

Trilateral Research Agenda for the Wadden Sea Theme 2. Ecology

Motivation

Although many historical regional drivers of ecological change (i.e., fishing, hunting, pollution, eutrophication, embankments) in the Wadden Sea have been mostly phased out or declined since its trilateral management became effective, the rate of ecosystem change in this coastal area has not slowed down. We aim to solve this paradox, and hypothesize that interactions with global change effects (e.g., air and ocean warming, wind and precipitation patterns, sea level rise, invasive species) are presently threatening the Outstanding Universal Values (OUV's) of this natural World Heritage (Fig. 1). Therefore, regional management based on interdisciplinary research will have to cooperate increasingly on a continental and global scale to efficiently and effectively protect the internationally recognized properties of the Wadden Sea.

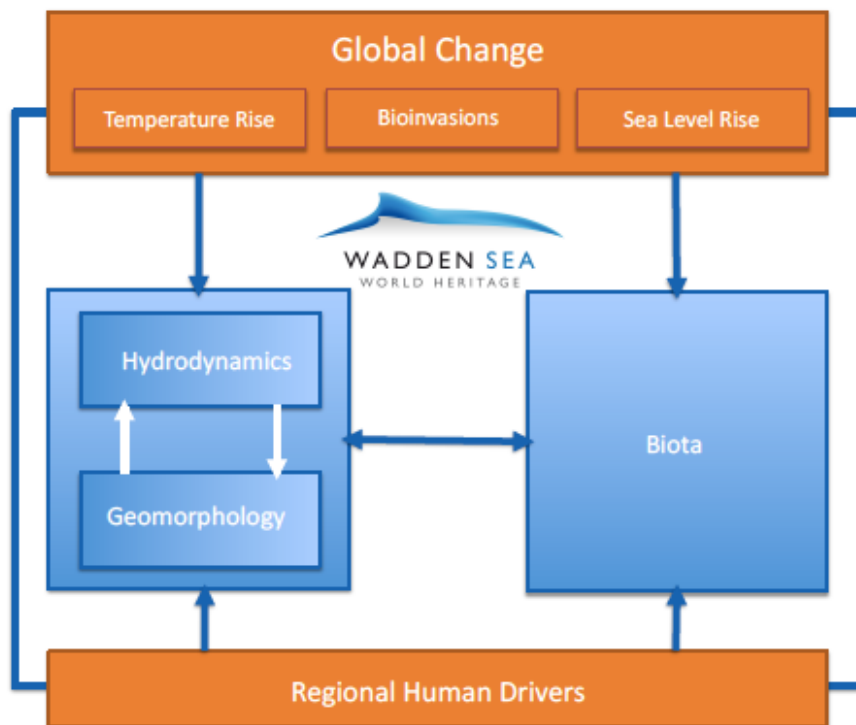


Figure 1. Conceptual model of drivers and interactions within the Wadden Sea ecosystem.

So far, long-term field observations linked with comparative analyses, experiments and modelling revealed important changes and indicated underlying causes. Examples include the relationship between riverine nutrient discharge and primary productivity, main causes in dynamics of macrobenthos and birds as well as resilience in seal populations towards diseases. New findings underline the importance of the connectivity between Wadden Sea regions (e.g. for fish, birds, seals) and the exchange processes with the North Sea (especially with regard to sediment, nutrients, phytoplankton, macrozoobenthic larvae, fish, birds, seals). Recent joint Dutch-German investigations (BMBF/NWO projects) also emphasize the increasing ecological relevance of invasive species and parasites but the magnitude and consequences of all these interactions are still largely unknown.

In addition, many ecological changes and patterns within the trilateral Wadden Sea remain unexplained including the decline in juvenile fish and migratory birds, and unequal distributions of seagrass, mussel beds, foraging and breeding birds. Many of these patterns are directly or indirectly affected by climate change as a main driver of accelerating alterations in biotic and abiotic patterns of the Wadden Sea. Therefore, target-orientated ecological research is required, which enables flexible, adaptive and timely management and protection measures for a rapidly changing environment.

