

Knowledge for a sustainable future of the Wadden

Integrated research agenda of the Wadden Academy



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Summary

1 The Wadden Sea Region

The Wadden Sea Region consists of an extensive system of barrier islands, sea, tidal flats and salt marshes, where almost undisturbed natural processes continue to shape the landscape and habitat. The Wadden Sea Area accounts for 60% of all the tidal areas in Europe and North Africa and provides a habitat for a very rich and varied flora and fauna. The area also contains age-old man-made landscapes reflecting a unique adaptation by human beings to the dynamics of a very special coastal area. The conservation status currently enjoyed by the area was not achieved without effort. Since the 1960s, the Wadden Sea Region and its future have been, and still are today, the subject of – sometimes heated – political and social debate and controversy. Gradually, however, it has become generally realised that the region requires special care. This has resulted in legislation and regulations, the guiding principle of which is to preserve the natural values of the Wadden Sea Region while allowing sustainable shared human use.

2 Ambition

It is the ambition of the Wadden Academy to develop the Wadden Sea Region into an incubator for widely applicable integrated knowledge of sustainable development of a coastal area, in which natural values are a key element and form the foundations of the local and regional economy. The region is a meeting place for scientists from the Netherlands and elsewhere, administrators, policy makers and management agencies. Together, they develop sustainable and innovative solutions based on interdisciplinary knowledge. By 2020, the trilateral Wadden Sea Region will be the best monitored and best understood coastal system in the world.

3 The Wadden Academy, its tasks and the research agenda

Devising a sustainable future for the Wadden Sea Region requires new knowledge and expertise concerning the natural, economic and socio-cultural condition and development of the region. Established on 30 July 2008, the Wadden Academy has the task of providing a sound scientific basis for the management of the natural and social values represented by the Wadden Sea Region. As the first task of the Academy, the present research agenda provides an overview of the gaps in our knowledge and the most pressing scientific questions. The agenda is the result of an intensive cooperative venture between the Wadden Academy and a large number of policy makers, administrators and scientists. As such, it also reflects the Wadden Academy's second task: to create a sustainable network for the joint formulation of research questions and the exchange of knowledge and information between science, government, private parties and social organisations. The Wadden Academy has entered into cooperative ventures with a number of ministries, organisations and institutes to ensure that the Wadden Academy's research agenda will play a part in the planning and consolidation of research relating to the Wadden Sea Region, the Wadden Academy's third task. When carrying out research, the Wadden Academy advocates a procedure which involves a co-production of knowledge by scientists, knowledge workers in public and private bodies and policymakers. All the parties benefit from 'engaged scholarship': more practical relevance and improved scientific backup.

4 The perspective of the Wadden Academy

The guiding principle for the Wadden Academy is to preserve the natural values of the Wadden Sea Area while allowing sustainable human use. However, the Wadden Academy notes that there is debate as to which natural values are the most important and as to the nature and extent of the restrictions on human use. For this reason, the Wadden Academy – in consultation with all the parties involved – is focusing on identifying the research questions which are relevant to achieving a sustainable future for the region. It is an objective of the Wadden Academy that all parties can put their trust in the systematic application by the Wadden Academy of the scientific rules for articulating problems and issues and for prioritising scientific questions.

The Wadden Academy focuses its attention on the study of changes which are taking place over different space and time scales and are the result of the interaction between the geosphere, hydrosphere, atmosphere, biosphere and humankind and society. Although, in the approach adopted by the Wadden Academy, great value is attached to knowledge of the



region's historic development on longer and shorter time scales, the historical conditions of the natural and socio-cultural system cannot automatically serve as targets for the region's future development. The Wadden Academy endorses research into conceivable future scenarios in which environmental and socio-economic developments or – rather – options are sketched out. How can the assets of the region be valued, what opportunities exist to preserve these values, and what investments are required? What values may be created under the changed circumstances that will pertain in future? What scenarios will produce a configuration of planet, people and profit that will have a permanent adverse effect on the resilience of the region and how can this be avoided? The Wadden Academy intends to play a part in this debate on future

options for the Wadden Sea Region by providing scientific understanding of how the region functions as a coherent system of natural processes, humanity and society.

Wadden Sea research has long been dominated by the natural sciences. Socio-economic research and, to a lesser extent, historical research is grossly under-represented in terms of volume and importance. The Wadden Sea Area and Wadden Sea Region should figure more prominently on the research agenda of economists, urban planners, experts on public administration, historians, sociologists, psychologists, anthropologists and cultural scientists. They can identify those who feel involved in the Wadden Sea Area and in what way, how this involvement is justified in history, what interests are at stake, what reference images of the landscapes are used and how this will affect the future of the area.

5 Values

The trilateral Wadden Sea Region has a prominent and special role in the global ecosystem. The region represents unique natural values, the protection of which is laid down in legislation and regulations. The Wadden Sea Region also represents a major value for the people who make their living from it. In addition, the movable and immovable heritage is an important force in creating identities and communities. Natural and cultural values play an essential part in tourism and leisure. An interdisciplinary perspective on value(s), valuing practices and value creation is therefore an obvious item on the Wadden Academy's research agenda. The Wadden Academy's aim is to compile the knowledge required to shape a future based on innovative and sustainable use of the natural and cultural values of the region.

6 A sound scientific basis

6.1 Geoscience

Geoscientific knowledge gaps with regard to the development of the Wadden Sea Region in time and space can be classified according to three themes. With respect to the subsurface of the Wadden Sea Region, more detailed knowledge is required of the geological composition and structure of the subsurface and other physical-chemical properties of rocks, faults and fluids. Detailed three-dimensional images form the basis for modelling and quantifying processes in the subsurface and thereby understanding and predicting the behaviour of rocks, faults and fluids. This is essential to optimise the present and future use of groundwater, salt and natural gas, the storage of gas and CO₂ and the retention of heat and cold for use in the winter and summer respectively. Within the theme of evolution of the Wadden Sea Region, a reconstruction should be made of the morphological development of the Wadden Sea Region during the late Pleistocene and Holocene and the influence of deeper structures on this process. This can provide a better understanding of the dynamics of salt marshes, flats, channels and outer deltas at different rates of sea-level rise. The role of human beings as a geological force – in relation to natural processes – must be made explicit. The theme of Wadden Sea morphodynamics requires more and better data on and understanding of the sediment balance for both sand and mud, including the impact of sand suppletions and the role of ecosystem engineers. A description in quantitative terms of the development of (components of) tidal inlet systems over a timescale of years up to a century is required in order to develop models that will enable us to predict the impact of sea-level rise and changing storm regimes in the Wadden Sea Region and to improve coastal defences.

6.2 Ecology

The Wadden Sea is a dynamic, coherent, open and highly valuable ecosystem. The food web is the backbone of this system. Understanding bottom-up processes in the food web requires improved monitoring, modelling and focus on qualitative aspects, as well as paleo-ecological reconstruction. With respect to top-down processes, too little is known about the effect of (partially extinct) top predators. Comparative research on other tidal flat systems is required. Non-trophic interactions occur due to the effect of biota on their abiotic environment. The dynamics of ecosystem engineers connect the ecological domain to the geomorphological domain, from tidal flats to dunes. The Wadden Sea is an open system: exchange with the coastal sea and the rivers plays an important role in determining the concentration of nutrients and organic matter. In addition, the region forms part of an international system of breeding and wintering areas for migratory birds. Global change is expected to alter the Wadden Sea Region substantially. This gives rise to the paradox of nature conservation in a changing world. It is essential to preserve and develop natural values while the boundary conditions are changing. 'Values' cannot be equated to 'states'; conservation of values cannot be obtained by returning to historic states in a world subject to global change. Consequently, a more detailed reflection on what are the most important values (and why) requires cooperation with the social sciences and the humanities.

6.3 Society and cultural history

Historically, large numbers of people have lived and worked in the Wadden Sea Region. In addition, this region has been used intensively and in various ways by visitors. The socio-political debate on how to care for the Wadden Sea Region is to a large extent dominated by questions about compatibility of human use of the region with preservation of the Wadden Sea Area as a nature reserve. In order to resolve these problems, more insight is needed into the perspective of residents and visitors. How do residents of the region shape their lives and earn their living; how do visitors regard the region and make use of it? How did this way of living and exploitation of the region's resources develop historically?

And what impact does it have on the region's climate, soil and subsurface and its natural values? These are the key questions in relation to society and cultural history. In terms of the triple bottom line model, they are questions concerning people (the first p), their way of life (p as in profit), their social organisation and the significance and value they attach to their natural and man-made environment (p as in planet), including how they deal with their impact on these values. We can add a fourth p to this model, namely their history and their relationship to the past. There are four subjects of research: the way in which people developed their way of life over time and how they used the natural resources that the region offered; the nature and interaction of 'wild memory' and disciplined history in the Wadden Sea Region; the historical development of the way in which the Wadden Sea Region is represented and valued; and the social and political organisation of a just and sustainable future for the Wadden Sea Region.

6.4 Social and spatial economics

From the perspective of social and spatial economics, the Wadden Sea Region challenges science to adapt existing economic ideas to a region with a very special economic, physical and spatial structure and institutional policy-related context. First of all, there is a need to describe present, past and future trends in the regional economic situation in terms of production, sectoral structure, employment, population, labour force and sustainability. To achieve this, regional economic models will have to be developed to predict how the Wadden Sea Region can adapt to global trends in the economy, to external developments such as climate change or to shocks such as the credit crisis. Scientific knowledge can also contribute to the sustainability of the Wadden Sea Region's economic structure. Central questions are how to provide sufficient employment and income, a pleasant social climate for residents and care for the region's natural and scenic values, which are also enjoyed by visitors. It is therefore vital to ascertain why firms, individuals and households decide to base themselves in the region and to develop sustainable forms of business. Another important contribution from the discipline of economics is the use and further development of the social cost-benefit analysis (SCBA) as a policy and decision-making tool for assessing whether or not interventions in the Wadden Sea Region can be allowed.

6.5 Urban and rural planning

The Wadden Sea Region shows a diversity of subareas, where either ecological value or economic value predominantly determines human use. Extensive monofunctional natural and cultivated areas alternate with highly dynamic centres for holidays and leisure, port activities and industry. The Wadden Sea Region therefore has a strict separation of functions and functional areas, which means that 'conservation' is appropriate in one area and 'development' in another. Yet there is an increasing demand for coherence and multifunctionality. In the Wadden Sea Region, this demand mainly occurs at the interface between nature and leisure/care and between agriculture and leisure/care. Given this demand, a defensive strategy focusing on further separation of functions and emphasising preservation or restoration is not always desirable. New opportunities can be found, particularly where an area is suitable for the combination of protecting natural or historic values on the one hand, and developing functions on the other hand. With a change in political and administrative thinking, this will switch from approval planning (no, unless...) to development planning (yes, provided that...). Protection 'per se' and protection 'no matter what' will no longer be practised in all cases and will more frequently be weighed against possibilities for area-specific development. Against this background, more knowledge is needed on how to interweave functions and how to develop areas in a multifunctional way focusing on combining the area's ecological and economic qualities. In this way, emphasis is placed on the Wadden Sea's connecting role, spreading the pressure of leisure activities, investing in quality of life and the function of transitional areas. This means that government bodies, private parties such as property developers and farmers, and nature conservation organisations

will have to join forces to implement regional coordination. Improved regional governance is facilitated by an analysis of underlying conditions, coordination issues and requirements from a 'multi-level', 'multi-actor' and 'adaptive governance' perspective.

6.6 Climate and water

To gain a proper understanding of climate change in the Wadden Sea Region, four research areas have been identified. First, more detailed studies of regional greenhouse gas emissions are required. How can the relevant processes be explained? To provide a complete understanding, such studies will have to be linked to ecological studies and models of primary production and decomposition and also to the net transport by tidal flows to the North Sea. This must enable us to better estimate how the management of rivers, the coastal zone and the Wadden Sea affects these emissions. Second, it is important to produce good region-specific scenarios for climate change and sea-level rise as a basis for impact studies and the design of adaptive measures. Cooperation with German climate institutes will be needed for this. For the decades to come, the uncertainty in global climate scenarios is small enough to allow downscaling to the Wadden Sea Region. Designing no-regret adaptation measures should be based on a thorough exploration of extremes in scenarios for climate and sea level trends. The main questions relate to the interface between the rate of future sea-level rise, the danger of drowning of the tidal flats and the role of natural climate buffers and sand suppletions in guaranteeing safety. Third, much more knowledge is required with regard to the possible impacts of climate change on the morphology, water management and ecology of the Wadden Sea Area and the robustness and resilience of existing natural and human systems. Finally, innovative and robust adaptive measures will have to be developed, based on this understanding. Cooperation across natural science disciplines is essential for the themes 'impacts' and 'adaptive measures'. Climate adaptation also requires a substantial catching-up exercise by socio-economic, planning and governance research disciplines.

7 An integrated research agenda

There is a substantial disciplinary knowledge base on the Wadden Sea Region, but – as indicated above – major gaps in this knowledge also remain. It is further noted that the existing knowledge and expertise is fragmented and compartmentalised. The lack of an inter-disciplinary approach hinders the understanding of the Wadden Sea Region as a coherent and open system. In a systems approach, different elements, features and processes of a (linked natural and socio-economic/cultural) system are explicitly connected to one another. The emphasis is on revealing feedbacks between different processes and subsystems, on the dynamics controlled by these feedbacks and on the interplay between processes occurring in different space and time scales.

In the Wadden Academy's view, an integrated approach is required to enable us to understand the Wadden Sea Region in the short, medium and long term at system level. According to the Wadden Academy, research can be described as 'integrated' if it satisfies the four criteria below:

- it shows a combination of two or more disciplines with the emphasis on crossing the boundaries between natural science, social science and humanities;
- it takes into account the interplay between processes at different temporal and spatial scales;
- it takes into account the accumulation of processes, interventions and impacts;
- it is based on the co-production of knowledge, where the formulation of knowledge demand, the production of knowledge and the use in management result from close interaction between scientists, government experts and policy makers.

Obviously, the emphasis on an integrated approach in the research agenda does not preclude disciplinary, in-depth and curiosity-driven scientific research in the Wadden Sea Region. The Wadden Academy also wishes to stimulate this type of knowledge development in collaboration with universities and research schools and link it to the wider need for administrative, political, social and policy-related knowledge of the Wadden Sea Region.

The following cross-disciplinary research themes have been identified:

- people as a geological force;
- sediment balances of sand and mud and the role of ecosystem engineers;
- sea-level rise, changing storm regimes, tidal flat morphology and the use of natural processes as coastal defences;
- paleo-ecological reconstructions of the food web;
- reflections on the paradox of (nature) conservation in a changing world, from the points of view of natural and social sciences;
- the impact of people and their activities on climate, land, water and nature over the past 2,500 years, as well as in today's Wadden Sea Region;
- regional economic developments in the light of external trends such as climate change;
- development of employment and income in relation to conservation of natural and cultural-historic values;
- sustainable economic development, the culture of entrepreneurship and social cohesion;
- economic valuation of use (consumption and production) and non-use values of nature and culture in the Wadden Sea Region;
- tidal flows, geomorphology, ecology and greenhouse gas emissions;
- human management of rivers, the coastal zone and the Wadden Sea and greenhouse gas emissions;
- (conceivable extremes in) climate trends and the design of robust adaptive measures;
- climate change effects on geomorphology, water management and ecology;
- governance and the design and implementation of adaptive climate measures.

8 Research in the Wadden Sea Region from an international perspective

The three countries in the Wadden Sea Region – the Netherlands, Germany and Denmark – have national and regional policies to protect the major natural values in the region. In 2009, the Dutch and German Wadden became a World Heritage Site. Joint initiatives have been developed to make an inventory of the region's nature and environment and its cultural and scenic heritage. Both the natural values and the rich history of human use of the region played a part in the nomination of the Wadden Sea as a World Heritage Site. The harmonisation and coordination of this policy has been set out in the trilateral convention to protect the Wadden Sea. In addition, at a European level, the three countries are bound by common EU legislation, such as Natura 2000 and the Water Framework Directive. Despite the agreement on general principles and the common legal framework, there are regional and national differences in the management regime. These differences generate interesting comparative material for studies of the impact of policy on natural values.

Scientists from the three Wadden Sea countries have been cooperating for fifty years. Changes in the worldwide environment, human activities, the legal regime and the socio-political situation call for new international research initiatives. New research could form the basis for the integrated management of the ecosystem in the Wadden Sea as a whole in line with European legislation and taking account of sustainable shared human use.

At the trilateral level, much has already been achieved regarding common monitoring and assessment. Recently, initiatives have been started to intensify and computerise the monitoring of nature and the environment. The harmonisation and integration of these

efforts could create a 'shared workspace' for the Wadden Sea as a whole as a basis for excellent research. Common European legislation and climate change are also making new demands.

Although it can be stated in general that research benefits from international embedding, particular emphasis is placed by the research agenda on cooperation on the following topics:

- 1 subsurfaces and natural resources;
- 2 ecological interactions within the Wadden Sea ecosystem and between the Wadden Sea, the North Sea and the various rivers;
- 3 research into the global importance of the Wadden Sea;
- 4 consequences of climate change for the Wadden Sea ecosystem and comparable estuaries elsewhere;
- 5 cultural history and society within the Wadden Sea Region;
- 6 economic trends, developments and planning;
- 7 policy, management and methods and, where possible, harmonisation of the approach.

9 Research programmes

The Wadden Academy is proposing a limited number of large-scale umbrella programmes for multidisciplinary research. These are divided, on the one hand, into three large generic knowledge programmes (the three bold horizontal bars in the diagram) the aim of which is to collect and disseminate essential scientific results needed to fully understand the operation of the integrated Wadden system. This research is relevant for social and political questions but is performed at a fundamental level which is usually outside the scope of demand-driven research. On the other hand, three large, more integrated, research programmes are proposed (the vertical bars) which relate to today's most pressing management problems. In addition to this, two conditional themes have been defined (expert training and international cooperation) as further supporting horizontal bars. All programmes are characterised by (see central circles) an interdisciplinary approach, international cooperation and comparison, effective interaction between knowledge demand and supply and connections between different scales of time and space. Information, data, knowledge and expertise are exchanged at the interface between the horizontal and vertical programmes.

