Polarforschung 82 (2), 147–150, 2012 (erschienen 2013)

Antarctic Thresholds – Ecosystem Resilience and Adaptation: a new SCAR-Biology Programme

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Abstract: Stresses on Antarctic ecosystems result from environmental change, including extreme events, and from (other) human impacts. Consequently, Antarctic habitats 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 both 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 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 is classified into three overlapping themes, which represent three levels of biological organisation: (1) molecular and physiological performance, (2) population processes and species traits, (3) ecosystem function and services.

Zusammenfassung: Umweltveränderungen einschließlich extremer Ereignisse und (anderer) von Menschen mitverursachter Einwirkungen können Stress für Antarktische Ökosysteme auslösen. So verändern sich manche Antarktischen Lebensräume sehr schnell, während andere recht stabil bleiben. Ein Domino-Effekt weitreichender Folgen ist zu erwarten, die sich vom Niveau des Erbgutes über das ganzer Organismen bis zu dem von Ökosystemen ausdehnen können.

Auf Grund der Unterschiede in biologischer Vielschichtigkeit und der Entwicklungsgeschichte zwischen beiden Polarregionen und dem Rest des Planeten kann man davon ausgehen, dass Ökosystemfunktionen in den Polarregionen unter Stress anders reagieren als die niederer Breiten. Erkenntnisse über polare Ökosystem-Prozesse können daher zu einem weitreichenden Erkenntnisgewinn über grundsätzliche Stabilität und möglicher Änderungen in der globalen Biosphäre beitragen.

Das Hauptziel von AnT-ERA ist es, die Erforschung von Veränderungen in biologischen Prozessen in antarktischen und subantarktischen marinen, limnischen und terrestrischen Ökosystemen zu unterstützen. Dabei sollen Toleranzgrenzen und Schwellenwerte, die Widerstandsfähigkeit und Erholungsfähigkeit von verschiedenen biologischen Systemen im Fall von Umweltveränderungen ermittelt werden.

AnT-ERA gliedert sich in die drei sich überlappende Themen, die verschiedene Niveaus biologischer Organisation repräsentieren: (1) molekulare und physiologische Leistungen, (2) Populationsdynamik und artspezifische Eigenschaften und (3) Ökosystemfunktionen sowie -dienstleistungen.

GENERAL BACKGROUND

The Scientific Committee on Antarctic Research (SCAR) *"… is charged with initiating, developing and coordinating high quality international scientific research in the Antarctic region…"* (www.scar.org). The main focus of SCAR's international scientific coordination is on the Scientific Research Programmes. Since the life period of the previous biology programme "Evolution and Biodiversity in the Antarctic" (EBA) came to an end in 2013, a group of experts met in Castiglionchello (Italy), Delmenhorst (Germany), and Modena (Italy) to discuss, design and harmonize new programs that would continue after 2013. The Antarctic biological community which includes ocean-, ice-, terrestrial- and freshwater (lakes, streams) biologists decided that, based on the success of EBA (DI PRISCO et al. 2012) acting as an overarching umbrella for many biologists, to (1) continue with this broad approach, but (2) better focus the scope of biological research activities by splitting these into two programmes and (3) integrate findings from single research projects. As a result the new "Antarctic Thresholds – Ecosystem Resilience and Adaptation" (AnT-ERA) programme deals with ecological processes at different organization levels, from the cell to the ecosystem (Fig. 1), while the second programme, "State of the Antarctic Ecosystem" (AntEco) focuses on large-scale patterns of biodiversity as a result of long-term evolutionary processes. In this paper we introduce AnT-ERA's scientific background, its general concept and potential links to main cooperation partners (Fig. 2).