Within this chapter, we present the most urgent trilateral ecological research questions to underpin policy and management during the coming 10 years and beyond, and indicate the links and interactions with the other research themes. Furthermore, we address the importance of the connectivity with researchers and managers in Europe and the rest of the world. Our selection of research questions is based on their urgency from a climate change perspective, includes research needs identified by the CWSS Science-Policy matrix, but also considers the feasibility of getting answers by means of a trilateral research approach and by applying innovative and harmonized observations, sampling schemes and analytical techniques.

In detail, our research questions focus on the direct and indirect effects of climate change on the occurrence and dynamics of species and communities (RQ 1), on the occurrence of habitats and primary production areas (RQ 2), on exchange processes between Wadden Sea systems and other environments (RQ 3), the responses of ecosystem functions (RQ 4) and coastal spatial planning (RQ 5). These questions were drafted during a trilateral workshop at the end of June 2016 (Appendix 1), and will be put forward for review to colleagues from different ecological fields of expertise, affiliated with various universities and institutes in Denmark, Germany and the Netherlands.

Research questions

RQ 1 Population level responses to warming and sea level rise	
How will climate change affect the regulation of populations (microbes, algae, macrozoobenthos, zooplankton, insects, fish, birds, mammals) and communities and how fast can marine species adapt to the actual and projected rates of environmental condition changes?	
<i>Context</i>	Climate change (CC) may affect local species densities via impacts on recruitment, growth and survival, via changes in timing of life cycle events (phenology), and via changes in import and export rates of native and invasive species (distribution shifts). Because not all species are impacted in a similar way, this will lead to changes in communities. The Wadden Sea ecosystem already exhibits signs of impacts of CC, which will further enhance if CC accelerates and if species are not or no longer able to cope with the changes by moving to favourable habitats or by phenotypic and evolutionary adaptation. So far, interactions between hydrodynamics, geomorphology and biota are mostly studied at a local scale.
<i>Novel approach</i>	Comparison of regional differences in climate conditions in different environments (e.g. tidal areas, salt-marshes, dunes, coastal zone), observation of coinciding differences in behaviour and traits of marine species combined with experiments may function as a model for future climate change at a larger than local scale.
<i>Policy-relevance</i>	Safeguarding of natural processes (e.g. bivalve recruitment, dune formation) that are most sensitive towards CC and have the largest implications with respect to the abiotic environment (e.g. tidal flats, dunes) and ecosystem services (e.g. aquaculture, coastal protection). Providing future climate information in the form of climate analogues is an approach being used by the scientific community to make long-term climate information more easily able to be integrated into adaptation decision-making.

RQ 2 Unequal distribution of habitats and production	
How are main habitats (benthic, pelagic, terrestrial, migratory pathways) and main areas of primary production (predominantly by pelagic and benthic microalgae) distributed over the trilateral Wadden Sea, which abiotic (e.g. exchange, hydrodynamics, exposure, nutrients) and biotic (e.g. bioturbation, biostabilisation, source-sink) factors determine this distribution and its dynamics, and how sensitive are these areas to climate change and other human activities (i.e. ecosystem integrity)?	
<i>Context</i>	So far, only variation in some intertidal habitats (e.g. seagrass, musselbeds) is consistently mapped at a larger than local (national) scale. Information on subtidal areas and on temporal and spatial dynamics in primary productivity is virtually absent, and structuring factors and resilience to human activities are largely unknown. Trilateral approach already gained some new insights on possible drivers (e.g. role of estuaries as natural barriers for larval transport). Recent findings underline the crucial role of pathways for the survival of migratory birds and fish (flyways, swimways).
<i>Novel approach</i>	Identification of habitats where populations are likely to establish and persist by means of habitat distribution models (HDMs), using measured and derived data at various scales, e.g. from satellite images to marine seabed mapping techniques. Identification of high and low productive areas by means of data derived from the new generation on satellites (Sentinels), in combination with application of new algorithms on automated measurements of PP (e.g. FRRF, oxygen optodes).
<i>Policy-relevance</i>	Identification of present and potential habitats as a baseline for spatial management within the Wadden Sea region. Sensitivity of carrying capacity towards CC, underpinning management goals with regard to numbers and trends of particular species relying on productivity of the Wadden Sea region.