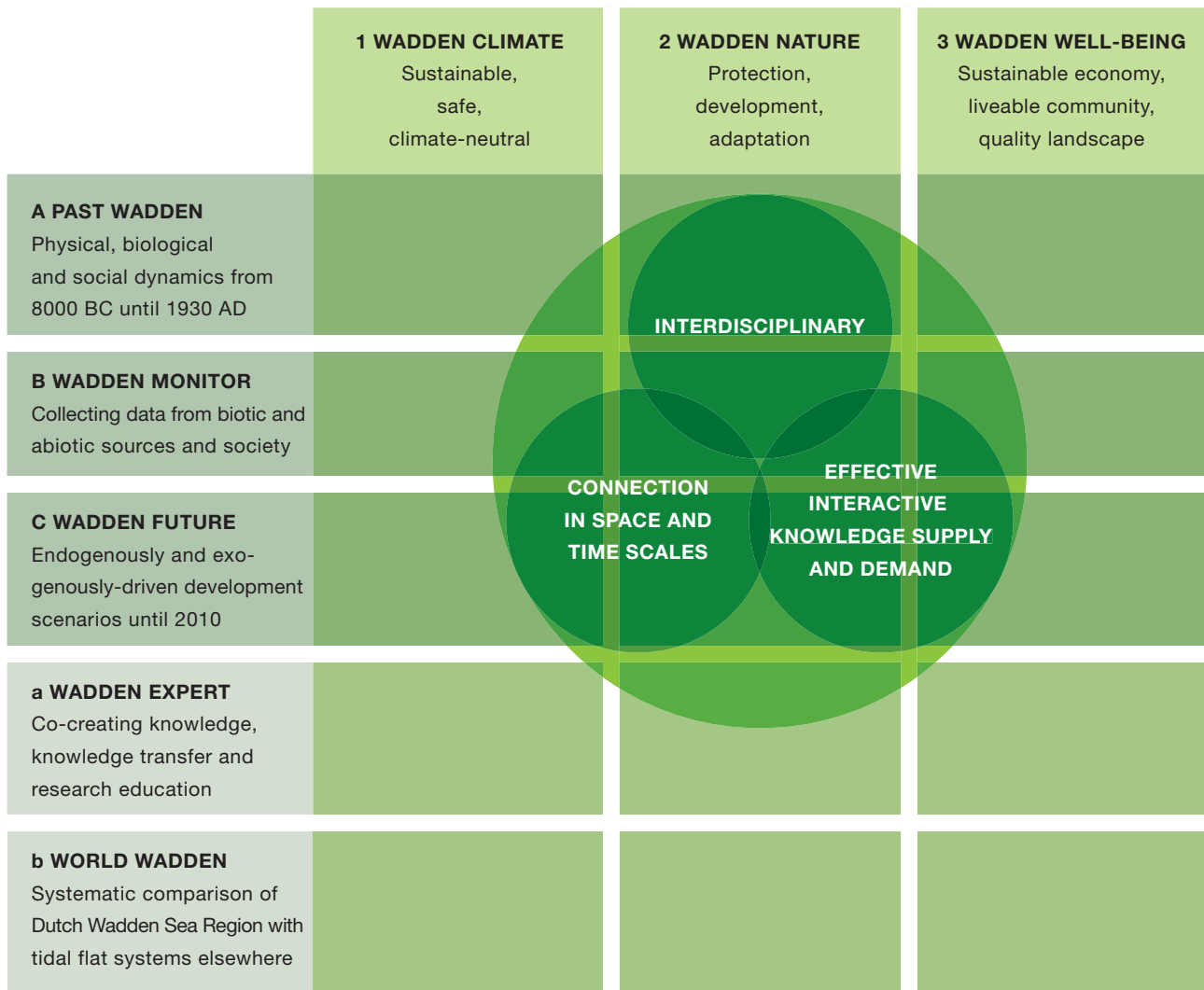
Together, the six programmes plus the two themes constitute the overall field of research for the Wadden Sea Area and Wadden Sea Region. They are long-term programmes. The knowledge programmes are as listed below:

A. Past Wadden: reconstructing the development of the Wadden Sea Region

The aim is to gain an understanding of the climatological, geological, ecological, economic and sociocultural dynamics of the tidal flat system between the end of the Pleistocene (8200 BC) and the construction of the IJsselmeer Dam (1932). Of necessity, the programme uses proxies for climatological, paleo-geographical and paleo-ecological reconstructions and those of man-made environments.

B. Wadden Monitor: monitoring the development of the Wadden Sea Region

The aim is to gain an understanding of the natural and social dynamics of the tidal flat system from 1932 (the closing off of the Zuiderzee) up to and including 2015 (the date on which several of the current monitoring programmes end). The programme focuses on the systematic collection and long-term supply of quantitative data for the entire Wadden Sea Region which are relevant to the various disciplines.



C. Wadden Future: predicting the development of the Wadden Sea Region until 2100

The aim is to understand and predict the development of the tidal flat system between 2010 and 2100. Conceivable, diverse scenarios for the development of the Wadden Sea Region will be based on multiple trend analyses and quantitative process models and will be updated as new information comes to light.

a. Wadden Expert: knowledge co-creation, knowledge transfer and training a new generation of Wadden Sea experts

The Wadden Academy's aspiration is to improve knowledge valorisation. Our aim is to achieve intensive interaction (co-creation) between scientists, governmental experts and policymakers at all stages in the knowledge development cycle. As part of this theme, the Wadden Academy has reserved itself the role of central knowledge broker, facilitator of multidisciplinary expert teams, organiser of education and training courses for public officials and management bodies, and of the joint initiator of an information system on the Wadden Sea Region. Finally, the Wadden Academy will participate in the transfer of knowledge to the general public, officials and policymakers, students and researchers.

b. World Wadden: the international study of the Wadden Sea Region

The aim is to systematically compare the Dutch, German and Danish parts of the Wadden Sea Region and to compare with intertidal areas elsewhere in the world. The focal points are: cooperation, coordination, prioritising, fund raising and knowledge dissemination.

An important position is occupied by the three integrated research programmes which are strongly demand-driven, tackle major societal issues and are therefore relevant to policy making and evaluation without lapsing into research with a limited perspective in terms of time and space. Below are the main issues and possible items for each programme.

1. Wadden Climate: the Wadden Sea Region sustainably safe and climate-neutral

Sustainably Safe: How can the safety of the Wadden Sea Region and its population be guaranteed in the long-term, also taking into account the possible harmful effects of climate change and sea-level rise? Can this be achieved in a way that preserves the natural and dynamic character of the region? Can large-scale interventions in the coastal zone – such as sand suppletions – make a positive contribution to the development of marine and terrestrial natural values?

Climate-Neutral: How can a sustainable energy balance for the Wadden Sea Region be realised, taking into account the region's specific values? There is a desire to exploit the potential of the Wadden Sea ports for transporting energy and bio-energy raw materials and for energy production, also making sensible use of residual heat, as well as the options for CO₂ storage in gas fields, the exploitable geothermal energy in the region and the energy potential of tidal and fresh-to-salt transitions. The most promising options, from the point of view of electricity generation and heat exploitation, is found in the coastal zone of the Wadden Sea Region. At the same time, the vast, open landscape, the natural environment and the tidal dynamics are values that must be cherished and protected. There are many knowledge gaps in the tension between the desire to create innovative 'energy landscapes' and to preserve natural and cultural-historic values.

2. Wadden Nature: protecting, developing and adapting the natural environment

Protection: What forms of (shared) use will affect the development of the natural environment and will it be possible to adjust them if they are found to be harmful? How can the value of the Wadden Sea in the world ecosystem be safeguarded?

Development: How can the management and landscaping of the Wadden Sea Region make an optimum contribution, on a scale of decades, to the natural quality of water flows, geomorphology, benthic processes, water, air and soil quality, and flora and fauna? Which developments will guarantee the highest natural values in the long-term, what are the essential characteristics of the natural values and which developments are possible within the (altered) constraints?

Adaptation: How will global change (climate change, introduction of invasive species, changes in the global economy) affect the natural environment in the Wadden Sea and how can the direction of the development of nature be adjusted?

3. Wadden Well-being: sustainable economy, liveable community and quality landscape in the Wadden Sea Region

Sustainable economy: How can work, income and quality of life for the residents of the Wadden Sea Region be guaranteed in a sustainable manner? How do we take account of the resilience within the system and of exogenously-driven changes in the regional and global economy? Is it possible to use minerals and geothermal energy sustainably in the light of climate change and sea-level rise, and if so, how?

Liveable community and quality landscape: How can the residents of the Wadden Sea Region be guaranteed a pleasant social environment, in view of the priority given to natural values in the region and in view of radical demographic, economic, socio-economic and cultural processes that extend far beyond the region? In this context, quality of life is interpreted in terms of social cohesion, a recognisable and vital man-made landscape and living heritage.

10 Implementing the research agenda

The research agenda will be implemented in different phases. These phases, some of which run in parallel, are consistent with the approach of the Wadden Academy to foster cooperation between, and involvement of, all parties from academia, policy and society.

Over two hundred of the main players from universities, research institutes, government agencies and non-governmental organisations have played a part in drawing up the research agenda. The Wadden Academy intends to update the research agenda regularly on the basis of the latest scientific insights and results and in the light of new policy developments.

Phase 1. Communication and feedback

During this phase, immediately after 30 May 2009:

- the dissemination of the research agenda is key;
- a wide-ranging consultation will follow (also by establishing a digital platform);
- a conference will be organised on 1 and 2 July 2009 to programme research for the future;
- knowledge groups will be established in the departments involved.

Phase 2. Drawing up plans to implement the programmes and projects

In the second phase, from 1 July 2009, it will be possible to form a multidisciplinary team around each research programme and each integrated demand-driven project. The Wadden Academy will facilitate the forming of the teams. The teams will be responsible for developing the programme or project in an implementation plan. The plan will contain a description of the societal demand, the scientific approach, a summary of subprojects, a work schedule and a budget.

Phase 3. Mobilising financial resources

The third phase involves financing. Two financing options are available for implementing programmes and projects: funds with a special relationship with the Wadden Sea Region (Wadden Fund, NWO-ZKO) and programme financing by ministries and research institutes. In the case of funds, applications can be submitted; the allocation or re-allocation of programme resources of ministries and research institutes will involve an interactive and iterative process, in which the Wadden Academy will assume the role of knowledge broker.

Henceforth, the Wadden Fund Advisory Committee will be involving the integrated research agenda of the Wadden Academy in the consideration and assessment of research projects submitted. To date, most of the research relating to the Wadden Sea Region has been funded from public funds, except for the active involvement of Nederlandse Aardolie Maatschappij (NAM). The Wadden Academy is actively seeking opportunities to involve more private market players in the Wadden research infrastructure, including the major energy companies and the financial sector.

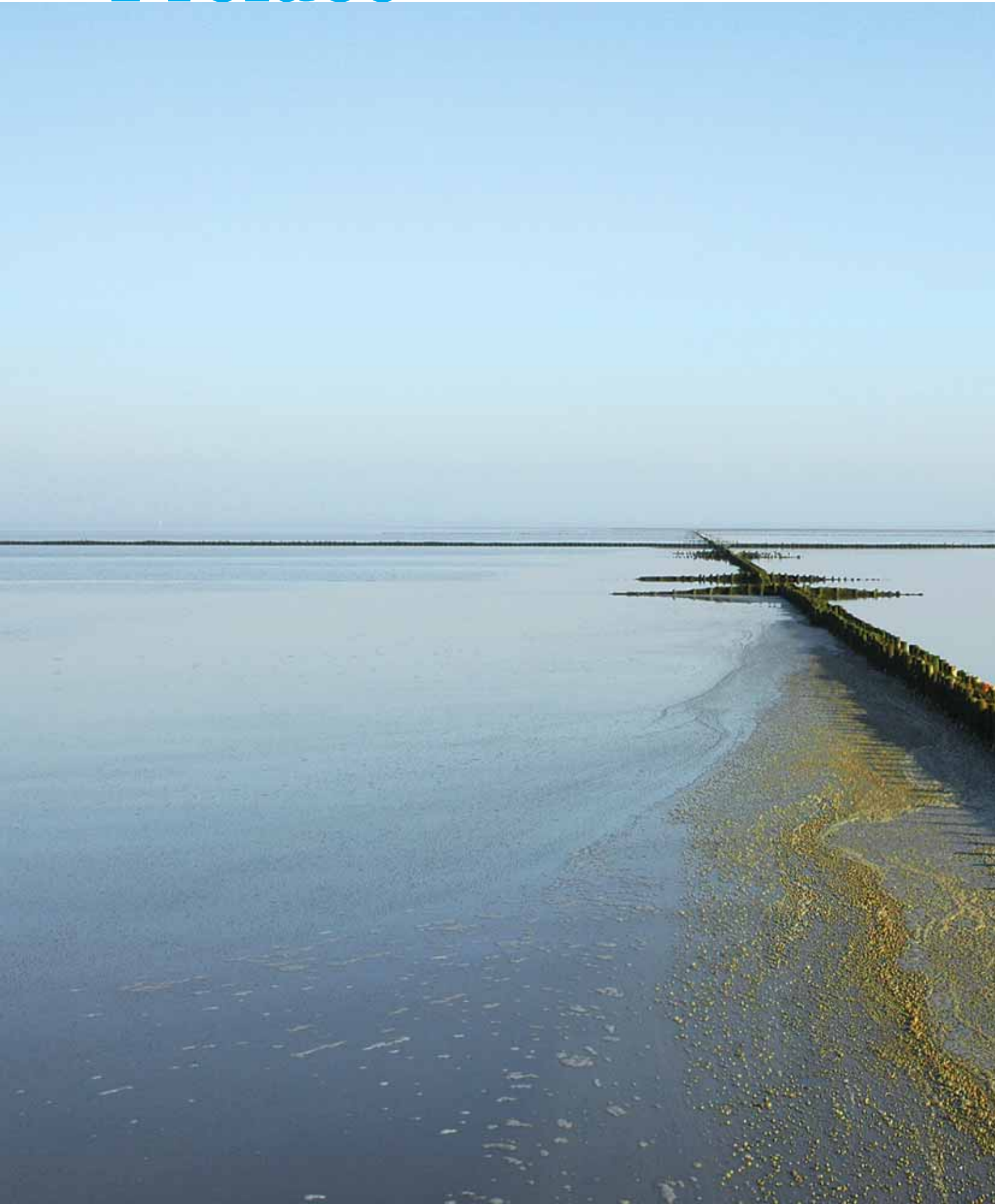
Phase 4. Internationalisation

In the fourth phase (from the second half of 2010), we will be actively seeking options for getting the research programmes accepted and funded as a trilateral arrangement and at EU level. The Wadden Academy will have a facilitating role in this process. A trilateral agency/research forum is being organised with major public research funders in Germany, Denmark and the Netherlands in association with the International Wadden Sea Secretariat in Wilhelmshaven, Germany. Together with German and Danish colleagues, we are investigating opportunities in the EU framework programmes and in EU Interreg programmes.

Phase 5. Evaluation and summary

In the fifth phase (early 2014), an independent audit and progress evaluation will be organised. The Wadden Academy and its partners will summarise the objectives of the research agenda which have been achieved.

Preface





Preface

This is the integrated research agenda of the Wadden Academy. The Wadden Academy is a new entity of the Royal Netherlands Academy of Arts and Sciences (KNAW) which was officially founded on 30 July 2008 by decision of the Dutch government and as a reflection of the recommendations of the Meijer Committee.

The Wadden Academy has three tasks:

- to identify gaps in cross-domain knowledge in order to assist in the sustainable development of the Wadden Sea Region and the formulation of research questions relevant to the region;
- to promote a coherent research programme at regional, national and international level and;
- to promote information supply and knowledge exchange in and between the knowledge world, government, industry and social organisations.

The Wadden Academy's objective is to integrate and further reinforce our knowledge of the natural development, socio-economic and cultural development of the Wadden Sea and the Wadden Sea Region in a way which is substantively stimulating for science and relevant to policy. The Wadden Academy believes that the integrated research agenda before you, which has been drawn up in close cooperation with numerous researchers and representatives of social and governmental bodies, will make an important contribution to achieving this objective.

The Wadden Academy therefore hopes that this research agenda will be used by policy-makers, administrators and scientists as an integrated and thematic framework and as a benchmark on the basis of which they can make choices in the area of Wadden Sea research in the years to come. However, the research agenda is not set in concrete, as both science and the Wadden Sea Region are constantly developing. The Wadden Academy will therefore ensure that a regular review will be carried out to ascertain whether choices which are now being made are still justified or whether there is any reason to update parts of the research agenda.

The research agenda has been compiled in a constructive and intensive dialogue with all the parties involved in the Wadden Sea Region. The contents of the research agenda are based on a number of position papers (see Appendix 1 for a summary). These position papers contain contributions from a wide range of scientific researchers in the Netherlands, representing all the relevant disciplines. Containing comprehensive lists of references to the sources and literature used in this research agenda, the position papers will be published separately by the Wadden Academy in June 2009.

The research agenda is arranged as follows:

- In the first section, a number of general principles are set out which have been important to the Wadden Academy in drawing up the research agenda.
- In Section 2, the scientific foundations and the knowledge gaps described in the research agenda are explained in respect of the themes used as building blocks in the integrated programming process.
- Section 3 puts Wadden Sea research into an international perspective.
- Section 4 describes the integrated nature of the research agenda.
- Section 5 discusses the implementation of the choices made in the research agenda.





1 Introduction

The international Wadden Sea has evolved over the last 8,000 years, and is therefore a very young ecosystem in geomorphological and evolutionary terms. It is one of the world's most beautiful examples of a temperate-climate sandy barrier coast that developed with the rising sea level in the Holocene (see **figure 1**). The present Wadden Sea is unique in that it consists entirely of a tidal system with sandy-muddy sedimentation and only minor riverine influences on morphodynamics. The Wadden Sea ecosystem is characterised by a system of tidal flats and barrier islands with extensive salt marshes. The Wadden Sea is also the only depositional system of this scale and diversity in the world. The tidal flats in the Wadden Sea form the largest unbroken stretch of sandflats and mudflats worldwide, accounting for 60% of all tidal areas in Europe and North Africa. As such it is 'the only one of its kind' and a textbook example of an intertidal habitat and the rich and diverse flora and fauna it sustains. Many examples of biogeomorphological processes can be found in the coastal dunes, the salt marshes, and on the tidal flats with mussel beds and eel grass meadows. This transitional environment between land and sea is characterised by the constant change of flood and ebb tides, great fluctuations in salinity, high temperatures during summer and occasional ice cover in winter. These circumstances have created numerous ecological niches, colonised by species that are adapted to these extreme environmental conditions.

Since the publication of the Mazure Committee report in 1974, the realisation has dawned that the Wadden Sea Region is a unique region, which has to be treated with extreme care. This realisation has now gained in influence at local, regional, national and international level. In the Netherlands, over a quarter of a million people live, work and spend their leisure time in the Wadden Sea Region. The number of people who feel involved in the natural tidal flat system is many times that figure.

The increasing realisation of the region's unique value has resulted in legislation and regulations, the guiding principle of which is to preserve the natural value and cultural-historic value of the Wadden Sea Region, allowing shared human use where this is sustainable.

This is also a guiding principle for the Wadden Academy. The Wadden Academy does however note that there is considerable debate regarding the prospects for shared human use in the Wadden Sea Region. This debate benefits from thorough interdisciplinary scientific knowledge of the current situation and how the current situation has arisen from interaction between humans and their environment throughout the ages.

Wadden Sea research has for many years been dominated by the natural sciences. Socio-economic research and, to a lesser extent, historical research is grossly under-represented in terms of volume and importance. The Wadden Sea Area should figure more prominently on the research agenda of economists, historians, sociologists, psychologists, anthropologists and cultural scientists. They can identify those who feel involved in the Wadden Sea Area and in what way, how this involvement is justified in history, what interests are at stake, what reference images of the landscapes are used and how this will affect the future of the area.



figure 1 A few important coastal zones with barrier islands and tidal flats.

A key task for the Wadden Academy is to study changes which are taking place over different space and time scales and are the result of the interaction between the geosphere, hydrosphere, atmosphere, biosphere and humankind and society. In the approach adopted by the Wadden Academy, great value is attached to knowledge of the region's long past and present. However, as far as the Wadden Academy is concerned, historical states of the natural and sociocultural system do not automatically become reasons for thinking about the region's future. The Wadden Academy aims to conduct research into conceivable future scenarios

Wadden Sea Area, Wadden Sea Region and Wadden Sea Provinces

The 'Wadden Sea Region' has been interpreted in the broadest sense in the research agenda. The four maps below illustrate the four territory designations covered by the agenda. Four different terms are used for them.



figure 2 the Wadden Sea Area

'The Wadden Sea Area' is used to indicate the area covered by the Key Planning Decision (PKB), as defined in the Third Wadden Sea Policy Document. It consists of the Dutch Wadden Sea plus the areas outside the dykes on the inside of the islands and the mainland.