SCIENTIFIC BACKGROUND, GOALS, AND KEY QUESTIONS

Stresses on Antarctic ecosystems result from natural seasonal and interannual variability, long-term climate change, extreme events (TURNER et al. 2009, CONVEY et al. 2010, TURNER et al. 2013), and from human impacts (CHOWN et al. 2012). The summary of the latest report of the Intergovernmental Panel on Climate Change (2013) concluded *"Warming of the climate system is unequivocal …"*. Current and projected

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climate changes are unprecedented in magnitude and rate and pose major threats to polar ecosystem functioning, services, and integrity. Areas on both sides of 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 (SHINDELL & SCHMIDT 2004, TURNER et al. 2009). The many species living in both warmed and unchanged areas provide an opportunity to compare the resilience of all levels of biological organisation. Such "natural experimental conditions" exist in very few places on Earth. Because some polar habitats are rapidly changing, it is pressing that we learn what vulnerabilities exist and where the tipping points are so that we can effectively contribute to the wider ecological debate about the nature of stability and potential changes across the biosphere and global climate-change policy. Otherwise, a unique opportunity may be lost.

In this frame, the main goal of AnT-ERA is to gather and facilitate the science required to examine changes in biological processes, from the molecular and population to the ecosystem level (Fig. 1), 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? 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, and key ecosystem processes? Who are the winners and who are the losers?
(3) What are the likely consequences of a changing environment for key ecosystem functions and services, e.g. maintenance of biodiversity and biological CO_2 uptake by the biosphere? How close to the "cliff" are we?

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.

DEFINITIONS OF KEY WORDS

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 (FOLKE et al. 2004). It can also be considered as "self-repairing capacity" (WALKER et al. 2004). Disturbance is defined as a discrete event that disrupts ecosystems, communities or populations and changes resources, substrate availability, or the physical environment (PICKETT & WHITE 1985).
Modern biomolecular studies ("omics") analyse *inter alia* at which rates genetic information is translated to metabolically relevant components, e.g. proteins, enzymes, and hormones.

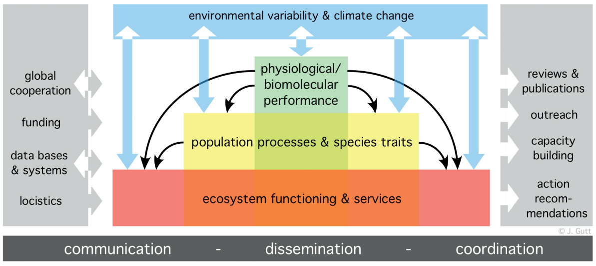

Fig. 1: AnT-ERA's structure. Scientific themes in the centre in colour, strategic and management issues shown in the grey boxes.

Abb. 1: AnT-ERAs Struktur mit den wissenschaftlichen Themen in Zentrum in Farbe, strategische und Mangementaufgaben sind in den grauen Feldern aufgelistet.

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.

THE SCIENTIFIC PROGRAMME

Environmental change occurs across broad temporal and spatial scales. Currently, organisms across the planet experience a range of environmental changes 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) time-scales. Although recent climate change is unprecedented, the rate of change is slow compared to daily and seasonal changes that some Antarctic organisms experience, 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 (MEREDITH & KING 2005, STAMMERJOHN et al. 2008). In contrast, sea-ice extent and persistence is increasing in the Ross Sea sector. This increase is predicted to slow and then reverse if the currently depleted stratospheric ozone (the so-called "ozone hole") recovers over the 21^{th} century. Terrestrial Antarctic species experience daily and seasonal temperature changes that marine species have not experienced in millions of years. Although regions of Antarctica are cooling, there has been an increase in warming events, which affect permafrost and the physiologies of their associated terrestrial communities (WALL 2007, GUGLIELMIN & CANNONE 2012). 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 in glacier surfaces) are vulnerable to environmental-, and especially climate changes (SHINDELL & SCHMIDT 2009, BRANDT & GUTT 2011, CLARKE et al. 2007, VINCENT & LAYBOURN-PARRY 2008). However, the possible responses of organisms to environmental change can vary markedly across process scales, from gene and population to ecosystem, and spatial scales from nanometre to regional (CONVEY 2011, PECK 2011, GUTT et al. 2012). As a consequence, AnT-ERA is classified into three themes with a cascading flow of information from one level to the next to support the integrative approach (Fig. 1).

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

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 include 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, as well as 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

Population performance and species interactions have important influences on community stability, key ecosystem processes, and the responses of ecosystems to change. Therefore, understanding interactions between environmental drivers and population processes is essential for predicting population resilience and persistence. Using a combination of observational (population dynamics in space and time) and experimental (laboratory, 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

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, e.g., primary production and food supply to higher trophic levels. 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.