RQ 3 Exchange Processes	
How strong is the influence of the exchange of dead and living matter between the Wadden Sea and the environment to which it is connected (North Sea, rivers, hinterland, terrestrial Wadden habitats) on local distribution and densities of species and on local structures of communities and how is this affected by climate change?	
<i>Context</i>	Part of the long-term changes in communities of marine plants (e.g. phytoplankton) and animals (e.g. fish and birds) in the Wadden Sea are attributed to changes occurring outside this area. Although the hypotheses are plausible, this cannot not yet be accepted or rejected due to lack of data and understanding.
<i>Novel approach</i>	Combination of trilateral hydrodynamic and sediment transport models with earth observation (e.g. SPM, chlorophyll), automated measurements (e.g. SST, O ₂ , nutrients), mark-recapture (e.g. shrimps, crabs, small fish) and tagging (e.g. fish, birds and seals) techniques.
<i>Policy-relevance</i>	Identification of possibilities and restrictions for local management of human activities, including protection measures within the Wadden Sea region.

RQ 4 Responses of ecosystem functions	
What are the consequences of CC and sea level rise (SLR) for the nature and rates of biogeochemical processes, and how does this affect the species, communities and ecosystem of the Wadden Sea?	
<i>Context</i>	Ongoing CC will affect biogeochemical processes within the Wadden Sea in various ways, possibly resulting in a lowering of pH, a lowering of oxygen concentrations and a reduced depth of the non-toxic (sulfate-poor) top layer of the sediment. Such changes lead to changing environmental conditions for estuarine life (including bacteria), resulting in shifts within communities in the sediment and the water.
<i>Novel approach</i>	Coupling of novel reactive transport models and molecular techniques to describe reactions, sources, sinks and advective and dispersive movement of natural compounds (e.g. nutrients, organic matter) in their natural environment with (automated) measurements of concentrations and fluxes of these compounds.
<i>Policy-relevance</i>	Future expectations with regard to ecosystem services, including retention of

	nutrients (related to carrying capacity) or elimination (denitrification), stocks of calcifying organisms (e.g. bivalves) and subsequently shellfish aquaculture and food provisioning of fish and birds.
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RQ 5 Coastal Spatial Planning	
What would be a good framework for Coastal Spatial Planning (CSP) of the Wadden Sea area (including North Sea coastal zones, river catchment areas, estuaries and land), what scientific information is needed and how could this be implemented?	
<i>Context</i>	Oceans and coasts provide people with diverse benefits, from fisheries that sustain lives and livelihoods to recreational opportunities that generate tourism. However, translating appreciation of these benefits into changes in management and policy is not trivial. Coastal spatial planning (CSP) is a process that brings together multiple users of coastal areas – including energy, industry, government, conservation and recreation – to make informed and coordinated decisions about how to use marine resources sustainably.
<i>Novel approach</i>	CSP generally uses maps to create a more comprehensive picture of a marine area, identifying where and how a coastal area is being used and what natural resources and habitat exist. By accounting for spatial variation in the influence of human activities on ecosystem services, results allow stakeholders and policymakers to refine zones of human use, reduce risk to ecosystems, and enhance delivery of multiple ocean and coastal benefits.
<i>Policy-relevance</i>	Through the planning and mapping process of an estuarine ecosystem, planners can consider the cumulative effect of industries on the ecosystem, seek to make industries more sustainable and proactively minimize conflicts between industries seeking to utilize the same sea area. The intended result of CSP is a more coordinated and sustainable approach to how our coastal areas are used – ensuring that marine resources and services are utilized, but within clear environmental limits to ensure estuarine ecosystems remain healthy and biodiversity is conserved, in particular during times of (climate) change.

Some additional remarks

For most (if not all) of the questions within the field of ecology, we foresee links with questions raised and activities suggested within the other disciplines. Furthermore, we would like to explore for each of the research questions if and, if so, how citizen scientists can help to gather data and information. Last but not least, we would like to (i) stress the importance of the continuation and further harmonisation of long-term field observations within the Wadden Sea area at large, (ii) advocate the importance of observations (e.g. satellites) and models covering the entire Wadden Sea and (iii) advertise a trilateral structure in the research and management community in order to facilitate fast and good answers to pressing questions.

Appendix 1. Contributors

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To be confirmed