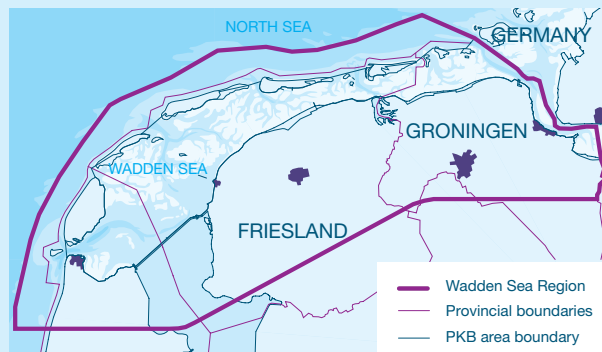


figure 4 the Wadden Sea Provinces

'The Wadden Sea Provinces' is used to roughly denote the marine clay area of the three northern provinces; that area of Noord-Holland, Friesland and Groningen that belongs to the Wadden Sea Region in cultural history and economic terms.



figure 3 the Wadden Sea Region

'The Wadden Sea Region' is used to denote the area that includes the Dutch Wadden Sea, the islands including the North Sea coast up to the 15 m depth line and the towns on the mainland that border on the Wadden Sea. This is also the working area of the Regional Wadden Sea Region Board.

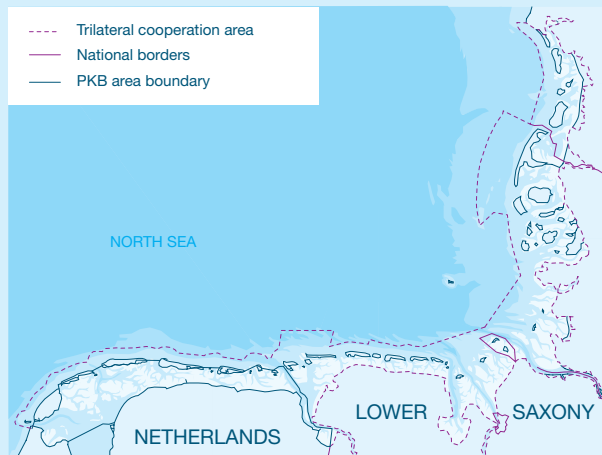


figure 5 the international Wadden Sea Area

'The international Wadden Sea Area' is used to denote the entire area that borders on the international Wadden Sea from the western Netherlands to western Denmark. This mainly coincides with the PSSA (Particular Sensitive Sea Area).

By 'the tidal flat system' we mean the entire body of knowledge obtained by the collected scientific disciplines on patterns, structures, processes and factors that operate together in the Wadden Sea Region and which are therefore vital for understanding and managing the region.

in which environmental and socio-economic developments or – rather – options are sketched out. What are the real options for preserving things of value and what investment do they require? What values may be created under the changed circumstances that will occur in future and how can we encourage this creation?

The trilateral Wadden Sea Region has a prominent and special role in the global ecosystem. The region represents unique natural values, the protection of which is laid down in legislation and regulations. The Wadden Sea Region also represents great value for the people who make their living from it. In addition, the movable and immovable heritage is an important force in creating identities and communities. An interdisciplinary perspective on value(s), valuing practices and value creation is therefore an obvious item on the Wadden Academy's research agenda. The Wadden Academy has set itself the goal of compiling knowledge on the way in which the natural and cultural values of the region are experienced and formed and how they can be incorporated into innovative and sustainable use by residents and visitors.

There is a great deal of professional knowledge about the Wadden Sea Region but existing knowledge and expertise is, to a large extent, fragmented and compartmentalised. The lack of an interdisciplinary approach is a limiting factor when it comes to understanding how the Wadden Sea Region functions as a system, e.g. in terms of shared human use, climate change (including sea-level rise) and nature restoration measures. In a system approach, different elements, features and processes of a (linked natural/socio-economic/cultural) system are explicitly brought into contact with each other. The emphasis is on the following aspects: feedbacks between and within different subsystems, consistency of the descriptions, coherence of different process descriptions on several scales, completeness of the descriptions and verifiability of the descriptions and the availability of the necessary data and/or experiments.

System thinking is in keeping with thinking in terms of resilience and the Triple-P approach (people, planet, profit), as shown in **figure 6**. The diagram shows that the resilience of the Wadden Sea Region is found at the (complex) interface of three domains, i.e. ecological resilience, economic resilience and social and cultural resilience.

Knowledge requirements

To enable it to perform its tasks as efficiently as possible, the Wadden Academy remains in close contact both with the scientific community and with policymakers and administrators at local, provincial, national and international level. Specification of knowledge requirements by policymakers is an important line of approach in the Wadden Academy's way of working, as is co-production of knowledge by scientists and policymakers. For this reason, over the past few months, the Wadden Academy has been having ministerial and departmental consultations with the Dutch Ministries of Agriculture, Nature and Food Quality, Housing, Spatial Planning and the Environment, Public Works and Water Management, Economic Affairs and Defence. One of the main subjects in each consultation was the question as to how ministerial research programmes concerning the Wadden Sea Region should be applied in future. This consultation process will continue periodically.

The scientific aspects of advisory services provided by the Wadden Sea Council have been coordinated with the Council. Meetings have been held with the Regional Wadden Sea Region Board to discuss which knowledge demands have to be met in order to perform the tasks set out in the Management and Development Plan. It has been agreed with the directors of the Nature and Reinstatement Programme that the Wadden Academy will assume responsibility for ensuring that the programme has scientific backing.

To study the interaction between science and policy in the Wadden Sea Region, the Wadden Academy has itself commissioned qualitative research into policy-science interactions. The results of this research will be published by the Wadden Academy as a separate report. The outcome of the consultation held with representatives of management and policymaking bodies has produced the three major knowledge programmes, two conditional themes and three integrated research programmes that the Wadden Academy is proposing to implement over the next few years. They are listed in Section 4 of the research agenda.



figure 6 Resilience of the Wadden Sea Area and the three Ps of the Triple-P approach.

The ecological resilience of a region is an indication of the way that region is able to adapt to changing ecological conditions, such as desiccation and desalination. The economic resilience of a region is an indication of how vulnerable it is to economic phenomena, e.g. an economic recession such as the present credit crisis, globalisation and technological innovation. Social resilience relates to the presence of sufficient 'social capital' and is an indication of groups' ability to create meaningful ways of living together. Universally known examples of social capital are neighbourly assistance, shared norms and views, social control and trust as well as the work ethic.

A resilient Wadden Sea Region requires 'adaptive capacity'. An essential part of this is harmony between the three Ps of the Triple-P approach, i.e. nature, society and economics must be harmonised. In the case of the Wadden Sea Region, P as in Planet is key.

It is the ambition of the Wadden Academy to develop the Wadden Sea Region into an incubator for widely applicable integrated knowledge of sustainable development of a coastal area, in which natural values are a key element and form the foundations of the local and regional economy. The region is a meeting place for scientists from the Netherlands and elsewhere, administrators, policymakers and management agencies. Together, they develop sustainable and innovative solutions based on interdisciplinary knowledge. By 2020, the trilateral Wadden Sea Region will be the best monitored and best understood coastal system in the world.

2 A sound scientific basis





2 A sound scientific basis

This section specifies the 'state of the art' for six major disciplines of importance to the Wadden Sea Region in terms of knowledge. It also sets out the main gaps in each discipline's knowledge. The international aspects of the research are discussed in Section 3.



2.1 Geoscience; the development on the Wadden Sea Region in time and space

Introduction

With the North Sea to the north of the islands, the Wadden Islands, the Wadden Sea situated behind them and the coastal zone of the mainland as its main elements, the region is characterised by its powerful dynamics, both in space and in time. The present condition and dynamic characteristics of the tidal flat system are the cumulative result of processes deep in the earth, near and on the surface and in the atmosphere which take place on different space and time scales. Changes to the surface of the tidal flat system are caused by natural processes and by recent human activities.

Geoscientific data, information and knowledge, including the modelling and quantifying of geological processes in time and space, are needed to achieve the goal of maintaining (partially 'restoring') the Wadden Sea Region with its current characteristics in a sustainable manner. This includes the natural system, safety for residents and the economic yields generated by natural resources such as groundwater, salt and natural gas. Of course, the Wadden system cannot be viewed in isolation but must be regarded as a part of larger natural systems.

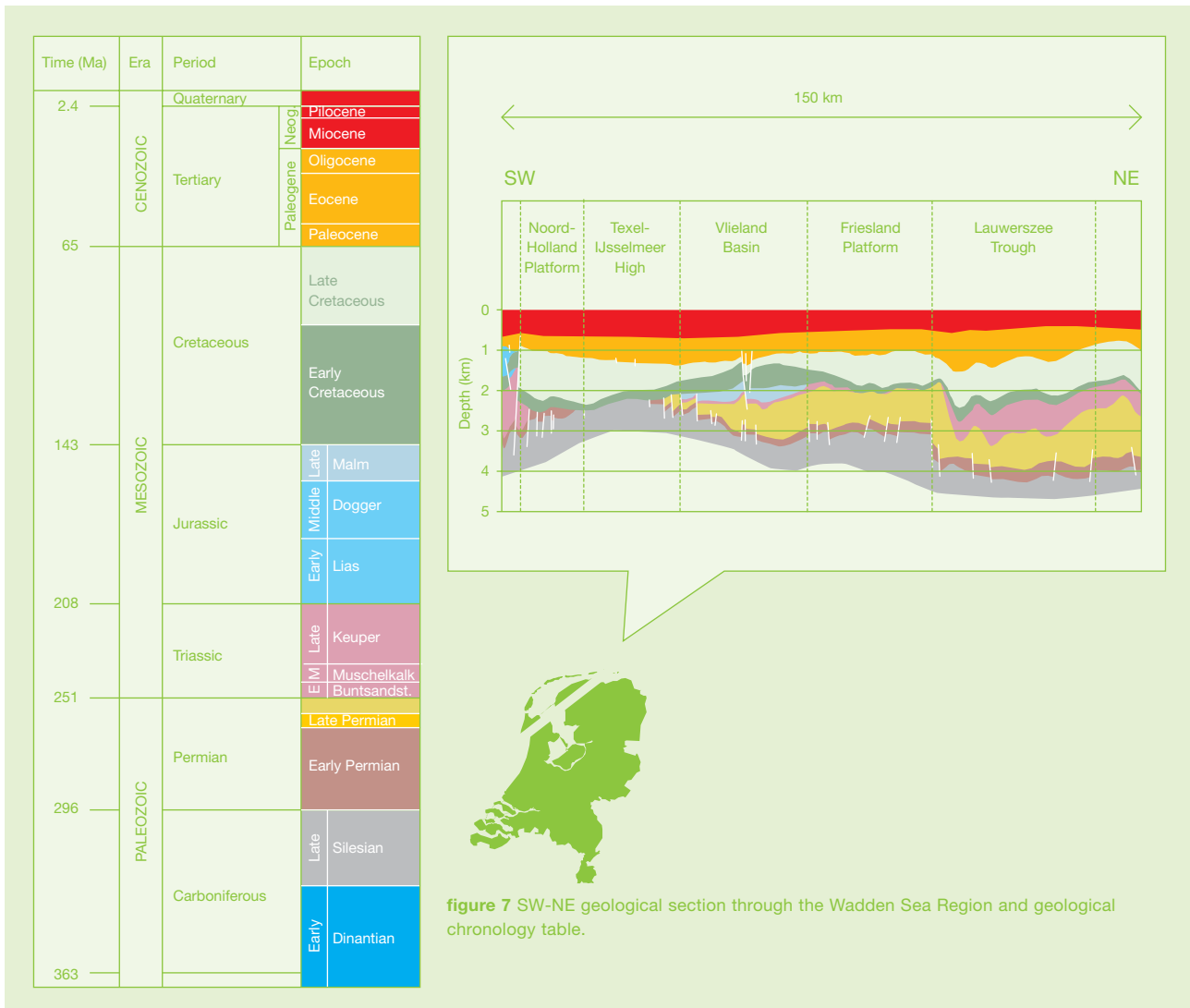
Three connected themes can be identified in the development of the Wadden Sea Region in time and space. The themes are Wadden Sea Region Subsurface, Wadden Sea Region Evolution and Wadden Sea Morphodynamics. The current status of the relative knowledge is described for these themes. Gaps in knowledge and research questions are also identified so that data, information and knowledge that contribute to the sustainable development of the Wadden Sea Region can be acquired. Most of these questions relate to the discipline of geoscience. But, often, they can only be answered satisfactorily with contributions from other domains. This will be explicitly stated where applicable.

1 The subsurface of the Wadden Sea Region

The Wadden Sea Region Subsurface theme focuses on the geological composition and structure of the subsurface and the physical-chemical properties of rocks, faults and fluids in the subsurface, the processes that take place over a considerable geological time and space scale and the relatively fast-moving processes in the subsurface which are connected with the use of the subsurface.

Geoscientific data and information from the Dutch soil/subsurface and from the natural resources they contain are managed at national level in a geoscientific information system. The information that the system contains includes deep and shallow drillings and borehole measurements, groundwater levels, soundings, geophysical measurements and results of geological, geochemical, geobiological and geomechanical analyses of rock and fluid samples. This type of data and information has been consolidated in maps and models at various scales, with relevant descriptions. Most of the mapping of the subsurface under the Wadden Sea Region at depths between 300 and 4,000 metres is based on the analysis and interpretation of 'old' 2D seismic data. More recent, much more informative 3D seismic data is gradually being released, following the new Dutch Mining Act [*Mijnwet*] of 2003, which also states that information concerning characteristics of rocks and fluids should be released more quickly. This is because detailed knowledge of the composition and characteristics of a deeper subsurface in the Wadden Sea Region is concentrated around areas where gas and salt extraction takes place and, in this case, the knowledge mainly concerns the most important reservoir and salt-bearing rocks.

The geological and hydrogeological composition of the relatively shallow subsurface has been mapped since the 1970s, and recently updated. This involves the subsurface from the earth's surface to a depth of approximately 300 metres (moderately deep subsurface), and more recently also a general description of the first 30 metres of the subsurface (the 'top system'). There is currently insufficient funding to provide further detailing of the area. Further detailing of the hydrogeological and geological composition of the subsurface of the Wadden Sea Region to a depth of approximately 300 metres is also required in order to gain a better understanding of matters such as spatial variation in natural compaction and regional groundwater flow. Detailed knowledge of the hydrogeological composition of the subsurface is available in groundwater extraction areas.



Varied and complicated composition and structure

Rocks have been drilled in the subsurface of the Wadden Sea Region which are up to 300 million years old. Over these millions of years, the Wadden Sea Region has experienced a highly varied development with characteristics and effects that also determine the Wadden Sea Region that we see today, which probably did not come into being until about 0.005 million years ago (see The evolution of the Wadden Sea Region).

From a geological point of view, the subsurface of the Wadden Sea Region is not a unit (see **figure 7**). The region is part of five different structural elements, each with a characteristic

history of sedimentation, upheaval and erosion. From west to east, the elements are as follows: Texel IJsselmeer High, Vlieland Basin, Friesland Platform, Lauwerszee Trough and Groningen High. For most of geological history, the Texel IJsselmeer High was an elevated area, where relatively little sedimentation and a lot of erosion took place. By contrast, Lauwerszee Trough, which was bounded by faults, was a mainly subsiding area on which a thick layer of sediment was deposited. The faults were regularly active until geologically recent times. The vertical throw along the main north-south Hantum fault zone level with Lauwerszee Trough extends as far as 1,100 metres. Typical of the relatively shallow and lightly faulted Vlieland Basin is the presence of the remains of the – approximately 150 million year old – Zuidwal volcano which were found approximately 2,000 m below sea level.

Natural gas in the subsurface

The oldest rocks drilled in the Wadden Sea Region date from the Late Carboniferous (300 million years ago). These occur under the entire Wadden Sea Region and mainly consist of clay stone containing strata of sandstone and coal. The strata of coal are the main source of natural gas. The top of the Carboniferous layer has a strongly pronounced contour, which is situated in the west at a depth of 2,500 metres and reaches a depth of over 4,000 metres in the Lauwerszee Trough. On top of the Carboniferous layer are the sandstones from the Upper Rotliegend. These rocks are covered by thick Zechstein salt strata. The Carboniferous coal strata, Upper Rotliegend sandstones and Zechstein salt strata are the main elements of the important Carboniferous-Rotliegend gas system: a number of gas fields are present in the Upper Rotliegend sandstones under the Wadden Sea Region. Owing to subsequent erosion, the Upper Rotliegend sandstones and the Zechstein salt strata are not present on and around the Texel IJsselmeer High and the natural gas in that area has migrated to more recent and shallower strata in the course of history (e.g. the gas deposit in the Zuidwal area).

Salt in the subsurface

The presence of Zechstein salt strata has had a major impact on the subsequent structural and sedimentary evolution of the Wadden Sea Region. Salt deforms much more readily than competent rocks such as sandstone and limestone. Faults in the rock below the salt do not usually continue into the salt. Major phases of salt deformation are synchronous with phases of tectonic activity and often related to fault zones. Major salt structures are particularly common in the eastern part of the Wadden Sea Region, such as the Ternaard salt cushion situated along the peripheral faults of the Lauwerszee Trough, the Groninger Wad salt dome and the Pieterburen salt dome. Salt movements have occurred until geologically recent times.

The geological period following the Zechstein until the early Cretaceous was a dynamic period with a lot of tectonic activity; a great deal of the sediments originally deposited from that time disappeared as a result of subsequent erosion. The mostly marine sediments (sand, claystone, marl, cretaceous chalk) from the Cretaceous period (144-65 million years ago) and marine, deltaic, fluvial and glacial sediments from the last 65 million years (during the Tertiary and Quaternary periods) are present throughout the Wadden Sea Region in varying thicknesses.

This complex geological history manifests itself not only in the geological composition and structures but also in the variation in characteristics and behaviour of the rocks (such as geochemical composition, porosity and permeability, thermal conductivity and compaction behaviour) and pore fluids (pore pressure, salt content of formation water and the fresh-salt distribution in groundwater) and in the temperature distribution in the subsurface (relatively high temperatures in the Zuidwal area and above salt structures).

Groundwater

Knowledge of the groundwater systems (quantitative and qualitative) is of great importance to management now and in future for people, agriculture and nature. The dynamics of the hydrological system are related to the dynamics of the landscape of the islands. For example, the dynamic development of the Wadden system in the Holocene, such as the rapid coastal migration and topographical development, had a direct impact on the shape and size of the freshwater resources under the islands and under the coastal zone and therefore on their distribution, on groundwater flow patterns and on the height of rise of fresh and salty groundwater. Important questions remain with regard to the future physical and chemical development of quality zoning as a result of processes such as fresh water lens formation, salt water intrusion and decalcification. Trends in precipitation and evaporation related to climate change provide additional dynamics (not fully understood).

Continued effect of deep structures on the surface

The coastal formation and topographical development of the Wadden Sea Region, as described in the Wadden Sea Region Evolution theme, have probably been directly or indirectly affected by the location and/or activity of structural elements (such as faults and salt structures), the heterogeneous composition of the subsurface and the continuing effect of geological processes. There is no good – quantitative – information on the individual contributions by the various geological influences on this Holocene evolution (the dynamic development) of the Wadden Sea Region that we see today.

Land movement

Land movements (land subsidence, land rising and earthquakes) partly determine the present and future topography/bathymetry of the Wadden Sea Region. Processes that cause land movement are partly the result of natural causes (isostasy, tectonics, compaction) and partly related to the extraction of natural gas, salt, groundwater, the storage of gas and water level control. These processes are fairly well understood. However, the various natural and anthropogenic causes of land movement are accumulating and intertwining. The quantitative contributions of the individual processes are still not fully known. For example, the relative contribution of different sedimentary layers to the natural subsidence of land and the spatial distribution of the rates at which it subsides is uncertain. Changes in groundwater pressure distribution, e.g. as a result of extraction, polder level control and even tidal movements, play a part in land movements but there is no clear view as to the relative importance of the various natural and anthropogenic causes of groundwater-related land movement.

Earthquakes related to natural gas extraction are closely monitored. At the present time, it is not feasible to predict them (either locations or magnitudes). The magnitude of earthquakes induced by the current natural gas extraction operations in the Wadden Sea Region is limited.

