2.2 Topic 2: Coastal change

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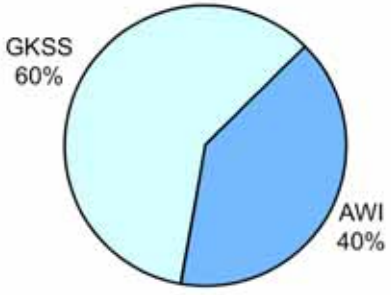

Mission
To reveal the consequences of global and regional change on the functioning and diversity of coastal systems in temperate and polar regions

2.2.1 Objectives and challenges

Coastal ecosystems, encompassing living and non-living components are increasingly subject to change as a consequence of manifold human activities. These range from the input of nutrients and contaminants, introduction/reduction of species, increased temperatures and involve different climatologies such as altered wind fields as well as altered hydrography. Moreover, increased use of the coastal area through growing populations, increased economic activities including fisheries, all lead to pressures on coastal systems. This global and regional change presents important current and long-term challenges for the North European coastal environment, as well as for comparable coasts worldwide. The amalgamation of all of these factors presents us with two grand challenges for the coastal programme in PACES for the next period:

- *understanding the effects of global and regional change on coastal temperate and polar coastal (eco)systems, and,*
- *responding to these diverse changing pressures*

Coastal seas provide valuable and irreplaceable services such as food and recreational space to a significant part of Earth's population. The function of these coastal and shelf ecosystems is based primarily on the diversity and trophic interactions between organisms which are governed and modulated by physical and chemical boundary conditions (weather, currents, water chemistry, and temperature), and – more than in terrestrial ecosystems - characterized by a high variability acting at nearly all temporal and spatial scales. In addition, new/different species and habitats are promoted by climate shifts, as well as by actual anthropogenic species introductions.

Special emphasis is placed on geophysical risks, related to regional climate change, and on the sensitivity of coastal and shelf systems to external drivers. These include the import/export of matter via runoff from catchments and atmosphere in the uninhabited Arctic through to densely populated areas of Western Europe. For the analysis of these dynamics and sensitivities, reconstructions of the climate of the past decades and scenarios of possible future regional climate conditions are generated and assessed with respect to a variety of natural and anthropogenic signals. We will especially focus on marine weather, such as wind, currents, waves, and surges.

Addressing the grand challenges identified above involves understanding of relevant dynamic processes and cause and effect relationships, an ability to monitor and interpret the environmental state and ongoing change, the documentation and analysis of long-term change, and the development of scenarios on the future consequences of such changes. The reliability of regional and international policy decisions will be enhanced by the emerging synthesis of and focus on the knowledge repertoire on coastal processes. Dissemination of scientific results is a difficult and time consuming process, since they are usually published in very small portions. Especially in the rapidly changing coastal environments this is very unfortunate. To improve communication and dissemination it was decided to move the LOICZ (Land Ocean Interaction in the Coastal Zone) International Project Office to GKSS, and to integrate it tightly into the PACES structure. The office makes the comparison with findings from elsewhere much easier and greatly increases the disseminative capacity of our knowledge to a global community of scientists working in other geographical areas with different levels of human pressures.

The programme topic ‘Coastal change’ contributes to the knowledge required for understanding the coastal zone in a global context and for the implementation of appropriate management mitigation/adaptation strategies facing the consequences of global change and local human pressure on the coastal environment.

To realize the challenges of this topic we have set two main objectives:
- *to substantially enlarge our understanding of coastal systems in temperate and arctic regions, by increased observational and experimental power in combination with novel data assimilation techniques*
- *to set up models enabling the construction of scenarios and management strategies*

In this Coastal Topic, emphasis is placed upon the North Sea region, which is an excellent large-scale study site because of the advanced state of data availability including long time-series. Empirical evidence for change provides the basis for studying the sensitivity of the coastal system, both in terms of geophysical and ecological phenomena. We study the sensitivity of the coastal system and focus on the interactive effects of climate change and human impacts on the biota and society. We combine regional Earth System modelling with advanced statistical analyses for constructing scenarios of possible and plausible future change. Reconstructions of past changes and the analyses of long-term ecological observations are required for a better understanding and for gauging sophisticated modelling methods. These methods provide a framework for assessing the relevance of anticipated change.