To support these scientific themes, several additional aspects of high relevance are encouraged (Fig. 1):

(i) Primary publications in peer-reviewed journals.
(ii) Reviews and syntheses identifying the current state of knowledge and important future research directions.
(iii) Optimization 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 Open Science Conferences and Biology Symposia, including AnT-ERA specific sessions.
(v) Presentations 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, streams and/or terrestrial) and an integration of ecological information into interdisciplinary models.
(vii) Providing mini-grants, especially for early career scientists and newly emerging national programs.

The major task of AnT-ERA is to use these mechanisms for an integration of results from the three themes to contribute to a better general understanding of most relevant biological processes in the Antarctic. AnT-ERA's lifetime is two four-year periods assuming a positive mid-term external evaluation.

AnT-ERA does not only appreciate, but it lives from appropriate input from, and cooperation within, the entire scientific community. Thus, any contribution is most welcome!

PROGRAMME CO-OPERATION

AnT-ERA is strongly linked to other Antarctic programme initiatives (Fig. 2), primarily AntEco. 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. Close relationships already exist with the SCAR advisory group "Antarctic Climate Change and the Environment" (ACCE). Long-term observations, which are needed to detect climate-induced *in situ* changes, will be considered in cooperation with Southern Ocean Observing System (SOOS), a new interdisciplinary programme run

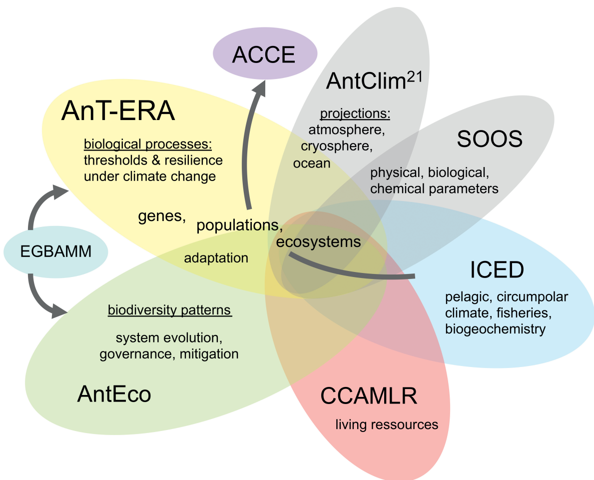

Fig. 2: Selection of some of the most important potential cooperation partners of AnT-ERA.

Abb. 2: Eine Auswahl der wichtigsten potentiellen Kooperationspartner von AnT-ERA.

by SCAR and the Scientific Committee on Ocean Research (SCOR). A close cooperation is also planned with the project "Integrating Climate and Ecosystem Dynamics in the Southern Ocean" (ICED). Further partners to which direct relationships exist are the International Arctic Science Committee (IASC), the Association of Polar Early Career Scientists (APECS), Polar Educators International (PEI), the SCAR's Expert Groups on Birds and Marine Mammals (EG-BAMM) and on Antarctic Biodiversity Information (EG-ABI), the Antarctic Biodiversity Information Facility (ANTABIF), the Antarctic Nearshore and Terrestrial Observing System (ANTOS), and the Southern Ocean - Continuous Plankton Recorder Survey (SO-CPR). Further potential partners are the Southern Ocean Research Partnership (SORP) focussing on whales, the International network for Scientific investigations of deep-sea ecosystem (INDEEP), the Global Soil Biodiversity Initiative, the EU-project EcoFinders, the Society of Nematologists, the Commission for Conservation of Antarctic Marine Living Resources (CCAMLR), and the International Whaling Commission (IWC).

ACKNOWLEDGEMENTS

The authors (full list and addresses see below) represent the composition of AnT-ERA's Scientific Steering Committee (as of July 2013) of which JG is the chair, CoSu and TM are representatives of APECS, EM liaison officer to ICED, TB to AntClim21, and DC to AntEco. GdP is *ex officio* the expert with overseeing capacity to ensure continuity with the previous SCAR-programme EBA.

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