2 The evolution of the Wadden Sea Region

The Wadden Sea Region Evolution theme mainly concerns the natural development and dynamics of the Wadden Sea Region over time scales ranging from decades to thousands of years, including the powerful anthropogenic impact of the last two centuries in particular on the system. The Wadden system is a barrier system consisting of barrier islands and the Wadden Sea behind them. The Wadden Sea is partly an intertidal region which dries out at low tide. The region is drained by tidal channels which discharge into the North Sea through tidal outlets. The outer deltas are located on the sea side of the tidal outlets.

A product of sea-level rise

Throughout geological history we have only seen systems like the Wadden Sea Area in periods characterised by sea-level rise. The Wadden Sea as we know it was probably created 6,000–5,000 years ago during the period of continuous but not constant sea-level rise which began in the Holocene, starting 10,000 years ago, after the end of the last Ice Age. Under the effect of the continuous rise in the sea level after the creation of the Wadden Sea, the barrier islands withdrew landwards across several kilometres. The Wadden Sea was also shifted with the southerly migration of the islands. Large-scale peat beds were created south of the Wadden Sea. On the sea side, the Wadden Sea Region was and is protected by the barrier islands. Land subsidence, which is partly due to human activity (including peat extraction), had a hand in the formation – due to inundation during major storm surges, such as the All Saint's Flood [*Allerheiligenvloed*] of 1570 – of the Zuiderzee, Middelzee and Lauwerszee. Some of these inundations may also be connected with some sea-level rise during the period in which the Zuiderzee, Middelzee and Lauwerszee were formed. There is also a self-reinforcing effect because the newly created sea areas caused greater differences in tides, which in turn increased the erosion of areas such as peat beds.

The Wadden system consists of a series of tidal inlet systems. An outer delta, the adjacent extremities of islands ('island points'), the tidal inlet, the channels and the flats of a tidal inlet system form a single unit, known as a tidal basin. Developments in the different parts of the area are closely interlinked and are mainly determined by the tidal prism. The adjacent tidal inlet systems have an impact on each other, mainly from west to east. Under the effect of the prevailing easterly wind direction and the west-to-east tidal flow along the coast, the tidal inlet systems and therefore the islands between them have a tendency to move eastwards.

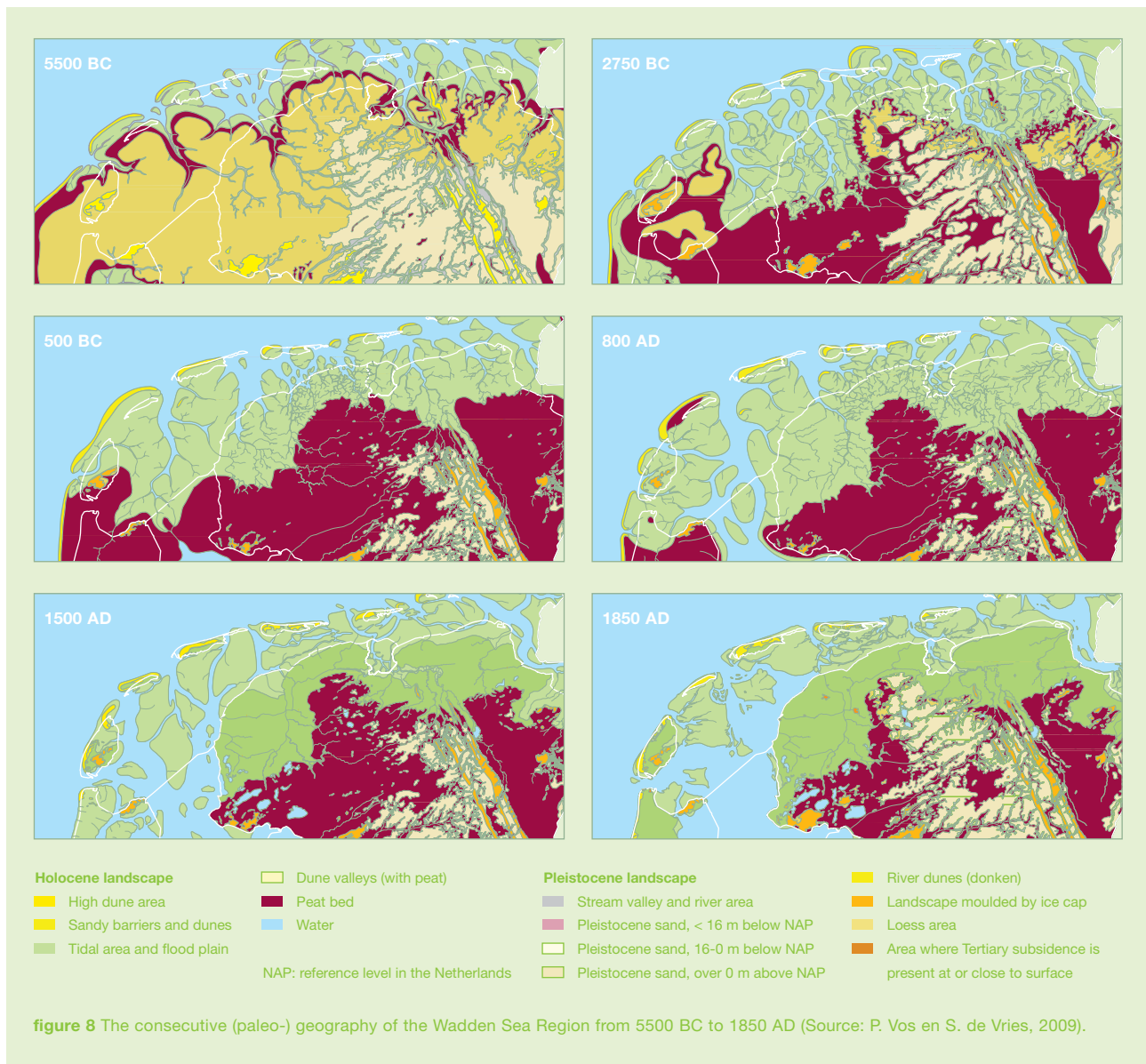
This is how the Wadden Islands have developed over a period of thousands of years. Over the centuries, characteristic main shapes formed on the islands under the effect of wind, sea, sand and vegetation, such as an island head, island tail and dune rows. Within them, smaller components developed, such as salt marshes and dune valleys.

A precarious balance

If the sea level stopped rising or actually fell, the Wadden Sea would silt up over time. If the rate of sea-level rise increases, it is expected that – without human intervention – large parts of it will become 'swamped' or, in other words, end up completely below the low-water line. The continued existence of the Wadden Sea as we know it is therefore determined by fairly narrow margins in terms of changes in sea level.

Understanding the genesis and future evolution of the Wadden Sea requires knowledge of relative sea-level rise, trends in tides and storm surges, large-scale sediment transport, morphology and interaction with biological and anthropogenic processes. It is therefore worthwhile distinguishing between the Pleistocene pre-history, the Holocene and the 'Anthropocene'.

The most important thing about the Pleistocene is the development of what is known as the 'forebulge', a topographical bulge on the front of an ice cap. During the Weichselian ice age, the northern Netherlands was probably situated on top of the forebulge while the central Netherlands was clearly on its southern flank. The increased settlement of the forebulge in a northerly direction after the ice cap disappeared has resulted in a more rapid sea-level rise in the northern Netherlands than in areas further south, possibly to this day. This means that the Pleistocene sediments in the northern Netherlands were originally higher than those in the southwest Netherlands but subsided faster. All of this had an impact, probably great but little understood in many details, on the development of the



northern Netherlands and in particular of the Wadden Sea Region and on the adjacent peat bed which was so important to the Wadden Sea Area at the time. If the differences between the western and eastern Dutch Wadden Sea Region are a relic of an Ice Age, we can still expect changes to a more comparable balanced situation in both parts. Land subsidence, island migration to the south, sand demand and ecological development are closely related to this.

The Wadden Sea Region's Holocene was very recently reconstructed on a semi-detailed scale and recorded in a set of maps with explanatory notes. The maps provide many pointers to the way in which the Wadden Sea Region developed. Six of them are shown in **figure 8**. The important question is: to what extent is the Holocene 'memory', e.g. in terms of channel and basin development, still a determining factor for current and even future trends? Models are mostly adjusted to the existing Wadden Sea Region and the water movements measured in it. The reconstructions of morphology and paleo-tides are now enabling us to use a wide variety of channel configurations to develop long-term models. This innovation would not only generate a greater understanding of the trends observed in the paleo-environment but also greatly improve future projections.

The Anthropocene is characterised by the major (intended or unintended) impact that humankind is having on its environment.

Humankind asserts itself

Since the High Middle Ages, the size of the Wadden Sea and the length of the coastline have been decreasing as a result of land reclamation. The oldest ring dykes were built around places such as Middag and Humsterland, followed by the Middelzee and subsequently areas in the northern regions of Noord-Holland, Friesland and Groningen and, in the twentieth century, the Zuiderzee and Lauwerszee. In fact, hydraulic structures (polders, salt marshes, dams and – most recently – sand suppletions) have been affecting the evolution of the Wadden Sea Region for a millennium and humankind has been proving to be a major ‘geological force’ during this period.

The inherent landward migration of the Wadden Sea has been blocked due to the construction of hydraulic structures and it has become kilometres narrower. If hydraulic structures had not been built, the Wadden Sea would therefore be substantially wider, the clayey part of the surface would be considerably thicker and the coastline would be much longer. As a result of human intervention, the present length of the coastline is a mere quarter of what it was in the year 1200 (see **figure 9**).

By constructing dykes and laying a strip of dunes along the North Sea coast, people have practically ended the natural dynamics of the different morpho-ecological elements of the Wadden Islands (island head, dune row complex, washover complex, island tail and beach/shore-face). This is mainly due to the restriction of wind- and water-driven sediment delivery and removal. For this reason the sedimentation and erosion on the islands is out of phase with the dynamics of periodic land subsidence and rise in the adjacent shoreface systems. Furthermore, the reduced dynamics can have a major ecological impact, mainly due to acceleration but sometimes also due to stagnation of the natural vegetation succession. Recent research into the options for combating both developments is leading to the conclusion that sustainable island management must consist of a combination of restoring the large-scale elements and allowing dynamics (overwash, storm erosion and aeolian sand transport) and, where this is not possible, of targeted management measures (grazing, mowing and turf-cutting).

3 The Morphodynamics of the Wadden Sea

The Wadden Sea Morphodynamics theme focuses on short-term dynamics and relates to natural and human-influenced processes/changes that take place on an ‘engineering’ time scale (from seasons to decades).

The Wadden Sea, the tidal inlets and the North Sea coasts of the Wadden Islands exhibit very dynamic behaviour. The dynamics relate to the flow of water and air and the transport, erosion and sedimentation of sand and mud. These processes result in a constantly changing morphology (topography/bathymetry) of the islands, the flats and the channels. Together with the biotic systems, this dynamic development – of the form and nature of the Wadden Sea Region – forms today’s tidal flat system.

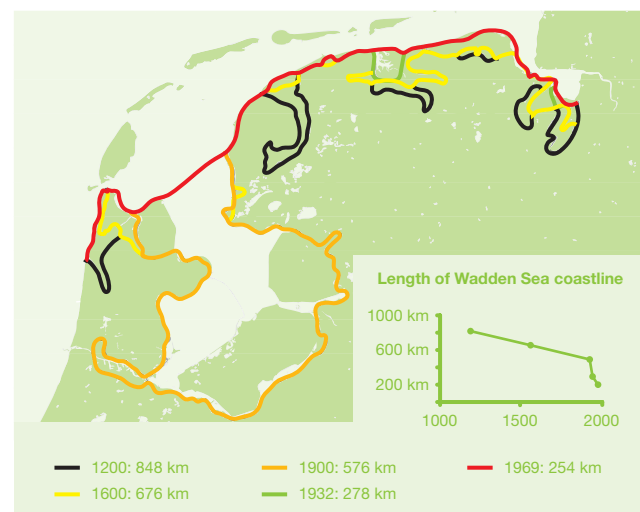


figure 9 Decrease in coastline length over the centuries, reconstructed from historical maps (Source: H Olff, 2009).

Seasonal fluctuations are an important factor along the North Sea coasts of the Wadden Islands. Erosion of beaches and dunes takes place during storms but this is partly or completely compensated by sand deposition when conditions are calm. This is usually encouraged in the coastal strip of dunes by erecting sand-drift screens. These processes cause soil fluctuations which can mount up to several metres, particularly in the shoreface, due to the displacement of breaker banks. On some Wadden Islands, especially Ameland, an annual regression of one or more metres takes place in the central part of its North Sea Coast.

Sand suppletions

Since 1990, the Dutch coast (the basic coastline) must, by law, be preserved and coastal erosion is being compensated by means of sand suppletions. The frequency of these suppletions depends on the rate at which the coast is receding. A substantial number of coastal suppletions take place in and around the Wadden Sea Region. This is probably because the Wadden Sea draws in a lot of sediment due to the 'sediment hunger' resulting from sea-level rise and human interventions (damming up of Zuiderzee and Lauwerszee). The Wadden

Sea is an important sediment drain for the Dutch coastal system (see **figure 10**). Some of this sediment comes from sand suppletions deposited on the coasts of Noord and Zuid-Holland since 1990. Some of the sand from the 'sand engine' [*zandmotor*] (an excess of sand deposited at one location on the Zuid-Holland coast) will also migrate to the Wadden Sea Region.

Until 2000, only the basic coastline of the Dutch coast, including the Wadden Islands, was preserved, which resulted in a sand suppletion in the order of 6.5 million m³ per annum. Under the current policy in force since 2000, as well as preserving the basic coastline, the suppletions must also be sufficient to ensure that the coastal foundations grow as the sea level rises. This requires an annual suppletion in the order of 12 million m³. If sea-level rise accelerates and if we want to take account of sediment loss from the coastal system, even more suppletion will have to take place in future.

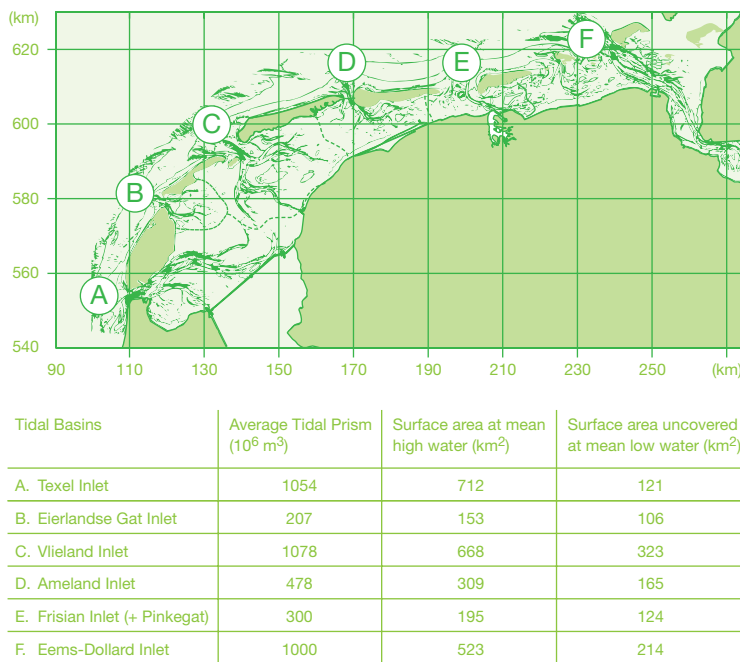


figure 10 Characteristics of the various tidal basins in the Wadden Sea
(Source: Wang, 2009).

The dynamics of the North Sea coast are becoming stronger towards the tidal inlets. This is caused by the dynamic behaviour of the channels in the outer delta and the tidal inlet. Under the effect of the tidal current and the lateral sand movement of the coastal transport, these channels generally migrate from west to east. This often gives rise to a certain cyclical behaviour in which the existing channel decreases in size as it approaches the east side of the outer delta and finally disappears. At the same time, a new channel appears on the west side of the tidal inlet, growing as it migrates, and takes over the task of the old channel. This process causes very dynamic behaviour of the channels in the tidal inlets and of the adjacent extremities of the Wadden Islands. Movements of hundreds of metres a year are completely normal.

The seabed in the Wadden Sea also exhibits dynamic behaviour due to movements of the water and the channel. Level changes of up to a few decimetres a year on the flats as a result of channel migration in or right next to the channels of up to somewhere in the order of one metre are regular occurrences.

Studies of the sediment balance have been carried out for various parts of the Dutch coastal system, usually based on soundings which have been held since 1926 and are presented in map sheets. However, the different balance studies contradict each other in important details and so, when using them, researchers have to take account of the uncertainties and inaccuracies they contain which were usually caused by non-simultaneous measurement (once every six years) and a relatively rigid classification which does not do justice to the real dynamics of the tidal divide (the watershed between two tidal basins). Studies conducted until now also do not distinguish between the different sediment fractions, i.e. between a build-up of mud and a build-up of sand, an important distinction both morphologically and ecologically. There is consensus about the fact that there is a critical rate of sea-level rise above which the Wadden Sea will start to be swamped, but not about what the critical rate of sea-level rise actually is.

The system is self-regulating

In general terms, a type of dynamic equilibrium does seem to exist for a tidal inlet system (see **figure 11**); it has a certain self-organising capacity. This is evident from the fact that the morphological condition of the system exhibits a good correlation with the hydrodynamic conditions. The tidal flat area in a flood basin relates well to the size of the basin. The total volume of the channel and of the outer delta correlate well with the tidal prism in the basin. The average tidal flat level measured from low tide relates well to the average difference in tides. Under natural conditions, these morphological quantities change slowly, if at all. A disturbance caused by, for example, human intervention can set a relatively rapid change in motion which will ensure that the natural relationships between the morphological quantities and the hydrodynamic parameters is restored. The same applies to any disturbance caused by a reversal of trend in, for example, sea-level rise. However, the limit to this self-organisation with regard to external constraints (resilience) is not known.

The stability of a tidal inlet is determined by two competing processes: the tidal current that keeps the tidal inlet open and the wind waves that are trying to close it. Less is known about this in quantitative terms and in particular how these processes relate to each other in several linked or unlinked tidal inlets.

The way in which an outer delta is formed is not only reasonably well understood in terms of quality, it can also be simulated in model studies. The model results confirm the empirically determined relationship between the size of the outer delta and the tidal prism as well as the relationship between the orientation of the main channel and the phase difference between the tidal current along the coast and the tidal current through the tidal inlet.

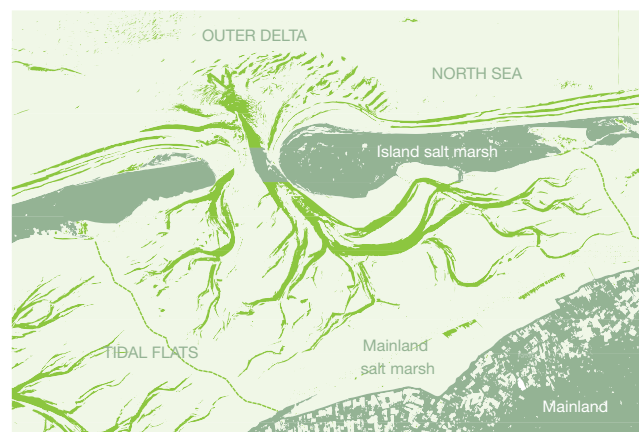


figure 11 The different geomorphological elements referred to in the text, illustrated by the Borndiep tidal basin between Terschelling and Ameland (Source: H. Olff, 2009).

Only recently has it been possible to show analytically that there are morphological balances for strongly idealised basins and their channels. Numerical models can do this for somewhat more realistic situations but it has been found that it is not possible to separate the large-scale morphological balance from smaller-scale phenomena, such as channel networks, banks and meanders in channels, for which separate theoretical analyses can also be found in the literature.