Based on the results of the successful coastal research within the MARCOPOLI Programme, we identified four main topics that urgently need further work, a choice supported by the recent review of major scientific needs in coastal research (KDM Küstenmeere im Wandel, 2007). These topics focus on:

1. Changes in biological diversity, food web structure, and biological resources;
2. Changes in cycling of matter with emphasis on eutrophication, and contaminants, and evolutionary strategies to deal with these changes;
3. Long term changes of the hydrodynamics and sediment dynamics;
4. Improvement of temporal and spatial observational strategies and systematic integration of data into model systems.

These four topics are the basis of four work packages, which are linked together at a variety of different nodes ranging from long-term evaluation of the physical and ecological status in the North Sea through to the identification of amelioration strategies for sensitive environments. Additionally, links to other topics in the programme are in place and include effects of CO_2 rise on ecological systems and changing Artic coasts.
The four work packages are divided into two logical parts: a system studies (ecological and genetic) part and a more physical and management-oriented part.
The first part with two work packages (WP1 and 2) encompasses the basic ecological and genetic know-how, which is mainly required for the first challenge.
The second part with two work packages (WP3 and 4) encompasses analysis of changes based on scenarios and the preparation of management strategies as well as an observational and modelling part required to address the second challenge.

In WP 1 **"Food webs and diversity under global and regional change"** we will primarily cover temperate coastal ecosystems, from organisms to communities, including their interaction with the abiotic environment. Currently, climate change and over-exploitation are causing substantial alterations in many coastal ecosystems, beyond the normal ranges of variability, resulting in changes in species composition (both through local extinctions as well as the introduction of new species) and, as a result, changes in the linkages between different food webs components. These shifts, coupled with changes in the coastal habitat threaten marine ecosystem stability and recovery potential, with significant and potentially irreversible changes in its characteristics and services. In WP1, we will study these issues and translate major findings into our ecosystem model, which will be fed into the integrated system developed in WP4.

WP 2 „**Integrating evolutionary ecology into coastal and shelf processes**" addresses species-specific responses of selected representatives of groups of organisms, with respect to their ability to adapt and evolve within changing regimes, specifically in coastal and shelf seas. Both genetic and habitat factors will be studied to understand their effects on physiological mechanisms and gene expression. The challenges are to unravel different adaptation strategies of these selected organisms, especially by comparing responses along latitudinal and ecological gradients. The WP has strong internal links to WP1 and WP4, and will complement WP6 in TOPIC 1 with regard to polar coastal studies. The hierarchical systems approach integrates physiological, metabolic and genetic processes, from the molecular and cellular level to whole organisms and populations.

In WP 3 "**Coastal Systems under Global and Regional Pressures"** global and regional pressures will be studied with respect to geophysical and ecological components of coastal systems. Emphasis will be given to the issue of regional marine climate change. Discrimination between natural variability and anthropogenic driving forces is one of the challenges. Past, recent and ongoing coastal changes will be quantitatively described – with respect to ecosystem composition, regional climate and fluxes and deposition of matter; scenarios of possible future developments will be derived. Extension of the modelling system is planned – with respect to other compartments of the regional Earth System and other regions (East Asia, Laptev Sea, Baltic Sea).

In WP4 "**Integrating observations for coastal management"** an integration of knowledge systems for coastal management is a final step towards applying our results to societal needs. New observational methods will be developed and implemented. A first step is the hardware under construction within ICON (Integrated Coastal Observatory). A new challenge will be to set up pre-operational models for assimilating the heterogeneous data streams. Extending the physical, sedimentary and biogeochemical variables resolved by the observational and modelling system will enable us to assess ecosystem health, for which we selected the wellbeing of top predators (marine mammals) as a proxy.

