, the sea-bed system receives phytodetritus from the sea-ice zone, and acts as a carbon sink, foodbank, and regenerator of nutrients, supporting rich assemblages of suspension and deposit feeders[38,39]. These in turn supply the pelagic system with food resources in the form of nutrients and larvae. Climate and soil warming may affect key terrestrial and freshwater biodiversity and ecosystem processes (e.g. primary production, soil respiration, vegetation composition) with feedbacks on the carbon-cycle as well as on species competitiveness[40]. For example, in terrestrial Dry Valley ecosystems, nematodes play a disproportionate role in soil carbon cycling: the population declines due to climate change result in a decrease in this ecosystem process[25]. Finally, some species or taxonomic groups, e.g., endemic microorganisms can serve as global-warming sentinels[41]. Biological complexity in all Antarctic systems may enhance resilience in ecosystem functions and services[42]. Gradual, climate-related changes may initially have little apparent effect on the state of Antarctic ecosystems but alter the "stability domain," increasing the likelihood of shifts to alternate ecosystem states[43].

Scientific approach and rational. In some Antarctic and Sub-Antarctic regions, ongoing rapid climate change is already altering ecosystem functions. Consequently, rapid scientific, multidisciplinary actions are urgently demanded to define baselines, including affected and unaffected areas to track ecosystem responses to such changes. There is also high demand from policy makers for knowledge on climate-change impacts to sustainably manage Antarctic ecosystems exposed to anthropogenic stress (e.g., by overfishing, tourism, pollution, and glacial retreat). Creative hypotheses concerning how key ecosystem functions will respond to climate forcing, such as high primary production (e.g. by microalgae in the ocean and moss pillars in lakes), secondary production of foundation species (e.g., krill), organic matter mineralization, nutrient regeneration, calcification, and carbon export to midwater and bottom sediments should be tested and corresponding ecosystem research activities coordinated. Another important suite of hypotheses deals with the importance of latitudinal shifts versus entire reorganization of Antarctic ecosystem functions and services in case of long-term environmental change. The results can contribute considerably to clarification and quantification of the role of the Antarctic, including the Southern Ocean, as a biological carbon sink at present and in the future.

Theme 3 will be pursued by (A) identification of priority study areas, such as the Antarctic Peninsula, where climate is warming rapidly, warm deep water is moving up onto the shelf, ice shelves and glaciers are retreating and permafrost is thawing. Other targeted areas will include ecosystem boundaries such as polar fronts, where major changes are expected in the future. In addition, reference areas with relatively stable end-member conditions (at least predicted until mid-century), e.g., the Eastern Weddell Sea, McMurdo Dry Valleys, and the shelf of East Antarctica will be studied to generate comparative information and to detect Antarctic-wide changes. (B) Synchronous analyses of linkages across subsystems will also be conducted, e.g., of phytoplankton blooms in the water column and their fallout and fate at the seafloor, and the effects of glacial melt and ice-shelf collapse on marine and terrestrial ecosystems. (C) Finally, findings from organismal physiology (theme 1) and population processes (theme 2) will be essential for development of these the ecosystem-level syntheses.

AnT-ERA's ecosystem approach will include identification of key functional and indicator species (e.g., seabirds, mammals, invertebrates, endemic microorganisms, plants, mosses, and lichens) associated with ecosystem processes. To make the observations representative of larger parts of the Antarctic ecosystems, detailed investigations over long periods at fixed sites and covering broad spatial scales (e.g. Continuous Plankton Recorder programme[61]) must be continued. Studying areas of contrasting environmental change will be critical, e.g. expanding sea ice in the Ross Sea region vs retreating sea ice in the Antarctic Peninsula region. These new insights will be fed into state-of-the-art models of ecosystem function to more accurately predict ecosystem resilience and tipping points over a range of future environmental scenarios.

Experimental section and methodologies. In order to assess the consequences of environmental change, we must first improve our knowledge of the current functioning of the various ecological systems. The relevant ecological processes that determine thresholds and resilience of Antarctic ecosystems will be evaluated through interdisciplinary surveys and studies. In terms of field methods, we will capitalize on the rapid development of a broad variety of *in situ* tools, which measure biological processes automatically or with a higher spatial resolution than in the past. Results from field measurements will be amplified by *in situ* experiments. An efficient approach in this context is to use extreme natural events as large field experiments. Examples are unusual early melting of sea-ice affecting krill recruitment, massive sinking of phytoplankton to the sea-bed after storms, disintegration of ice shelves changing the marine ecosystem structure, disturbance and succession of benthos following iceberg scouring, warming across terrestrial landscapes altering biogeochemistry and respiration of soil habitats and primary production and increased snowfall affecting survival of penguin chicks and eggs. The ecosystem approach will also benefit from laboratory experiments conducted under Themes 1 & 2. The use of a variety of cutting-edge technologies, from transcriptomics to remote sensing, will provide the basis for integrative ecosystem modelling. Approaches which correlate current and future environmental conditions with biological features will be refined by including extreme events, using finer spatial scales and implementing known physiological performance/limits. This diversity of approaches will enable the development of robust and dynamic models, which are spatially explicit and include physical forcing and population interactions and processes (e.g. dispersal, growth, mortality and reproduction). These models will be able to simulate a broad range of environmental and biological characteristics and thus allow determination of specific combinations of parameters at which the ecosystems reach thresholds or tipping points. The incorporation of findings from molecular ecology (Theme 1) is a challenge for the future and demands new modelling concepts to be developed[66].

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