Our knowledge of intertidal areas is perhaps the most limited. The special phenomena of drying out during ebb tides and flooding during high tides make this type of area difficult to model. All kinds of organisms have a considerable effect on sediment characteristics and transport.

Ecosystem engineers

The topography and bathymetry of the Wadden Sea are determined by a combination of both abiotic and biotic processes. The dynamic processes and associated characteristics of soil structure, clarity of the water and supply of nutrients determine the ability of bottom-dwelling organisms to establish themselves. Conversely, so-called ecosystem engineers affect organisms living in and on the seabed that retain mud and sand (including mussel beds, eel grass fields and salt marsh vegetation), the morphodynamic processes. Because of this, these ecosystem engineers are, over large tracts of the tidal flats, the determining factors for their topography and bathymetry.

All of these kinds of processes cause the North Sea coast of the Wadden Sea Region to fluctuate considerably over a scale of years, if not decades. Sand from the outer deltas will be displaced along the islands under the effect of currents moving eastwards along the coast. This will happen first in the form of a more or less coherent sand wave but the sand will continue to split up slowly but surely and the coherence will be lost. The main mechanism in the transport process is the stirring up and transport by waves, which produces a powerful grading effect.

The dynamics reduce drastically in places where the sea and the waves have less free play, such as on high salt marshes and in the dune areas behind the coastal strip of dunes. The sea seldom if ever reaches there and the soil is held together by dense vegetation. For this reason, both the water and the wind cease to have any effect on the sediment. Only slight changes occur as a result of sand drifting inland or mud being deposited during extreme storm surges.

4 Gaps in knowledge

The gaps in geoscientific knowledge concern each of the three (interconnected) themes relating to the development of the Wadden Sea Region in time and space.

The theme of Wadden Sea Region Subsurface

- Regional knowledge in terms of the current geological composition and structure of the subsurface beneath the Wadden Sea Region has been recorded at a scale of approx. 1:250,000. It is recommended that this should be refined to a level of approx. 1:50,000 and – where the available information allows – finer for the top 300 metres. There is a gap in knowledge in terms of the physical-chemical properties of rock, faults and fluids in the subsurface: this knowledge does exist for specific locations and geological strata but there is not a reliable picture for the Wadden Sea Region as a whole. A detailed knowledge of the 3D composition and structure of the subsurface and the physical-chemical properties of rocks and fluids is the basis for modelling and quantifying processes in the subsurface.

- The processes, the interaction between these processes and the properties of rocks and fluids deep in the earth and at or near the surface which are important for understanding the dynamic behaviour of the current tidal flat system and predicting its natural development in future have only been analysed and modelled to a limited extent. These processes have to be analysed and modelled in order to arrive at quantitative judgements.
- The improved knowledge of processes is also needed in respect of present and future use of the subsurface beneath the Wadden Sea Region (currently the extraction of natural resources such as groundwater, salt and natural gas, the storage of gas and exchange of heat and cold; possibly also geothermal energy and storage of CO₂ in future) and the linked changes in the subsurface and their effect continuing to the earth's surface/Wadden Sea bed (to the biotic and abiotic tidal flat system), including land subsidence, land rise and earthquakes on different space and time scales.

The theme of Wadden Sea Region Evolution

- A reconstruction of the morphological development of the Wadden Sea Region during the Pleistocene/Holocene, in particular the relationships with the variations in climate and sea level trends. This involves both the development of the Wadden Sea Region as a whole and differences in development between parts of the Wadden Sea Region under the effect of regional variations in relative sea-level rise.
- The effect of pre-Holocene geological structures (see the preceding theme) on the current geomorphology and the geomorphological processes in the Wadden Sea Region.
- The natural dynamics on the islands (overwash, storm erosion and aeolian sand transport) and the robustness of the islands in different sea-level rise scenarios.
- The dynamics of salt marshes, flats and channels and outer deltas in different sea-level rise scenarios.
- The effect of humankind as a 'geological force' on the Wadden Sea Region from Roman times up to and including the twenty-first century.

Theme of Wadden Sea Morphodynamics

- Detailing of the sediment balance for both sand and mud (including the impact of sand suppletions) of the Wadden Sea Region related, inter alia, to the erosion of the North Sea coast. Aspects of this are the inaccuracies and uncertainties of available data, the frequency of bathymetric measurements and the classifications used in the Wadden Sea classification systems.
- Forecast of the dynamics of the tidal inlet systems likely to occur in the Wadden Sea Region. An outer delta, the adjacent island points, the tidal inlet, the channels and the flats of a tidal inlet system form a single unit.
- Quantification of the processes over an engineering timescale, interaction between these processes (water movement, sand and mud transport, soil changes) in the Wadden Sea.
- Development of modelling tools both through the implementation of improvements in physical-mathematical formulations and improved data.

Cross-domain gaps

Gaps in knowledge that extend across disciplines and domains are of a higher order. Such gaps can only be reduced by combining data and knowledge from different domains. From the point of view of the physical development of the Wadden Sea Region in time and space, these include:

- together with the ecology domain: The effect of biological processes (ecosystem engineers) on soil characteristics and vice versa (biogeomorphology). The statement and prediction of insight into the Wadden Sea is closely connected to this. The interactions of terrestrial vegetation with changing fresh-salt gradients in response to seepage and infiltration;

- together with the cultural history domain: The impact of human activities on physical development in the past, present and future (humankind as a geological force);
- together with the economics domain: The impact of natural gas production, geothermal energy and the storage of heat and cold, natural gas and CO₂ both on the welfare and well-being of the people living in the Wadden Sea Region and on the physical values of the region;
- together with the climate domain: The impact of climate change (sea-level rise, storm regimes) on the morphodynamics of the tidal flats resulting in swamping, silting up or the continuation of the current situation. Reconstruction of paleoclimate trends. Design and evaluation of interventions to improve coastal defences.

For the creation of the geoscientific component of the research agenda for the Wadden Sea Region, the following factors are important:

- The status of the current knowledge base with regard to the Wadden Sea Region: the quality management and accessibility of geoscientific data, information and knowledge are sometimes good and sometimes limited.
- The issues versus the knowledge base: increase in complexity and degree of articulation of cross-domain issues and of issues relating to sustainable development.
- Monitoring (measurement systems), better management and use of (part of) existing data and information and need for new data and information to be acquired to be able to respond to complex issues.
- Quantifying geological processes, especially those during the period from the beginning of the Holocene up to and including the twenty-first century (from descriptive to specific).
- Recruiting and training a new generation of geoscientists with specific knowledge of and expertise in the Wadden Sea Area.



2.2 Ecology;

the ecology of the Wadden Sea Region: an ecological valuation

Introduction

Based on ecology and landscape, the Wadden Sea Region as a whole can be roughly divided into three systems: the Wadden Sea proper, the land-water transition zone and the polders. The Wadden Sea proper is the part which is affected by the tide each day, the land-water transition zone consists of the edges in which the effect of the tide is gradually diminishing (salt marshes, dunes, etc.) and the polders are cut off by dykes. The Wadden Academy's research agenda is to a great extent confined to the Wadden Sea proper and the transition zone. This does not in any way imply that the polders do not have any urgent ecological problems. However, with a few exceptions (particularly the construction of the transitions and the ecological response to climate change and salt-water intrusion), these are more closely associated with the rest of the terrestrial system in the Netherlands than with the problems of the Wadden Sea. Examples are the construction and maintenance of the ecological network, landscape planning in the agricultural area, conservation of grassland birds, scale expansion of agricultural activities, etc. The research agenda for these problems is to a large extent determined in other places. They are not dealt with in detail in this research agenda, except for issues which are specific to the Wadden Sea Region. However, these ecological problems require special attention when considering landscape values or spatial planning. Also, the ecological relationships between the tidal flats and the polders (e.g. between breeding populations and wintering or migrating populations of birds) should receive proper attention.

The Wadden Sea is a rich and extremely dynamic ecosystem, which is also the subject of passionate and emotional debate. Current policy defines the region's natural function as its most important value; the main policy objective is to preserve and strengthen natural values in the Wadden Sea Area. Although this objective has been clearly formulated and recorded, its implementation is not without problems. The Wadden Academy's approach is based on a number of principles which are indicated briefly below and further developed in the text.

The Wadden Sea as a coherent system

As a coherent system, the Wadden Sea is more than an accumulation of separate populations or, in an even narrower approach, natural values. The Wadden system is based on biological, biogeochemical, climatological, hydraulic, geological and geomorphological components and processes. Structure (observable natural values) and function (processes enabling the structure) cannot be viewed in isolation. Coherence between biotic and abiotic components is important: not only trophic interactions (eating and being eaten in the food web) but also interactions that occur via the environment (e.g. mud content being affected by organisms) are important and require a multidisciplinary approach within the natural sciences.

The Wadden Sea as an open system

The Wadden Sea is an open system. Important exchanges of water, nutrients, mud and organic matter take place between the rivers and the coastal sea. As a typical example of these exchanges, much more organic matter is broken down than produced in the system; this can only be balanced out when major net imports of organic matter occur. The open structure requires a conceptual approach to the Wadden Sea as a link in the continuum from land to sea and not as a self-contained or isolated unit.

The Wadden Sea as a dynamic system

The Wadden Sea is a dynamic system. It is in a continuous state of change. On a geological timescale, the Wadden Sea is an ephemeral phenomenon. However, on the much shorter ecological timescale, radical changes can also be observed. Change happens under the in-

fluence of both local (e.g. human exploitation, construction) and global drivers (e.g. climate, invasion by exotic species). Climate-related factors for the ecosystem can be expected to change at accelerating rates during the coming decades.

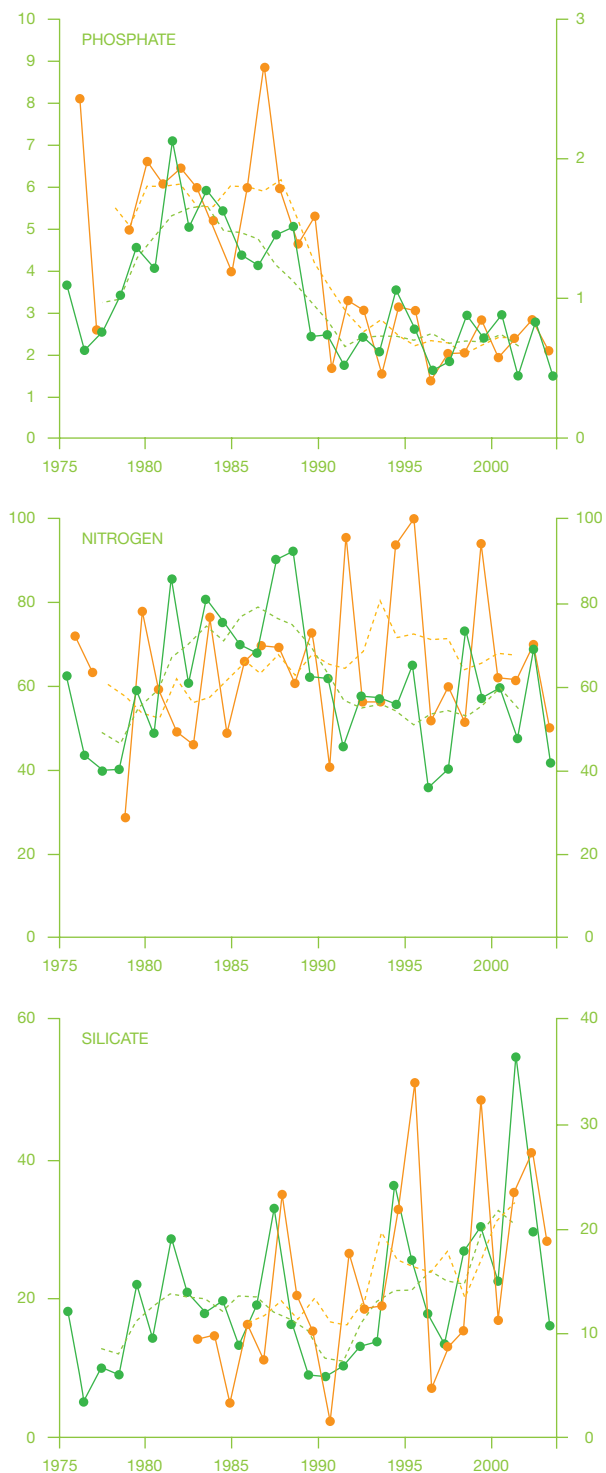


figure 12 Nutrient load from Lake IJsselmeer (solid dots, bold trend line, left axis) and concentrations in the western Wadden Sea at the onset of the spring bloom of phytoplankton (open dots, light trend line, right axis). A. Phosphate B. Nitrogen C. Silicate (Source: Philippart et al., 2007).

The Wadden Sea as a value-rich system

Any discussion of natural values involves the ‘paradox of conservation in a changing world’. Changes are bound to happen in the system, but viewed from the point of view of nature conservation, not every change is equally desirable; within the shifting boundaries of what is ecologically feasible, policy will have to focus on facilitating the most ecologically desirable changes. Because of the shifting baseline, one cannot aim for a history-based target. More generally, a distinction must be made between ‘state’ and ‘value’: what is valuable cannot be defined on the basis of an existing or historic state of the system. An in-depth reflection on the basis of valuation systems is needed. This should explicitly include social, cultural-historical and economic factors. To achieve this, a multidisciplinary study, including life and cultural sciences, is required.

The Wadden Academy is convinced that ecological research can and must remain the basis of the management of the Wadden Sea for the decades to come. In this process, the Wadden Academy regards critical reflection on the relationship between (often implicit) value systems and the role of natural sciences as an important step towards clarifying this role and incorporating it better into the policy as a whole.

1 The base of the food web

The fluxes of energy and matter in a food web determine to a great extent the size of biological populations. Depending on the population’s position in the web, its size may be limited in particular by lack of food (bottom-up) or by pressure from grazers and predators (top-down). This ‘direction’ of regulation is important to ensure the dynamics, diversity and resilience of (part of) the ecosystem. The base of the food web in the Wadden Sea system is primary production by algae which float in the water (phytoplankton) or live on the sediment (microphytobenthos, macroalgae) and by higher plants in the water (eelgrass) and on salt marshes and dunes.

The production of phytoplankton in the Wadden Sea is limited by nutrients in spring and early summer and mainly by light in autumn to early spring. Light in turn is determined by the mud content of the water. Nutrient dynamics of the Wadden Sea has been studied for over five decades, reaching a peak in the years 1970-1980, related to the eutrophication problems recognised during those

years. On the basis of nutrient concentrations, the Wadden Sea appears to have completed an – anthropogenically driven – cycle on a scale of decades, from an initial phosphate

limitation (prior to 1970) to nitrogen and silicate limitation (1970-1990) and back again (see **figure 12**). Primary production rose immediately with the increase in phosphates but responded slowly and with a time lag to their reduction; in terms of structure and function, the entire food web has reached a different state after the reduction in eutrophication than before it started. A more detailed study of these phenomena is required. Observations of primary production are not always consistent with calculations based on nutrient concentrations and changes in light climate have also taken place simultaneously with changes in nutrients. Changes in light climate are also not consistent between different series of observations. Analysis of the historic time series is hindered by the lack of essential monitoring series during the 1990s. Moreover, measurements of primary production are restricted to (discontinuous) series in the Marsdiep (tidal inlet between Den Helder and Texel). Proxies estimating primary production over prolonged periods (e.g. also before the damming up of the Zuiderzee) and a wider area, would make an extremely valuable contribution to our historical overview. They are not available at present.

More organic matter is consumed than produced in the Wadden Sea. The system therefore relies heavily on the supply of organic matter from outside. There are indications that these relationships with the 'outside world' have changed in recent years, because the balance between production and consumption in the coastal zone has changed. It is still unclear how significant this shift is and whether it has been caused by a changed supply of nutrients, system changes in the North Sea or large-scale (cyclical) weather patterns over the North Atlantic Ocean. The effect of changed primary production on the rest of the system is reasonably well understood in qualitative terms, but is still poorly quantified. Moreover, it seems that not only the extent of the primary production is important but also the composition of the phytoplankton. In this case, our knowledge of the benthic system (living on or in the seabed) is greater than our knowledge of the pelagic system (suspended in the water). The role of viruses and parasites in the Wadden Sea is largely unknown and even 'classic' pelagic components such as mesozooplankton and the microbial food web have been insufficiently studied.

Shellfish are an essential link in the food web, as grazers of primary production and as prey for birds in particular. Yet, here too, quantitative knowledge is limited. Intertidal population densities are only monitored in Balgzand and subtidal only for mussels, which makes it difficult to extrapolate them to the Wadden Sea as a whole and other species. Only littoral macrobenthos has been monitored in recent years across the whole Wadden Sea. The populations of shellfish fluctuate sharply from year to year. Recruitment, the success of young organisms shortly after they establish themselves in the sediment, is a key process to understanding how bottom-up processes affect the food web as a whole.

2 The top of the food web

Over the past few centuries, many species have died out in estuarine systems in general and in the Wadden Sea in particular. On the one hand, this involves a number of ecosystem engineers – with serious consequences for the total system, due to their powerful structuring role. On the other hand, they were the top predators such as sharks and rays, porpoises and some birds. The loss of their regulating function has resulted in a simplification of the food web. Historically, the main causes of disappearance have been over-exploitation and habitat loss. Recently, eutrophication and pollution have been added to the list of causes. Worldwide, successful reintroduction and population recovery are usually the result of the simultaneous removal of different causes of disappearance.

The structuring role of predation ('top-down processes' in the food web) in an estuarine system such as the Wadden Sea cannot be studied within the Wadden Sea itself because important predators have now, to a large extent, disappeared from this system. For this

reason, comparative research involving other areas (e.g. in Mauritania and Oman) is important for understanding the possible impact of reintroductions in the Wadden Sea. The Wadden Academy is in favour of explicitly including such research in estuarine systems elsewhere as Wadden Sea research.

Within today's Wadden Sea, predation by shrimps, crabs and starfish is of great importance to the dynamics of shellfish. Shrimps and crabs themselves are eaten by fish, which makes

a cascade effect from fishing in the North Sea on the functioning of the Wadden Sea possible. Little direct knowledge is available on this point.

The feeding ecology of birds is – for a limited number of species such as the knot and the oystercatcher – very well-known and can be modelled in great detail. Because only some of the prey animals are edible (depending on size, shell thickness, habitat depth, etc. of the prey, but also depending on interference between birds) the food supply has to be much larger than what these birds actually eat. The supply of shellfish has a strong impact on the condition and population dynamics of birds and therefore shellfish fishery also has an impact. The relationships are complicated because although migratory birds have some site fidelity, they can also choose between alternative sites. In addition, their numbers are not only determined in the wintering area but also in other parts of their life cycle which take place elsewhere. Over recent decades, remarkably different trends in bird populations have been observed in different parts of the (international) Wadden Sea (see **figure 13**). Closer analysis of these differences could tell us a lot about the direct and indirect impact of management on the bird populations.

Conversely, the direct impact of birds and other predators on the size of shellfish populations is less than the indirect impact – through selection – on the behaviour and energy allocation of these same shellfish.

3 Non-trophic interactions

Non-trophic ecological interactions, i.e. interactions between populations which are not based on eating and being eaten, can be of great importance to the dynamics of an ecosystem. Of particular importance to the Wadden Sea is the role of so-called ecosystem engineers. Ecosystem engineers are species that affect the abiotic environment (e.g. mud content of sediment and water, spatial structure of the habitat), thereby partly determining the quality

of this environment for themselves and for other species. The Wadden Sea contains various examples of ecosystem engineers which determine the mud dynamics in particular: mud is deposited by shellfish in their beds, by microphytobenthos on the flats, by salt marsh vegetation and (formerly) by eelgrass. It is mobilised by many species of burrowing macrobenthos.