WP1 : Food webs and diversity under global and regional change (Maarten Boersma, Kai Wirtz)

We identify key relationships between ecosystem structure and function and improve our understanding of the response of coastal food webs to global and regional change

Objectives and challenges

Over-exploitation and climate change cause substantial modifications in coastal ecosystems: biodiversity changes, and food web structure and energy flow patterns change accordingly. Combined with habitat alterations, such shifts not only threaten marine ecosystem stability and recovery potential, but also will lead to significant and potentially irreversible changes in coastal ecosystem characteristics and services. The main objectives of this WP are to generate fundamental understanding of the structure and function of coastal ecosystems, to assess coastal biodiversity, and reveal both its dependence and its impact on ecosystem functioning. In pursuing these objectives, we face the following challenges:

- To develop and establish the tools and expertise for assessing diversity both within and among species, and to link this to functional biodiversity;
- To understand the implications of changing coastal habitats for individual key species, biodiversity and specific ecosystem processes;
- To determine the role of food web interactions and the implications of changing players, for the energy and matter flow through coastal and shelf systems.

Implementation

Facing the challenges identified above requires a suite of complementary approaches. We will study communities, populations, individuals and processes within individuals both in an analytical and an experimental manner in the laboratory and in the field. We will link observed processes and patterns with environmental conditions and manipulations. We will assimilate our results into ecosystem models, which will serve in hypothesis testing, in putting adaptive properties into the context of coastal food-webs (link to WP2), in long-term hind-casting (link to WP3) which will also be integrated into an operational monitoring and simulation system (link to WP4). On the basis of our challenges we have established four organisational foci:

Changing diversity

The shifts in species composition in many coastal ecosystems have been considerable in recent years, and even within species, intrinsic adaptations to changing conditions might be substantial. Biodiversity plays a pivotal role for ecosystem function in a changing environment. Increasing species richness can enhance ecosystem productivity and stability; genetic diversity within species might have equivalent effects. Unfortunately, our current knowledge on such intra-specific variation and their consequence for ecosystem functioning, as well as the identity and diversity, particularly of organisms, which are too small or delicate to study using “classic” taxonomical methods, is still very limited. Hence, we intend to shed light on both diversity aspects, studying the “hidden” intra-specific diversity of known species (e.g. microplankton), as well as the “cryptic” diversity of organisms in the pico- and nano-meter size range. By means of molecular biological tools we will analyze all phylogenetic levels from communities to populations, from species to ecotypes. Because species diversity is directly linked to functional diversity, genomic and expression (EST) studies will be included for species that might be particularly sensitive indicators of environmental change. We will study the consequences of the introduction/arrival as well as the disappearance of species on the overall diversity and functioning of coastal systems. These alterations in the species pool will presumably have cascading effects in coastal marine food webs from prey-predator relationships down to microbial communities. Examples are bacterial communities associated with new organisms in

the system, the invasive Sargasso weed and its associated species assemblage, the effects of the neozoan ctenophore *Mnemiopsis leidyi* on plankton diversity and hidden changes in microalgal communities.

Habitat structuring species interactions
Coastal systems comprise a variety of habitats. Local physical, chemical and biological properties determine which consortia of organisms live in particular habitats. Moreover, invaders such as the pacific oyster can change habitat characteristics substantially, and, consequently, modify species composition. For selected habitats, we will study the effects of variation within and among habitats on species composition and interactions. For example, if extreme weather events become more frequent, we expect a shift from macroalgal domination to filter feeders such as mussels, oysters or barnacles in exposed habitats. Studies on the persistence and success of organisms found in different habitats will complement work on adaptation and will provide substantial insight into the inter-dependency between diversity and ecosystem function. Interactions between habitats, for example via exchange of biomass by means of drifting benthic organisms or their meroplanktonic larval stages, as well as the active migration of mobile organisms will be studied. Methods for a continuous assessment of the distributions of highly mobile predatory species, such as cod and the competitive invader red mullet in these habitats will be developed. By artificially manipulating the habitats and the composition of habitat-forming species (oysters, mussels and settling space) experiments will elucidate the way how individual (key-) organisms modify their environment as well as the associated community on a short- and long term scale. Studies will include the comparison of oyster dominated versus mussel dominated habitats, the role of seagrass meadows as a fish refuge, the effects of invaders on the fish community, and macroalgae as habitats for epiphytic species.

