WP 6: Ocean warming and acidification: organisms and their changing role in marine ecosystems. (Hans-Otto Pörtner, Tom Brey)

We investigate how climate change affects marine polar organisms directly and, thereby, their interactions and ecosystem functioning.

Objectives and Challenges

Organisms responding to warming and acidification are found in all groups and phyla, among autotrophs, heterotrophs, calcifiers and non-calcifiers. Animals in particular specialize on state and variability of their environment and hence are sensitive to conditions outside their normal range. Recent interdisciplinary research at molecular, physiological and ecological levels of biological organization (see details in ANNEX) has identified key mechanisms of animal response to climate change. These mechanisms require further investigation in order to elaborate the capacity and limits of acclimation and adaptation processes and the associated reasons for projected shifts in ecosystem species composition during climate extremes.

The climate regime is one major driver of functional specialization from gene to organism, thus shaping organism fitness, which is reflected e.g. in growth performance, fecundity and the capacity to perform relevant behaviours. Solely integrated analyses from molecule to ecosystem allow to identify cause-and-effect, functional constraints and trade-offs associated with adaptation and their consequences for biogeography and ecosystem functioning. The species inventory of a given ecosystem results from the interplay of environmental conditions, evolutionary adaptation and the immigration of pre-adapted species. Accelerated environmental change topples the delicate balance between selective and adaptive forces, when species elimination and replacement are out of equilibrium, causing change or loss of ecosystem functioning. Understanding ecosystem change, thus, requires understanding of organism response. Differential responses of organisms affect their interactions and might thereby explain changes at even higher levels as in marine food webs.

The challenges are to:

- elaborate the climate dependent evolution and functioning of selected key polar marine organisms and their ecosystems
- identify critical stages in the life cycle of selected organisms (e.g. eggs, larvae, adults) based on performance measures as indicators of sensitivity to ocean warming and acidification
- analyse physiological mechanisms defining performance levels and sensitivity and estimate acclimation capacity (gene expression capacity) for those mechanisms as the background of functional plasticity
- quantify impact and tolerance thresholds (tipping points) for various species and the consequences for their interactions
- compare responses and mechanisms in different populations of a species (e.g. in a climate gradient) reflecting potential for evolutionary adaptation (genetic differences)

Implementation

This work package focuses on selected species (e.g. among plankton, benthic invertebrates, fish and mammals) in Antarctic and Arctic oceans in general and of specific ecosystem compartments in particular, such as the head-down benthic community recently discovered at the underside of the Antarctic Riiser Larsen Ice Shelf, or the deep reefs at high latitudes, which are among the most vulnerable to Global Change. We use a comparative approach across latitudes to develop a deeper mechanistic cause-and-effect understanding of organism and ecosystem responses to variable climates and to ocean acidification. Organism effects to be identified include those causing shifts in material fluxes, food quality and food web structure. Organism effects may also lead to changing species abundance, biodiversity and, last not least, modified availability of marine living resources.

We integrate field and experimental studies to elucidate the impact of climate factors like temperature and CO_2, and the responsive mechanisms that set the performance of individual organisms, the genetic structuring of species and species complexes as well as species-to-species interactions. The respective analyses will range from effects of present change to those of climate variability in the past (TOPIC 3), the latter via studies of proxies (stable isotopes, trace metals) in lifetime growing hard structures or via phylogenetic trees. Remote sensing through marine mammals will identify hot spots of biological activity and reveal their own biogeography and acoustic behaviour. We will investigate across latitudes (in cooperation with WP 1 and WP 3), how selected species cope with changing environments and how this influences the flux of energy and organic matter, in the euphotic layer where zooplankton feed and reproduce, in deep water layers where dominant species over-winter, and in the benthos of open waters and under the ice shelf of polar areas.

An integrated approach across levels of biological organization identifies the molecular underpinning of climate dependent organismal performance associated with key processes like oxygen supply and food consumption in animals, energy budgeting and turnover, ion and acid-base regulation and stress resistance. Genomic and thus bioinformatics approaches in combination with systems biology identify differential gene expression patterns, gene clusters and regulatory networks as well as new candidate genes for further functional characterisation. Through the respective cellular functions protein structure and functional capacity as well as molecular networks and regulatory or signalling pathways define whole organism performance, tolerance and capacity to acclimate or adapt to change. Finally, implications of organism level processes for ecosystem structure and functioning are elaborated as potentially crucial for an understanding of ecosystem resistance.

We explore how specific performance, adaptability and sensitivity of our model species define their competitiveness and interaction patterns, and how changes at this level modify aggregate ecosystem-level processes that may finally add up to significant ecosystem transitions. The synoptic identification of physiological and ecological mechanisms operative across levels of biological organisation will provide a solid basis for a cause and effect understanding as well as for future scenarios and models of organism and ecosystem functioning and response to change.

Through studies of succession, population growth and competition, ecosystem transitions will be identified depending on the specific performance, adaptability and sensitivity of member species, their interactions and aggregate ecosystem-level processes. In specific examples, the identification of physiological and ecological mechanisms operative across levels of biological organisation will provide a solid basis for a cause and effect understanding as well as for future scenarios and models of organism and ecosystem functioning and response to change.