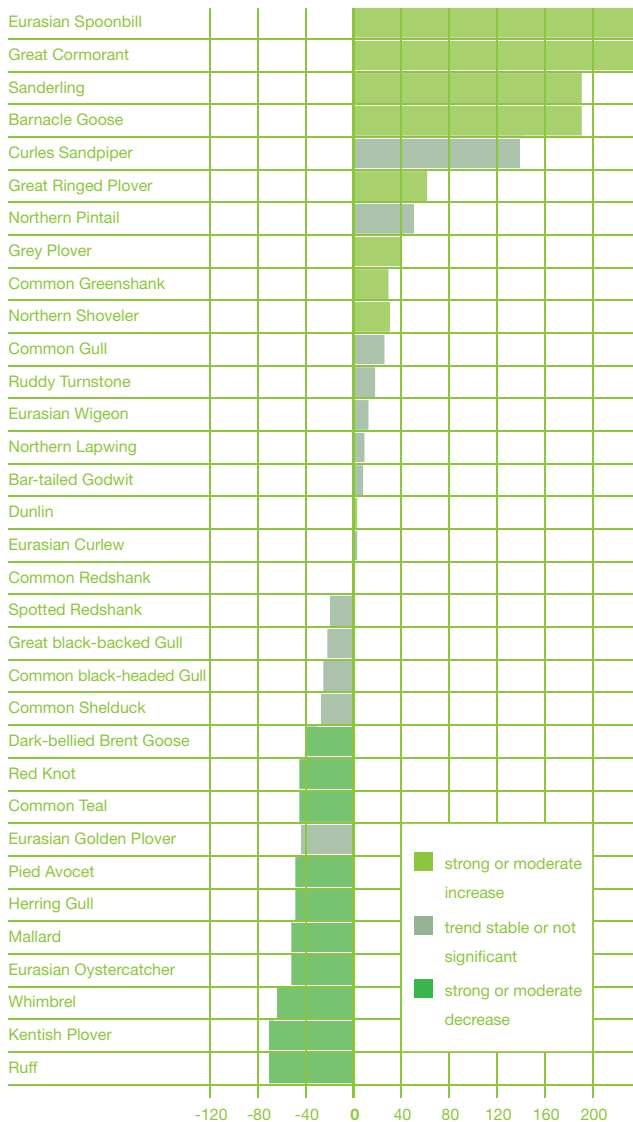


figure 13 Trends for the period 1987/88 to 2003/04 in the incidence of bird species in the international Wadden Sea, expressed as a percentage change over the 17-year period, arranged in order from ascending to descending trend values (Source: Blew et al., 2007).

The effect of ecosystem engineers on the deposition or mobilisation of mud is quantitatively significant in relation to the size of the annual mud flows to the Wadden Sea, but the timescale over which deposition and remobilisation takes place is of great importance. This timescale ranges from seasonal for microphytobenthos to several years for shell banks, to almost permanent for salt marshes. Only deposition over a long timescale has an impact on the morphology of the estuary and perhaps also on the average mud content of the water. In this connection, it is significant that the damming up of the Zuiderzee, as well as a change in the tidal regime, has also caused a large permanent mud sink for the western Wadden Sea to disappear. The relative importance of this in comparison with the impact of, for example, large eel grass must be investigated more closely before a clear estimate can be made of the chances of eel grass returning. In any case, it is clear that the damming up of the Zuiderzee was a tipping point for the western Wadden Sea because of its effect on water and mud movement and therefore on the functioning of the entire ecosystem.

The positive feedback created by ecosystem engineers changing their environment in a direction by which they themselves are stimulated results in complicated non-linear dynamics of the system as a whole. A typical feature of the behaviour of such systems is the occurrence of alternative stable situations and rapid state reversals or 'regime shifts'. As an example, it is well documented that eelgrass previously occurred over an area exceeding 100 km² in the Wadden Sea, which made the water much clearer (locally) than it is today. Around 1930 it suddenly disappeared and it will only be able to return if the light transmission of the water improves. Such 'reversals' make special demands on the management regime because it is difficult to switch the system from one state to the other without large-scale interventions.

The theoretical and abstract study of state shifts has been better developed than the practical aspects. Before these concepts can be applied in management, a linked physical-biological predictive model should be developed and experimentally tested, in which not only realistic parameter values must be used but more importantly alternative hypotheses which are area-specific (e.g. the impact of damming up the Zuiderzee) should also be investigated. Detailed modelling is not only useful for careful examination of the concepts. It also opens up possibilities for studying practical management strategies (e.g. collecting and permanently storing mud in innovative coastal defences).

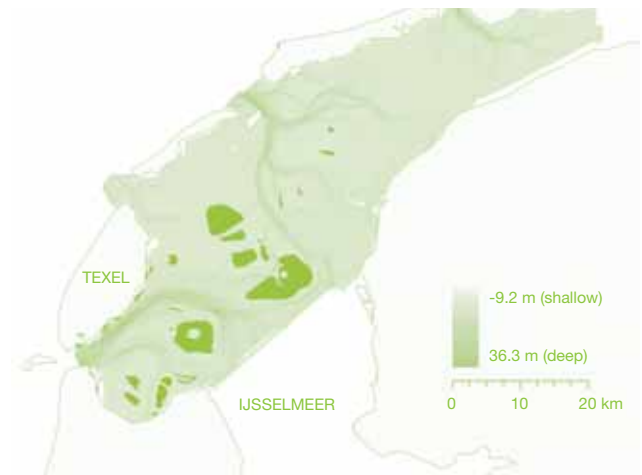


figure 14-A Spatial distribution of eel grass beds (black areas) in the western Wadden Sea before the collapse of the population in 1930, superimposed on the depth chart for 1930.

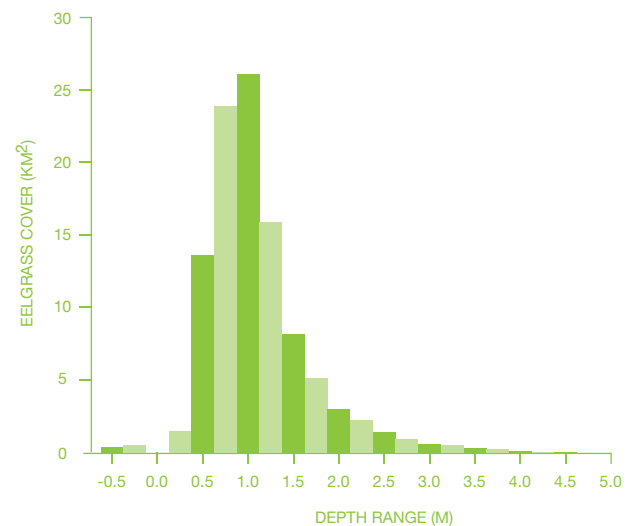


figure 14-B Depth range (metres below average tide) of the areas with eel grass during this period. The total surface area was 105 km² and the median depth was 1.0 (Source: Van der Heide et al., 2007).

4 The dry tidal area and the boundaries with the polders

The 'dry tidal area' is formed by the islands, recently formed sand bars and the salt marshes close to the mainland. The islands exhibit a decrease in biodiversity because natural succession is slowing down. This in turn is caused by the severe restriction of abiotic dynamics and, to a lesser extent, by enrichment resulting from nitrogen deposition, although this is declining now. Stabilisation of sand reduces habitat for pioneer vegetation on the islands and slows down the freshwater lenses in recently formed flats.

Salt marshes fulfil an important function as a buffer for the Delta dykes. Besides which, they have high intrinsic natural value. The main items for research are the interactions between silting-up, sea-level rise, vegetation growth and grazing.

There is a tension between safety issues on the one hand and the minimum dynamics required for nature on the other. This gives rise to questions concerning the interactions between geomorphological dynamics and habitat quality, the dynamics of freshwater lenses and the role of humans and animals as managers of vegetation.

Specific questions exist with regard to the boundaries between the (wet and dry) tidal flats and the area inside the dyke. Hard, engineered fresh-salt transitions are experienced as problematic. Sometimes specific problems arise which can in principle be solved by technical means, e.g. fish passages. However, general problems of habitat diversity also arise. The lack of typical brackish water areas in the Wadden Sea Region impoverishes it in comparison with a more 'natural' system. We should however guard against adopting an approach exclusively based on biological considerations. In our regions, mixing fresh and salt water without tides is almost impossible, and there is a great risk of water stratification and generation of anoxic bottom layers. Experience gained in the Zeeland Delta (Veerse Meer, Grevelingen, Haringvliet) could serve as a warning in this regard. Both the physical system and the scenic and economic aspects should be carefully considered.

Land-water transition zones are another major planning issue. On the islands there are possibilities (and problems) for natural transition zones between beaches, dunes, salt marshes and polders. A better understanding of the (geo-ecological) laws on the creation and development of these land types is required. At the mainland coast, problems such as coastal defence and the salinisation of polders could create innovative opportunities in which the use of salt marshes for coastal defence, saltwater fish farms, aquaculture inside dykes and other innovations could help to revitalise an area while conserving natural values.

5 Global influences on the Wadden Sea Region

Global change affects the Wadden Sea Region in the form of sea-level rise, climate change and the introduction of exotic species. Consequences were systematically studied in the 1990s (NOP) and a new review has recently been carried out.

Depending on the rate of sea-level rise, a tidal flat system could either adapt slowly, e.g. with a coastward migration of islands, or be swamped, after which the entire morphology will change radically (see the 'Geoscience' and 'Climate' and 'Water' themes in this section). If we want to protect the inhabitability of the islands and prevent the tidal flats from being swamped, adaptation measures such as large-scale sand suppletions may be necessary. It is still difficult to predict the ecological consequences of this on the Wadden Sea Area. Mud is the great unknown in this regard. It determines the distribution of aquatic benthos and shellfish populations, terrestrial vegetation succession on the salt marshes, primary production in the water and the import and export of organic matter and therefore the balance of carbon, nutrients and greenhouse gases. Predicting ecological impacts places great demands on geomorphological modelling and requires relatively greater attention to be focused on mud

fractions than on sand fractions and on the role of ecosystem engineers and the role of salt marshes as a permanent sink.

Climate change in the form of rising temperatures and the consequences of this for the northward migration of fish and birds has been well documented. Changes in species composition are already described and will continue (with greater intensity) but are difficult to predict in detail. The consequences for the functioning of the tidal flat system are unknown. The impact on production, phenology, migration and species interactions (including disease and epidemics) has rarely been investigated in situ and research is often restricted to an exhaustive review of possible effects. This also applies to more indirect effects (changes in storms, freshwater influx, physical-chemical properties of the sea water, etc.).

Invasive species in the aquatic system do not appear to cause extinction of endemic species, but can have a significant impact on the functioning of the food web. It is unclear whether the initially rapid expansion of new species followed by a fall-down and embedding in existing structures is the exception or the rule.

6 Local pressures on the Wadden Sea system

Human beings have had and are still having a direct impact on the Wadden Sea system due to changes in boundary conditions, exploitation of living and nonliving resources, tourism, shipping and military activities.

The effects of eutrophication have been well investigated in the past (see above) but attention may have tailed off too soon because the response of the ecosystem to an increase in nutrient input is not symmetrical with its response to a reduction. The impact of interventions in mud dynamics, e.g. as a result of dredging activities inside and outside the Wadden Sea and the damming up of the Zuiderzee and Lauwersmeer have been relatively under-reported. The first-order effects of toxic substances have been well documented but little is known about interaction effects of multiple substances; the introduction of new substances requires continuous attention.

With respect to fisheries, cascade effects of North Sea fishing on the tidal flat system are not well known. The effects of shellfisheries have been studied in much greater detail. A transition towards a more sustainable practice has been started; following up on the ecological consequences of this will be an important focus in future.

The effects of gas exploitation, more specifically land subsidence, have been extensively studied and are limited in scope. The disturbance of animal species by recreational activities including sailing has only been investigated occasionally.

Spatial planning questions, particularly regarding port activities, have recently emerged as an important subject in the debate about human impact on the Wadden Sea Region.

In general, studies of human impact were small-scale and tended to focus on demonstrating the impact rather than on making practices more sustainable. Diffuse effects, cumulative and shifting effects have been studied much less frequently. The scale at which the problem was examined was mainly local without looking at the impact and socio-economic embedding across a wider region. A more integrated approach which also includes economic and social aspects on several scales is still only adopted sporadically.

7 The evaluation of ecological values in the Wadden Sea

Different views are possible on the development of nature in the Wadden Sea. On the one hand, one could focus on the current system and ask how the boundary conditions for that system could be changed in the hope of improving biodiversity or the functioning of the ecosystem. On the other hand, one could assume that the current system is strongly affected by species losses at the top of the food web or in ecological engineering species, and reason that this has caused the loss of major potentials in terms of biodiversity. It is often difficult to choose between these views on scientific grounds because there are gaps in our understanding of the coherence within the ecosystem and because there is no doubt that major changes will occur over the decades to come.

All these problems come together when reference or target conditions are defined for nature in the context of human society. It is virtually impossible to use current or historical states of the system as target conditions. The paradigm of 'systems in motion' which will inevitably be imposed by global change is a threat to the concept of protection ('conservation', 'restoration') of nature. The system will change anyway, but not every change is equally desirable or justifiable from the point of view of nature. Although there are currently robust policy frameworks for nature conservation, which the Wadden Academy in no way questions, it will be necessary to ensure that nature protection policy continues to have a foothold in future. This foothold must safeguard the essential qualities of the region as well as possible but remain achievable while the world (and the Wadden Sea) changes.

The key question is: 'what are the essential qualities or values of the Wadden Sea's natural environment?' And, if these values cannot be defined on the basis of its current or past state, because the system will change in any case, how can we estimate these values and maximise them in management? Some key values can be sketched out: maintaining migrating bird populations; maintaining the expanse of the (international) Wadden Sea and thereby the possibility of retaining or restoring populations requiring large areas; allowing free play to large-scale natural processes; maintaining scenic qualities (tourism, natural values). Achieving these objectives in scenarios of global change requires a continuous process of reflection.

The protected status of the Wadden Sea allows us to choose sustainable and nature-oriented development in this region and not developments which will have a major impact on the natural environment. The scale for such choices is not the Wadden Sea Region itself, but international: the key factor is what the Wadden Sea Region has to offer by way of unique qualities in the Netherlands, Europe and the world. In the global ecosystem, tidal flat systems are much more important than their relatively modest surface area would suggest. They exhibit a special combination of rapid recycling of organic matter, nutrients and greenhouse gases. They have a high productivity in terms of fishing. Tidal flat systems are of great importance to migrating species and are breeding and resting places for species that feed at sea. These interests should definitely be taken into account for the Dutch Wadden Sea. The Wadden Sea can be compared with other tidal flat systems but can also be used as an example for managing other ecosystems of global importance.

Qualities should not be defined solely in ecological terms but they are also connected to history (ecological history, human history) and cultural tradition in the region. The ecological history of the Wadden Sea Area is considerably less well known than the human history.

The main gap in this area is the tension between general principles as stated above and the detailing which is required in the current governance structure to formulate policy. An interdisciplinary study of this issue is required. It must also be accompanied by research aimed at achieving optimum governance, based on the scientific uncertainties surrounding the future of the natural environment (but also of economics and culture) in the region and (at the same time) the need to apply enforceable rules.

Research into the basis for the system's natural values will serve a dual purpose. On the one hand, it is very important to define the role of (natural) science in the policy more clearly. The definition of 'natural values' is not a scientific problem but a cultural, social and economic (and therefore political) problem. Natural science is instrumental in determining how natural values can be measured, in determining what natural developments are possible within the given boundary conditions and what technical and management measures can be taken to steer the development of nature in a specific direction. But it must leave the actual discussion about value systems where it belongs: in the arena of public debate. On the other hand, it is very important for social science to understand the basis of formulated conservation or restoration targets, if only to give the adaptation of these targets to a changing future a firm foundation.

The increasing influence of legal procedures on management of the area gives rise to an additional problem. 'Natural values' are or have been legally defined in a limited number of iconic species or habitats which are perceived to be emblematic for all kinds of reasons but are not necessarily indicative of the way the ecosystem functions. Sometimes the emblematic value survives the role of indicator: if the seal was *the* symbol of the impact of organic pollutants twenty years ago and therefore an indicator *par excellence*, it is now mainly an emblem without an underlying problem. Iconising a limited number of species and habitats makes policy objectives more readily understandable, makes a connection between policy and the public's expectations, but creates a risk that the policy is directed at preserving the indicator and not the system for which it is acting as an indicator. For example, where an indicator points to a 'shortage' of mussel beds compared with a properly functioning system, there may be a tendency to lay additional mussel beds instead of ensuring that the system is functioning in such a way that mussel beds recruit naturally. The study into the basis of natural values is intended to prevent this kind of confusion or at least make it a subject for discussion.

8 Gaps in knowledge

- A better understanding of bottom-up processes in the food web. Greater attention focused on pelagic processes and benthic-pelagic exchange. Predictive capacity. Attention focused on exchanges at the boundaries, with the adjoining North Sea and international parts of the Wadden Sea Region.
- A better understanding of the interaction between organisms and physical processes, particularly as regards the dynamics of mud in the system.
- The biological interactions in the system, particularly those interactions that can show a positive feedback which could give rise to threshold values in the dynamics, require further research.
- Paleo-ecological research. Reconstructions of structure and functioning in the past are very important for gaining an understanding of function, for the discussion of ideal or desired states and for practical restoration options where these are required.
- Comparative research with other tidal flat systems. This provides an opportunity to subject 'top-down regulation' mechanisms to a critical examination, to compare different types of management and to study a sequence of system conditions at different levels of human pressure.
- International connections of the Dutch Wadden Sea. Analysis of functional relation

between habitats connected to the Wadden Sea. Important connections are migratory birds that form a link between Arctic breeding grounds, tropical wintering areas and the (international) Wadden Sea, but current patterns, nutrients and climate also connect the water in the Wadden Sea to processes on a much larger scale.

- Gaps in knowledge of the supralittoral areas are to be found in the tension between, on the one hand, human-induced restriction of dynamics for the sake of safety and, on the other hand, the dynamics (fresh-salt, inundation, shifting sand, grazing and humans) required for biodiversity. There are organisational questions and innovative opportunities concerning transition points (fresh-salt, wet-dry).
- Changes can be expected in the Wadden Sea as a result of global change but the form they will take is almost completely unpredictable. Targeted long-term monitoring is required. This could also form the ideal background for process-oriented research. The environmental consequences of mitigation measures such as sand suppletions must be monitored.
- There is a need for an integrated strategic vision and an evaluation process for human activity in the region. To do so, attention must be paid to the cumulative aspects and the interconnections between different activities; the evaluation must be interdisciplinary, aiming at future sustainable development, taking into account external and diffuse disturbances and concentrate on the Wadden Sea as a whole. Evaluations must seek international attention by treating the Wadden Sea as an example of regions essential to the global ecosystem.
- There is a need for a much clearer definition of ecological values in the Wadden Sea that takes account of expected future changes, governance structures and the need to safeguard the essential qualities of the region.

The main interfaces with other disciplines are:

- Biogeomorphological processes and their integration into the modelling of the dynamics of mud, sand and geomorphology, both on the supralittoral areas and on the tidal flats.
- Development of probable scenarios for climate change and its consequences for the ecology of the Wadden Sea Area. Integration of ecological studies with monitoring efforts and process studies directed at the causes and effects of climate change.
- Research into the basis of the ecological values in the Wadden Sea, taking into account the cultural, social and economic dimensions of the problem; iconising species in relation to image creation and policy.
- Integration of ecological and economic aspects of research into human interventions in the system, focusing particular attention on the integration of natural values as a non-use value in the economic estimates.
- Research into governance structures in which the unique role of the Wadden Sea Region for the world ecosystem can be given a correct valuation and in which the management of the Wadden Sea Region can serve as a model for other ecosystems of world importance.