Foodweb structure & shifts: trophic interactions in a changing food web
Dramatic changes in species composition have occurred in many shelf seas. In the North Sea, for example, loss or reduction of dominant species (e.g., cod or blue mussel) as well as the appearance of invaders (e.g., red mullet, Pacific oyster) are prominent harbingers of change. Less visible modifications, such as changes in the seasonal presence of certain fish species, can be of equal or even greater significance for ecosystem function. We will define characteristic properties of the food web which will facilitate the identification of control mechanisms (e.g. imbalances in nutrient stoichiometry or presence of toxins) and their changes. Such structural shifts will be linked to energy flow patterns as well as to exchange rates and pathways of specific substances. In the pelagic compartment, emphasis will be placed on higher trophic levels, in particular, on the shifting balance between gelatinous plankton and fish and on small sized predators such as ciliates and heterotrophic dinoflagellates. In benthic habitats we will focus on the impact of species gain and loss on overall food web dynamics. We will analyse spatio-temporal dynamics of both pelagic and benthic communities with respect to seasonality in abiotic parameters and in hydrodynamics. Experimental approaches will simulate the loss or gain of particular species and will tackle trophic relations, behaviour and competition of key species. An existing energy flow model, based on network analysis, of the coastal North Sea that describes functional processes and properties of benthic and pelagic sub-systems will be refined and further developed to incorporate effects of seasonal and spatial heterogeneity. Particularly significant tasks are the mechanisms of key species mediated shifts within functional groups, the incorporation of metabolic scaling (size dependence of metabolic processes) into size-based models of plankton interactions, and the significance of cell size and stoichiometry for food preferences. Our over-arching task is to provide modular components for future ecosystem models, which will be developed.

Organismal physiology and success
Links between ecosystem structure and function will be studied by incorporating organism information of key species into our conceptual framework. This will enable us to consolidate our understanding of the individual species response and extrapolate to changes on the community level. Key species will be used in integrated studies on life-history reactions in response to the changing environment by combining laboratory and field experiments. Comparisons between

organisms from different climatic regions will be carried out thus linking WP1 and WP2 tasks. Planned and ongoing research in this topic includes studies on dietary adaptations of brown shrimp (a species central to the North Sea fishing industry) to different resources, the external (temperature, feeding conditions) and internal (ontogenic) factors that influence the toxicity of selected jellyfish species, and the effects of changes in toxicity on the pathways of energy and matter through the food web. Other studies will target the effects of changed food sources and changing salinity or temperature on crustaceans, ciliates and dinoflagellates, and effects of different food sources on fish and sea bird behaviour.

Integration and deliverables

This work package will generate knowledge on structures and processes pivotal to the maintenance and functioning of different habitats and associated species in changing coastal ecosystems. We will provide models that incorporate the aspects of metabolic scaling, variable stoichiometry and size-based trophic interactions. Given data on shifts in plankton diversity, these models can be applied to investigate sensitivities of food webs and their vulnerability to anthropogenic and natural changes. We will exemplify how the adaptive capacity of key organisms is related to their habitats and potential change, leading to the following deliverables:

- Trophic level evaluation of key species and corresponding models of adaptive shifts in food web functional properties
- Analysis of changes in biodiversity in coastal regions, and its impact on ecosystem function
- Models coupling food web dynamics and key organisms response to the physico-chemical environment
- Sensitivity atlas of change in key habitats, with focus on habitat-related biodiversity

Milestones

- Inventory of ongoing and recent change in biodiversity in significant coastal habitats (year 2)
- Models of adaptive shifts in coastal food webs (year 2)
- Analysis of the significant biotic factors that determine the transfer of energy and matter through a food chain (year 3)
- Trophic models of significant coastal habitats and simulation of future scenarios (year 4)