Milestones

- Likely scenarios for future climate development in different Polar Regions (Peninsula, Weddell Sea, Arctic waters) to generate realistic input data for abiotic experimental settings (year 1 in cooperation with other WP´s).
- Standardised methodologies for long term experiments (e.g. CO_2) and associated analyses (molecular, cellular, whole organism to field studies) (year 1).
- Key mechanisms that define sensitivities in relevant species, identification of corresponding threshold levels and links between organism response and ecosystem change (year 2-3).
- Modules for conceptual models of mechanisms in acclimation and adaptation and their consequences for population genetic structure (year 4).
- Contribution to mechanistic models of combined thermal and ocean acidification effects at the ecosystem level, naming uncertainties and probabilities and perspectives on new ecosystem states (year 5).

Deliverables

- Relate environmental change (e.g. ice conditions, ocean physico-chemistry) to principal ecological determinants, i.e. organism performance including calcification, population genetic structure as well as to ecosystem matter cycling, resistance and transition.
- Identify the physiological levers linking species biogeography, life history and fitness, energy budgets and metabolism, gene functions and regulatory networks depending on environmental and climate restrains.
- Define organism bio-recorders – high resolution archives of environmental change, recorders of evolutionary pathways and propensities in polar and temperate climates – that contribute to characterizing the relations between climate, climate variability, and genetic structures of key species, changing species interactions and biodiversity patterns across latitudes.
- Contribute to conceptual and quantitative models explaining climate forcing of ecosystems and linking mechanisms and processes at genetic, physiological and ecosystem levels.
- Specify organism mediated ecosystem change: past, present and future; contributions to vertically integrated, mechanism based modelling (environment – physiology – population dynamics – ecosystem functioning in polar and temperate latitudes).

2.1.3 Expected results, milestones

- The impact of shelf ice and ice sheet dynamics on the earth climate including heat and the water budget will be quantified and linked to global earth system models in TOPIC 4. A more detailed mapping of ice sheets is the basis for identification of future ice-core drilling locations for deciphering the past climate in TOPIC 3. Ecological key factors that maintain, reduce or increase the biodiversity under ice shelves and after its disintegration will be identified.
- A spatially and seasonally resolved aerosol data set for the Arctic will be delivered for implementation into climate models (TOPIC 4). Assessments for the Arctic of warming / cooling rates due to observed high aerosol load episodes, of dynamical influences on water vapour and ozone profiles in troposphere and stratosphere, of contributing factors

to the observed ozone variability including new chemical schemes and reaction constants will be provided.

- Interaction processes between ocean, sea ice, atmosphere and ecology will be identified and quantified by means of new data obtained during several campaigns in the Arctic and the Antarctic with ship and aircraft supplemented by data obtained from remote sensing and will used in modelling studies. The results will improve the understanding of the mechanisms controlling the sea ice variability and its impact on ecological processes in both Polar Regions.
- Description and improved understanding of the function of key physical, chemical and biological processes that determine short-term, inter-annual and decadal variability in properties (also as contribution for modelling studies in TOPIC 4) such as circulation, occurrence of proxy organisms and biochemical fluxes (with established links to TOPIC 3). Assessment of the impacts of large scale iron input in the Antarctic on global climate and of the feasibility and risks of employing iron-fertilization as a geo-engineering option to mitigate the greenhouse gas problem.
- The current state and the rate of change of permafrost in key areas in the Arctic will be determined. Parameterization of Ocean Colour satellite data will allow using ground truth spot measurements for spatial extrapolation. In addition satellite-borne remote sensing information will be used to close the gaps between the understanding of small-scale pattern and the large scale processes for the detection and interpretation of changing surface patterns with links to TOPIC´s 2 and 4.
- The influence of environmental change on molecular, physiological and ecological mechanisms and processes will be determined in distinct organisms and ecosystems to explain past, present and possible future ecosystem change in polar and temperate regions (in cooperation with TOPIC 2).

2.1.4 Cooperations

The work in TOPIC 1 “The changing Arctic and Antarctic” benefits from 68 international, bi-lateral co-operations additional 3 international multi-lateral co-operations and 30 national, bi-lateral co-operations that were established in the past and have been extensively used during the previous MARCOPOLI programme. In the following we exemplarily mention some of the foremost important partners for our research topic.

National Partners:

Fachbereiche 1, 2, 5 at the University	Bremen
University	Göttingen
IFM-GEOMAR, Institute for Polar Ecology, and the University	Kiel
Laboratory of Meteorological Physics at the University	Mainz
Max-Planck-Institute, Center Marine Sciences and the University	Hamburg
Geo-Forschungs-Zentrum, Potsdam Institut für Klimafolgenforschung and the University	Potsdam

International Partners:

Arctic and Antarctic Research Institute	St. Petersburg	Russia
Australian Antarctic Division-CRC	Hobart	Australia
British Antarctic Survey	Cambridge	UK
IFREMER	Brest	France
Lamont-Doherty Earth Observatory of Columbia University	New York	USA
National Institute for Polar Research	Tokyo	Japan
National Institute of Oceanography	Goa	India
National Oceanographic Centre	Southampton	UK
North Polar Institute and Bjerknes Centre	Tromsø, Bergen	Norway
Permafrost Institute	Yakutsk	Russia
Russian Academy of Sciences	St. Petersburg and Moscow	Russia
University of Alaska	Fairbanks	USA