Infrastructural preconditions for bridging these knowledge gaps are:

- Consistent monitoring of basic variables in the ecosystem, linked to modelling bottom-up processes in the food chain. Extrapolation of observations in time and space and consistent modelling of exchanges with peripheral areas are required.
- Integration of geomorphological and ecological research, modelling and monitoring.
- Developing a methodology and tradition of integrated long-term policy development and evaluation, combining natural, social and economic sciences. This requires a great effort from the natural sciences to incorporate their observations in an evaluation process.
- A meeting place for natural scientists, social scientists, artists and opinion leaders in which the value system around the natural environment in the Wadden Sea Area can be studied and examined more explicitly.



2.3 Society and cultural history;

Introduction

The Wadden Sea Area is one of the world's most important intertidal regions. Its natural values rightly enjoy special legal and institutional forms of protection. For almost three thousand years, however, large numbers of people have been living and working around the Wadden Sea Area. In addition, the Wadden Sea Region is subject to intensive and varied use by visitors. The sociopolitical debate on how to care for the Wadden Sea Region is to a large extent determined by the question as to where human use of the region is in conflict with the preservation of the Wadden Sea Area as a nature reserve. To answer this question, it is first necessary to gain an insight into the way in which residents of the region live their lives and earn their living and into the way in which visitors regard the region and make use of it. How did this way of living in and making use of the region develop historically? And what impact does it have on the region's climate, soil and subsurface and its natural values? In general terms, these are the questions which are dealt with in this section. In other words, in a development of the triple bottom line model (people, planet, profit), this section deals with questions concerning people (the first p), their way of life (p as in profit), their social organisation, their relationship to the past (a fourth p) and the significance and value they attach to their natural and man-made environment and how they deal with it and their impact on it (p as in planet).

The (cultural) historical and social science research for the Wadden Sea Region is sparse and moreover fragmented. This is a field of research which until today has received little attention within the Wadden Sea Region. In general, it is not oriented towards the knowledge demands that exist among the various groups involved: an internal scientific agenda predominates. The influence of the humanities and social sciences on policy-making is almost non-existent and is also not something that is explicitly sought by scientists. The field of research therefore has to be emancipated into established research interests with regard to climate, geology, ecology and economics. The use of programmed guidance will reap substantial rewards. The question as to 'what works' in establishing a sustainable future for the Wadden Sea Area can and should not be answered solely in terms of technical tools. This is definitely also a socio-cultural issue. Changes in the fishing industry in the Wadden Sea Region are a good example of this. The permanent reduction in or outright ban on catching cockles, seed mussels or fish 'touches' fishermen and fishing communities not only economically but also psychologically and socially and in deeply ingrained perceptions of their relationship with the natural environment and of the place that they have historically occupied in the region. A good knowledge of this impact is essential if a sustainable and equitable future is to be devised for the region's fishing industry.

Although, since the construction of the IJsselmeer Dam, outsiders have regarded the Wadden Sea Region as a single unit, the question is whether this also applies to the people living there. The powerful segmentation of the landscape always seems to have been at odds with the creation of coherence and unity. However, it is certainly clear that not only the islands and the tidal flats but also the clay areas that are part of the Wadden Sea Area in terms of

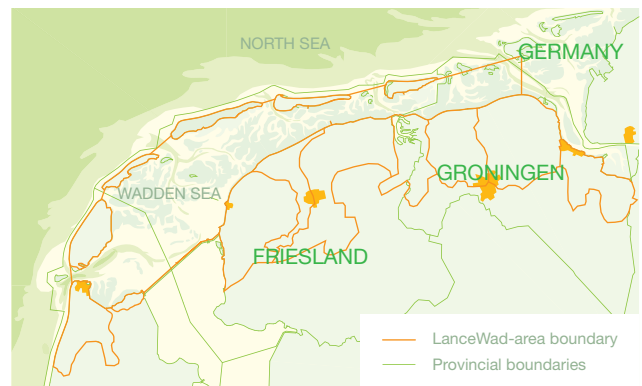


figure 15 For the 'society and cultural history' theme, the Wadden Sea Region is defined as in the international LanceWad project. This is an inventory of a number of islands and old districts which have been inhabited since the early Middle Ages.

both the genesis of the landscape and its cultural history. Higher levels of aggregation comprise the provinces, the government of the Netherlands, the Wadden Sea Region of the Netherlands, Germany and Denmark, and the EU. In historical terms, this section looks at the period from the early beginnings of the continuous human habitation of the coastal region, just less than 3,000 years ago, until today. We had to choose this relatively long period of time because it was already apparent at an early stage how human communities in the region became and remained a significant factor in terms of the geology and ecology of the region and its spatial formation. Sometimes in a negative sense and sometimes in a positive sense. The successive adaptations of the coastal areas of the northern Netherlands in pre- and proto-historic times to the natural and sociopolitical dynamics of the region and the surrounding area are also interesting. However, this part of the research agenda will be focusing on the Middle Ages and early modern and modern times, from the Carolingian period up to and including the 20th century. Any approach to the historical dimension from the perspective of residents and visitors requires us to pay special attention to the history of 'yesterday', i.e. the history of their grandparents and great-grandparents. In social terms, it is not only the residents or inhabitants who are the focus of interest but also visitors or outsiders. They are experts and lay people, policymakers, decision-makers and the public but they are not, of course, homogeneous, immutable entities. Outsiders are sometimes part-time residents and lay people may have a level of education which is often on a par with that of experts.

1 A brief history: 700 BC - 2000 AD

We know from archaeological research that the coastal area of the northern Netherlands had been colonised by people by the early Iron Age. Over 2500 years ago, a situation arose in which the natural supply of sand and clay provided 'an answer' to the ever slower rate of sea-level rise. Migrants from the sandy areas in the interior were able to settle in new salt marshes. One hundred or more successive generations have formed an almost unbroken chain of inhabitants since those beginnings in the early Iron Age until today. The history of human habitation and the relationship of the inhabitants to the natural and man-made environment has been roughly divided by archaeologists and historians into five periods: prehistory (approx. 700 BC - approx. 800 AD), the Middle Ages (approx. 800-1500), the early modern era (1500-1800), the modern era (1800-1940) and the present post-war period (1940-2009).

In the Iron Age (seventh century BC until 12 BC), the Roman Iron Age (12 BC up to and including 406 AD), the period of mass migrations (fifth century) and the early Middle Ages (sixth and seventh century), the region was populated by warlike agrarian tribes. In absolute terms, the numbers were relatively small, a few tens of thousands of people in total. However, compared with the hinterland, the population density was relatively high. Although this area, still without dykes, was subject to regular flooding and, at first sight, can be regarded as a hostile environment, offered great opportunities in agricultural and economic terms, particularly for cattle-rearing. Permanent habitation was made possible by the construction of houses on podiums consisting of sods (terps or mounds). This was a unique adaptation. Intersected by estuaries, coves and tidal creeks, the region was readily accessible by ships. Close contact between the Wadden Sea Region and other regions along the coasts of the southern North Sea is well documented for different periods. The northern Netherlands was only part of the Roman Empire for a short period. However, there was certainly contact with the area to the south of the imperial border. For the North Netherlands region, the large-scale developments during the latter days of the Roman Empire also meant a radical change and reordering of tribal groups. This very probably resulted in the almost complete depopulation of the North Netherlands coastal area. The arrival of new tribal groups resulted in radical changes in the habitation and use of the landscape and the naming of sites and settlements.

In the eighth and ninth centuries, the region came first under the sphere of influence and subsequently under the control of the Frankish Carolingian Empire. In the longer term, however, this did not mean that the monopoly of force in the North Netherlands was centralised. In fact, until the end of the 15th century, there was a substantial degree of socio-political fragmentation. Headmen [*hoofdelingen*] were in charge in the Frisian areas. Disputes between families could result in violent and sometimes deadly feuds which were carried on over generations, although they could also be settled by the awarding of compensation in the form of precious metals or cattle. Even before the establishment of a permanent ducal authority in the region, the introduction of gunpowder brought with it an increase in scale of political relations.

The incorporation of the region into the Carolingian Empire did of course mean that all the inhabitants of the region were converted to Christianity, although it was probably many generations before the religion really took a hold on the personal inner life of the faithful. From the 9th century until well into the 20th century, ecclesiastical institutions played a dominant part in local communities and in the design of the built environment and the landscape. For example, the role of these institutions in dyke construction cannot be ignored. Dykes were erected during the High Middle Ages (from the 11th to the 13th century) and signified a reversal in the relationship between man and nature. Where the sea previously flowed freely over the whole region during high tides, it was now shut out. This provided an enormous boost to the options for habitation and agricultural exploitation but at the same time a new form of disaster was born. In places where storm surges broke through dykes, people and cattle could drown in large numbers. The construction of dykes also had a major impact on existing patterns of natural drainage: a chain of many unforeseen effects called for a series of new human interventions. In any case, it is not only the building of dykes in the High Middle Ages that attracts attention but also the large-scale exploitation of the large peat areas between the clay areas and the sandy areas. In terms of water management, the construction of dykes and the exploitation of the peatlands cannot be considered separately. In demographic terms, the 9th to the 14th century must have been a major transitional phase: the basis for radical developments during the early modern era.

The early modern era saw major changes in the areas of economics, politics and religion. Although the region was not unfamiliar with a modest farm production for an urban market, the 15th and 16th centuries witnessed the development of market-oriented agricultural production, agricultural specialisation, the development of a variety of manual trades and urban growth. In economic terms, these developments resulted in a boom period, as can be seen from the monumentalisation of the built environment, the rich material, private and religious culture, a prominent political role in the Dutch Republic and intensive participation in international trade and shipping. The many ship remains in the Wadden Sea bear witness to this phenomenon. In sociopolitical terms, people in the region adapted themselves to a central power and different social classes became established. The Reformation influenced the moral economy in the region at an early stage and in a fundamental way.



figure 16 During the Iron Age, a unique adaptation was conceived which made it possible to live in a landscape which flooded many times a year. From the 6th century BC until well into the Middle Ages, large numbers of inhabitable terps or mounds were built on the medium-height and high salt marshes of the northern Netherlands coastal zone (Source: Knol, 2005).

In the course of the 19th century, agriculture in the region underwent substantial changes and a form of agricultural capitalism arose which had a major impact on society. Arable land and pasture was concentrated in the hands of large-scale gentlemen farmers who employed large numbers of agricultural workers. Social inequality was a key feature for the modern era and well into the 20th century. In political terms, the region adapted itself to the new relationships within the newly created Dutch state. Middle-class elites played a key role in creating a situation in which provincial self-confidence at a social and cultural level was relatively naturally combined with loyalty to the state and the Crown. In addition to a wide range of religious denominations, various sections of the population developed ideological perspectives in which research, progress, edification and development played a key part.

Of essential importance for the most recent history is the transition made in the middle of the 20th century from a situation of scarcity for many to one of abundance for many. Although there was no large-scale industrialisation or urbanisation in the region, the progressive mechanisation process enabled its inhabitants to choose a quite different relationship with their natural environment and landscape. Rationalisation and economies of scale are the key terms used to describe the trends in agriculture, the design of the built environment and the infrastructure. In addition, because of the development of (large-scale) tourism – a sign of the development of a welfare state – a production landscape turned into a consumption landscape. This is one of the reasons why the region was redefined – mostly by outsiders – as a nature reserve in the course of the 1960s and 1970s. Interventions to promote nature conservation, restoration and even development commenced. The considerable increase in mobility in terms of home, work and travel, particularly from the 1960s onwards, allowed people to identify with different landscapes of value, both at home and abroad. In political terms, the region did of course participate in the national creation of a parliamentary democracy but that did not prevent it from remaining on the periphery of political life. For the North Netherlands, secularisation and the waning influence of the churches are key to understanding trends on the religious and ideological front.

2 Perspective: social sustainability, justice and taking care of natural and cultural heritage

Currently, the Wadden Sea Area is mainly valued for its natural environment, tranquillity, openness and darkness. These are the core values that deserve to be safeguarded for the future. Their protection has been enshrined in various policy proposals, laws, guidelines and regulations. For everyone involved, the task is to identify the trends and developments in terms of climate, land and ecology that will affect these values. After all, nature is shaping the Wadden Sea Area. However, the question is whether a natural science focus is enough. There is also a task in designing a future that is socially sustainable and just and shows respect for the region's natural and cultural heritage. An enduring and just development also requires knowledge of the way in which residents and visitors, inhabitants and outsiders, experts, policymakers and lay people, the public and decision-makers organise and represent themselves or are represented, the way they relate to each other and to the region and its history and the ideas they have for the future of the Wadden Sea Region. Both nature and man contribute to the development of the Wadden Sea Area.

For a coherent study of the social organisation and political representation of residents and visitors and of the way inhabitants and outsiders treat the natural environment, landscape and heritage, we have to be aware of the fact that not only the public perception but also research are strongly determined by two images of the region. First, the region is considered relatively traditional and marginal. Second, the region is regarded as a nature reserve.

3 Memory: the Wadden Sea Region as a traditional and marginal area

Viewed from the socio-economically and culturally dominant West, the region around the Wadden Sea Area is regarded as a relatively traditional and peripheral area. In general, its traditional character is considered a positive assessment. The region consists of open countryside in which the built environment and spatial planning provide an accurate picture of centuries past. In social terms, it consists of relatively tight-knit face-to-face communities.

However, its marginal character also includes a rather negative assessment. The region has a low population density, its share in the gross national product is low and it has higher than average unemployment. The region is strongly oriented towards agriculture and tourism and has inadequate links to the national and international transport infrastructure. Threatening trends such as an ageing population, demographic shrinkage and vacant property are more apparent here than in most other peripheral parts of the country.

Many observers regard the region's traditional and marginal character to be an intrinsic feature. But nothing could be further from the truth: it is a product of developments in the second half of the 19th and first half of the 20th century and a result of the creation of the Dutch state and national and international economic processes. This consisted of a process of ruralisation, lack of or failed industrialisation and administrative marginalisation, which caused the region to disappear economically, socially and culturally from the national and international scene. By contrast, in the centuries prior to about 1850, the region around the Wadden Sea was densely populated, urbanised and prosperous, and the region's beauty was expressed by its excellent possibilities for agricultural use. Its agricultural and maritime wealth had been evident since the High Middle Ages in the form of large-scale interventions in the landscape and of monumental, ecclesiastical and profane architecture. The region's (material) culture had a strong international orientation. Although the region was fragmented administratively, it was autonomous and important nationally and internationally.

Putting the traditional or archaic character of the region into perspective provides an interesting angle from which to think about the future of the Wadden Sea Region. After all, even the most profound changes have also taken place in the Wadden Sea Region down the ages. Perhaps, contrary to what the image of the region referred to above suggests, its emancipation is in prospect due to a combination of factors favourable to the Wadden Sea Region: a growing political-administrative interest in the region (within the Netherlands and Europe), a self-confident cultural development (cultural localisation as opposed to cultural globalisation), the spatial uncoupling of supply and demand in the service sector, the development of a tourist experience and contemplation economy – a term coined by Tom Bade – and the increasing importance of 'capital landscapes' as a location incentive in the knowledge economy. This line of thinking provides positive pointers to ways of formulating future-oriented scenarios based on social sustainability, political justice and respect for the region's natural environment, man-made landscape and historical heritage.



figure 17 Historically, the northern Netherlands has been considered a rural and relatively marginal region. This image only dates from the 19th century. Before that, however, the region around the Wadden Sea was densely populated, urbanised and prosperous, and the region's beauty was expressed by its excellent possibilities for agricultural use.

4 Experience: the Wadden Sea Area as a nature reserve

In political pronouncements and in the public imagination, the Wadden Sea Area is first and foremost a nature reserve which deserves to be safeguarded for the future. Logically, therefore, the area gives 'priority to nature with limited shared human use'. The debate on the future of the Wadden Sea Area places the emphasis on protecting and developing it as a nature reserve and as a unique open landscape. Historically – for almost three millennia – several tens or hundreds of thousands of people have lived and worked in the area. In

addition, the area is currently visited by large numbers of tourists from inside and outside the Netherlands. Many people – from centuries ago and from modern times – have left their mark almost everywhere in the area, not only on the islands and on the coast but also in the Wadden Sea Area itself. It would be equally correct to describe the Wadden Sea and the Wadden Sea Region as a man-made landscape. Although, by its nature, the Wadden Sea is not an example of cultivated rural 'nature' such as Waterland or Achterhoek (both in the Netherlands), it is certainly not a breathtaking wilderness like the Grand Canyon or the Gobi Desert either.



figure 18 The tidal flats of the Wadden Sea near Holwerd, Abe Gerlsma (1919-). Artists are often able to take new non-dogmatic 'readings' of the landscape and popularise it.

The emphasis in the public image of the Wadden Sea Area as a nature reserve has resulted in a view in scientific research and opinion-forming in which the development of the region is regarded as a physical result of natural processes, in which humankind intervenes – usually in a negative way – as an exogenic factor. The discourse of scientists and conservationists does not seem to differ on this point. This explains why for decades research into the Wadden Sea

Region has focused so much on natural science-based research in general and geological and ecological research in particular. Social science-based research and – to a lesser extent – historical research is grossly under-represented in terms of volume and importance.

5 Value(s)

'Value' is the key concept in research into ways of achieving a socially sustainable and just future in which there is respect for the natural environment, man-made landscape and heritage. This is not, therefore, just about natural values; the concept of 'value' is more broadly defined here, in both empirical and theoretical terms. The research agenda for social science and cultural history relates not only to the codified natural values of the region, but to all the (spatial) values (or qualities) that the Wadden Sea Region represents for inhabitants and outsiders. This question fits in directly with the definition of 'landscape' according to the European Landscape Convention (2000): landscapes are identified "by taking into account the particular values assigned to them by the interested parties and the population concerned". In this question, 'value' is considered not only as a special and important quality of the region which must be treated with care. 'Value' is considered as an expression of views as to how the world has been or should be ordered and organised. Of what ideal concerning our own environment are the values an expression? Only by adopting this approach will it be possible to understand the cognitive-emotional involvement of the (various groups of) participants in the region.

6 Knowledge about values

Scientific insight into the ideas and values applied by individuals and groups is very important for bringing about a sustainable future for the Wadden Sea Area because people are and will remain an essential factor in shaping the region. A common understanding of different, sometimes conflicting ideas, ideals and motives and of the different possibilities for highlighting them in the media, in the public debate and in government and politics is a necessary precondition for talking about 'what people should do' or 'what people should stop doing' – without there having to be any congruence in values – and for creating a willingness to act in order to flesh this out as well. Below are the main questions for acquiring the above-mentioned insight:

- What conceptions do inhabitants and outsiders – residents, visitors, experts, policymakers, lay people, the public and decision-makers – have about the region and its past and future?
- What values does the region represent and for whom are these values important?
- How are these values justified (economically, socially, historically, ideologically)?
In other words, why are they important?
- What knowledge (in the widest meaning of the word, i.e. not necessarily scientific knowledge) is deemed to be significant for designing a future based on these values? And how is it acquired?
- What conceptions are there about ownership (in a legal and metaphorical sense), private and public interests, rights and duties and control?
- What transformations of the region are, in the opinion of experts and lay people and of inhabitants and outsiders, helpful or in conflict with the above values?
- In what way do these values form a basis for (ideals about) the economic, social and cultural design of the future?
- In which informal or formal (i.e. institutionalised) bodies are these values promoted and a commitment made to the debate on the future of the region, and with what success?
- Which forms of formal and informal cooperation or opposition play a part?
- What paths have been taken by governmental and non-governmental parties to reconcile public and private interests?

7 Knowledge gaps and questions

It is the above wide-ranging and complex questions that have to be developed into a series of more specific, thematically arranged questions. The following clusters have been identified in which it has been expressly stated for each cluster where relationships exist with abiotic, biotic, economic and administrative domains:

History and heritage

a. The development of scientific knowledge of the Wadden Sea Region's past

- What are the main features of the development of the Wadden Sea Region in terms of the natural landscape, society and the man-made landscape from the start of the first habitation until the construction of the IJsselmeer Dam? The key question is how people shaped their way of life over time and how they made use of the natural resources that the region provided. How did man become a factor in the development of the climate and how did he acquire (decisive) influence over the geological and ecological development of the region?

b. Research into recollection and history in the Wadden Sea Region

- What forms of recollection and history can currently be identified which are relevant to the processes of forming an identity and community for the various actors within the Wadden Sea Region? How do forms of recollection and history manifest themselves

in writing, images and the built environment? What part do these manifestations of recollection and history play in the individual, social, (tourism-related) economic and political domains and in protecting the region's natural and man-made heritage?

Perception: research into the image and evaluation of the Wadden Sea Region

- What were the contemporary images of the natural and man-made landscape of the Wadden Sea Area and Wadden Sea Region in the 19th and 20th centuries among islanders, coastal inhabitants, visitors and decision-makers? What values of the natural and man-made landscape are identified (unspoilt, open, tranquil, dark nights, authentic, old, etc.)? When and in what context have they been defined and how have they been highlighted, and to what political and social effect?

Research into the social and political organisation of a just and sustainable future for the Wadden Sea Region

- Which groups are identified by inhabitants and outsiders/visitors themselves and how do they distinguish them from each other? How are these groups organised socially and/or politically, in what contexts do they manifest themselves, how do they relate to each other and how have they developed?
- How and to what effect are values relating to natural and man-made landscapes highlighted by groups of inhabitants and outsiders?
- What forms of economic and cultural entrepreneurship can be identified in the region and what cultural dimensions (i.e. attitude to risk and innovation) typify them?
- Are there any 'mechanisms' in the region for achieving congruence in views, ideals and/or actions or does the debate about a sustainable and just future call for the introduction of new forms of consultation and decision-making models?
- What future scenarios are conceivable if there is interplay in the Wadden Sea Region between social commitment to the natural environment and cultural history, the experience economy and the human preoccupation with nature and the man-made landscape in the light of processes of technologisation, commercialisation, popularisation and globalisation (and its opposite: localisation)?

Research into systems for documenting, evaluating and selecting cultural history values

- What are the strengths and weaknesses of existing cultural history knowledge systems? What measures lead to greater quality, more supervision and improved accessibility of information and knowledge? How can these knowledge systems be of assistance in monitoring the degradation of the region's heritage?
- What best practices are suitable or should be developed for the preservation and meaningful development of the region's heritage in terms of archaeology, man-made landscape and built environment?

Underlying conditions

- Answering the above questions requires an interdisciplinary approach in which archaeology, socio-economic history, the history of ideas, the economic sciences, historical anthropology and cultural anthropology play a part. In many cases, there will be a need for participatory, action-oriented forms of research.
- The Wadden Sea Region's research agenda for social science and cultural history requires the active and serious involvement of residents and visitors.
- As regards archaeological and historical research, it can generally be stated that there is a need for a cross-border approach that takes account of the international nature of the Wadden Sea Region and therefore also provides a framework for comparative research on European wetlands.

- The research requires the planning and development of new and existing historical information and knowledge systems.
- The visual arts deserve special attention in this regard. The recent trend towards 'valorisation' of natural and cultural values is an additional important subject of research.



2.4 Social and spatial economics; social and economic opportunities in the Wadden Sea Region

Introduction

The Wadden Sea Region is characterised by a powerful interaction between man and nature. A number of people live there continuously and some families have a history that dates back centuries. This applies both to the islands and to the coastal strip. The people who live there feel bound to the Wadden Sea Region and many make their living in the ecosystem of the tidal flats. The region contains a wide diversity of socio-economic activities and cultural history. Economic activities range from fishing, agriculture, leisure and tourism, exploitation of natural resources such as oil and gas, to maintaining sea defences.

The ecosystem of the tidal flats bears the marks indicating the presence of man, both for the better and for the worse. On the one hand, the unique open landscape that we see today has been formed by nature and man together. On the other hand, a number of threats to the ecosystem of the tidal flats can be ascribed to man, such as land and water pollution and overfishing. The interaction between man and nature in the Wadden Sea Region implies that each must be regarded as dependent on the other. This interaction is acknowledged in Part 4 of the Key Planning Decision [*Planologische Kernbeslissing*] (PKB, also Third Wadden Sea Policy Document [*Derde Nota Waddenzee*], 2007) and is expressed in the wording of the perspectives for development:

- The economic activity in and around the Wadden Sea provides the population with employment and income and is sustainable.
- A situation of sustainable tourism has been reached which is environmentally tenable, economically viable and socially acceptable. It is possible to enjoy an excellent perception of the natural environment and landscape in the Wadden Sea Region.
- The ports on the Wadden Sea have developed sustainably in a manner which does justice to their specific location and facilities. The ports have differentiated themselves and specialised by mutual agreement.
- The Wadden Sea is used for various kinds of fishing in such a way that abundant and varied fish stocks have developed and that other (bottom) fauna and (bottom) flora and the scenic qualities of the Wadden Sea do not suffer as a result.

To ensure the socio-economic development of the Wadden Sea Region, its resilience must be preserved and strengthened. A resilient Wadden Sea Region requires 'adaptive capacity'. An essential part of this is harmony between the three Ps of the Triple-P approach referred to in the introduction, i.e. nature, society and economics must be in harmony. This is due to the fact that resilience in one domain is closely tied up with resilience in the other two domains. The three domains affect each other continuously. By way of illustration, when the Wadden Sea Region is vulnerable to an economic downturn, it is logical that this will have an impact on the people living in the region. These people will tend to move out of the region and as the population declines, so the social capital in the region is reduced. This can be accompanied with a decline in qualities associated with social capital such as entrepreneurship and creativity in the development and application of innovations. Likewise, ecological resilience has an effect on economic resilience and/or social resilience and a change in social resilience has consequences for ecological resilience and/or economic resilience. The presence of robust nature and the open landscape form the basis for both ecological and economic functions, as well as for quality of life. It must be emphasised that both the *use* and the *non-use* of nature and landscape can have an economic value. The open landscape goes hand in hand with a low population density and a relatively thinly stretched economic structure. This can be a disadvantage where the concentration of economic

activities (agglomeration benefits) is a determining factor for regional economic growth but also an opportunity because there is less traffic congestion and a pleasant social climate in which to live. This can encourage sustainable economic growth, both on a large scale in specialist zones and on a small scale in valuable man-made landscapes, provided that it takes place within natural limits.

These foundations of the management and development plan for the Wadden Sea Region result in three main, interconnected subjects for research:

- The development of living, working and leisure activities;
- The conflicts between economics and ecology;
- Strategies for sustainable spatial development.

1 The development of living, working and leisure activities

Living

The Wadden Sea Region has approximately 260,000 inhabitants, which is equal to 1.6% of the total population of the Netherlands. The age structure of the Wadden Sea Region's population does not differ much from that of the Netherlands and North Netherlands. Moreover, the differences decrease over time. The proportion of the potential working population in the total population in the Wadden Sea Region is 1% lower than the national average and hardly differs at all from the figure for the North as a whole. The difference is similar for the percentage of older people.

Of crucial importance to population growth are migration movements, which vary much more over time than births and deaths. For decades there was a net outflow of people from the Wadden Sea Region to other parts of the Netherlands. As regards emigration in more recent times, it appears that the negative migration balance was mainly caused by young people leaving for towns with higher education facilities. This applies to a greater extent to the islands, where there is no secondary school and employment prospects are limited. Terschelling is an exception to the migration pattern because of the nautical college based there, but this only affects a very specific occupation.

With regard to immigration to the North, it appears that until now older people have mostly gone to Drenthe, to a lesser extent to Groningen and Friesland and not at all to the coastal towns in the Wadden Sea Region. In this situation, the tide may be turning because recent research into residential preferences shows that Drenthe scores well but Friesland scores even better. It is not known whether this also applies to the Friesian coastal towns but housing on the islands is certainly sought

after. However, because of the small and therefore expensive supply, the possibilities there are limited. Groningen does not do badly either in terms of residential preferences.

At the present time, we see the population of the coastal towns declining (see **figure 19** as an example of the coastal towns in Friesland and Groningen) and predictions point to a further decline. Restrictions on residential development (to prevent unregulated house-building) may be causing this as it keeps potential new incomers out or results in a situation where existing residents cannot move to a better home and therefore relocate to the more centrally situated communities where building is allowed. For some groups, the Wadden Sea Region is a valued region for sustainable living. Space, an important precondition

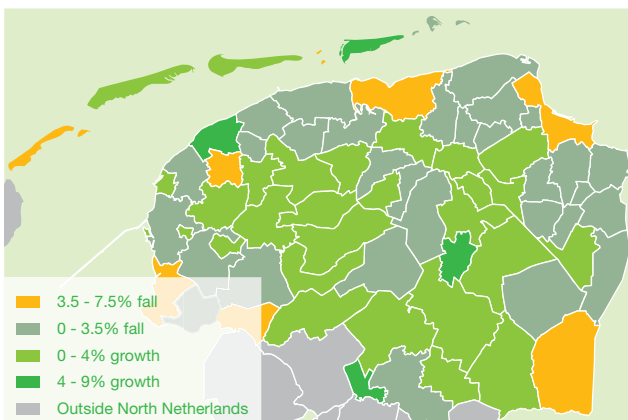


figure 19 Population trends, January 2002 - January 2008
(Source: Statistics Netherlands).

for many people to enjoy their homes, is in ample supply on the mainland. This can be attractive to the growing group of over-65s and also to people who find employment in the various tasks of the creative and freelance sectors, such as art, ICT and design, who are relatively footloose or mainly use electronic forms of communication. They find that the open landscape of the Wadden Sea Region is a major source of inspiration rather than a restriction.

Working

Global economic trends are having repercussions on the Dutch economy and are also filtering through to the economy of the Wadden Sea Region. The disappearance of simple manufacturing to low-wage countries mainly affects the industrial sector. Technological changes such as the increasing use of the Internet have major consequences for promotion and reservations in the tourism sector, for example. The credit crisis mainly affects businesses dependent on the production of goods for export and luxury and capital goods. If consumers consume less, this could have a negative impact on the tourism sector as expenditure on holidays declines. But if the reduction in holiday expenditure produces a shift from foreign holidays to holidays at home, the outlook could also be positive for the Wadden Sea Region. Because of the differences in economic structure, the consequences of global trends for the Wadden Sea Region could turn out to be different than for the Netherlands or the North. But at industry level, the impact of the trends on the Wadden Sea Region will not differ very much from the consequences for the Netherlands as a whole. Trends in the world economy are considered a fact of life as far as economic growth in the Wadden Sea Region is concerned. Over the last 15 years, the economy in the North has grown at the same rate as the rest of the Netherlands and the historically higher levels of unemployment have been gradually declining. But there are differences within the North. The growth in jobs is mainly taking place in the core areas of Groningen-Assen, the A7 zone and the Westergo area. The growth in employment in the Wadden Sea Region (see **figure 20** for the coastal towns of Friesland and Groningen) over the period 1984-2004 was among the lowest in the Netherlands, with the exception of the islands, but in absolute terms there are few jobs involved. As at the end of 2005 the total number of jobs in the Wadden Sea Region was 78,500, of which 9,000 were on the islands.

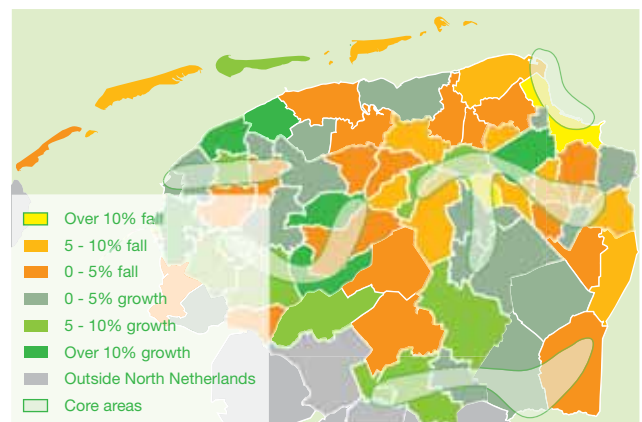


figure 20 Employment trends, 2002-2007 (Source: PWR).

In the Wadden Sea Region a relatively large number of people are still employed in the primary sector (agriculture and fishing) (3%). Leaving aside the island communities, employment in the secondary sector (industry and energy supply) in North Netherlands stands at 21%. The tertiary sector (commercial services) is the most important sector for all the regions. This is particularly true of the island communities with 61% in the tertiary sector, which is mainly due to the great importance of leisure and tourism. As regards the quaternary sector (non-commercial services), the low percentage for the islands is worthy of note.

The commuting survey for 2001 shows that, in the Wadden Sea Region, it is only on the islands that the number of jobs exceeds the working population. More detailed and more recent (2005) data for Friesland show that there is a considerable amount of commuter traffic to municipalities outside the Friesian part of the Wadden Sea Region, mainly to Leeuwarden. This is also true of the province of Groningen. Although towns such as Appingedam, Eemsum, Loppersum and in particular Delfzijl have substantial employment of their own, there is nevertheless a net loss of 4,500 commuters to the city of Groningen. The growth in employment in the core zones around Leeuwarden, Drachten and Groningen is therefore very relevant to those living in the Wadden Sea Region for obtaining work and income.

Unemployment in the coastal towns of Friesland and Groningen is above the national average, although it did show a relatively large drop in the period 2003-2008 in these areas. In parts of some islands and in the headland of Noord-Holland, the situation is relatively favourable. The unemployment rate is reflected in a relatively high percentage of the working population (age 20-65) receiving state benefits. In 2006, 24.4% of the potential working population in the Wadden Sea Region were receiving a benefit on account of unemployment, disability or relief compared with 22.2% for the Netherlands as a whole. As the coastal towns in the North have a low score in terms of minimum subsistence benefits, the relatively high overall percentage of social security benefit claimants must be due to higher levels of unemployment and disability claimants.

A large part of the industry in the Wadden Sea Region is linked to the ports of Den Helder, Harlingen and Delfzijl. The ports operate in a highly competitive North-West European market. Clusters of associated businesses and specialist suppliers who benefit from synergy effects are of great importance to the industrial ports. At the same time, this also causes greater vulnerability if certain businesses fail, as is the case in the present credit crisis. On the other hand, Delfzijl at last appears to be making up lost ground on the economic front as a result of major investments which are in the pipeline in this area, mainly in the energy sector. At the same time, an increase in the tension between economics and the environment is therefore becoming apparent.

Besides the industry in the ports, there are also mostly small-scale businesses in the smaller centres. The appearance of these businesses is sometimes at odds with scenic values, which can make tourists' and residents' experience of the region less attractive. It may be possible to prevent this negative impact by spatial planning measures that regulate the location decision of firms with the aim of fitting them neatly into the existing landscape.

Historically, the Wadden Sea Region has been home to different forms of fishery, with catches ranging from shrimps and shellfish to round fish and flat fish. Fishing and fish processing are of substantial importance to the municipalities of Wieringen, Harlingen, Dongeradeel and De Marne. A robust tidal flat system is a crucial precondition for a sustainable fishery and, conversely, a sustainable fishery is a necessary precondition for a sustainable ecosystem. An important requirement for the development of a sustainable fishery is innovation in the form of aquaculture behind the dykes, such as the breeding of mussels and cockles combined with seeking alternative uses for salinised land, developing vertical cultures for seed mussel fishing and breeding shellfish, lugworms and clam worms. It is also the case for fishing ports that specialising in different sectors of the fishing industry provides opportunities for sustainable development.

Although employment in primary agriculture is in decline, it is still important for the regional economy of the Wadden Sea Region. In addition, agriculture has a major indirect impact on employment, involving suppliers and processors. What is more, agriculture is

responsible for the man-made landscape, particularly on the islands, but further expansion and unfettered building may put pressure on that landscape. Innovations that reduce pollution and strengthen the natural environment and the landscape are a key factor in making agriculture more sustainable. In this connection, attention should be focused on expanding primary agriculture to include agricultural nature and landscape management, agrotourism and care, especially on the islands. There are also opportunities for agriculture on the mainland in the form of cultivating new crops and increasing the added value of the primary products.

Leisure

Leisure and tourism are the main economic backbone of the islands. In order to retain market share in a highly competitive international market, it will be necessary to improve quality, extend the season, attract new target groups and develop and market new forms of leisure and tourism. Because certain types of leisure activity can cause damage to the natural environment, sustainability is also very important in this case, both from an ecological perspective and from the perspective of nature as a long-term economic asset in terms of tourism. On the mainland – unlike the German Wadden Sea Region – there is no intensive leisure and tourism activity except for a few locations, mainly around Lauwersoog and Wieringen. Because of its thinly stretched economic structure, it is of great direct importance to the economic development of the region but also of indirect importance through its contribution to improving the quality of life to make maximum use of the leisure and tourism opportunities on the mainland. The region's cultural-historical qualities offer good prospects. The tourism sector on the mainland can also be strengthened by making shrewd links to the tourist potential of the islands and the urban centres of Leeuwarden and Groningen, e.g. by arranging special deals to visit the Wadden Sea Region. The number of recreational boaters on and around the Wadden Sea has grown substantially over the past decades. Improving quality and safety could make the ports more attractive for leisure sailing, even on the coast side. Bearing sustainability in mind, it is also essential in this case to focus attention on the impact of leisure sailing on the quality of the Wadden Sea's natural environment by providing information on and supervision of the implementation of the Covenant for Aquatic Sports on the Wadden Sea [*Convenant Vaarrecreatie Waddenzee*].

2 Ecology and economics

The Wadden Sea Region has a large number of physical and ecological (for the sake of simplicity jointly referred to as ecological) functions which generate a multitude of very diverse values. It is usual to classify the functions according to the two main categories of values that they generate: use and non-use values. Use values arise from the use of the Wadden Sea Region for production and consumption purposes, e.g. fish, gas and oil and flood protection provided by the salt marshes. This also includes non-material use values, such as experiencing scenic beauty (non-material consumption) or producing films and books on the resources of the Wadden Sea Region (non-material production).

Non-use values are derived from the mere existence of the Wadden Sea Region, without any consumption or production. A distinction is usually made between existence value, bequest value, altruism and option value. Existence values arise from the mere (continued) existence of the Wadden Sea Region: we believe that the Wadden Sea Region forms an integral part of Dutch and world heritage. When we are thinking particularly about future generations, we refer to bequest value. Where we have the interests (well-being) of our contemporaries in mind, we refer to altruism. Option value relates to future use, e.g. experiencing nature in the Wadden Sea Region in future.

¹ The economic subsystem must be interpreted here in the broadest sense, i.e. it should be considered to contain all welfare aspects, including social and cultural welfare.

It is characteristic of the Wadden Sea Region's functions that they are interconnected in a complex way. For example, the landscape function produces a tourism product in conjunction with the ecological functions. The ecological functions of the Wadden Sea Region, together with existing economic activities, an ecological-economic (E-E) system¹. This means that changing a particular ecological function or economic activity can cause a chain reaction throughout the E-E system, with various feedbacks as a result. For example, fishing for shellfish affects the bird population, which has consequences for both use values (such as our own current perception of nature) and non-use values. The impact on use and non-use values can in turn have consequences for the development of leisure and tourism activities with consequences for the consumption of shellfish in the Wadden Sea Region.

It is a typical feature of the E-E system that a certain trend, e.g. a decline in the bird population, can be affected by a number of functions which can strengthen or offset each other. For example, the bird population is affected not only by a deterioration in the food supply but also by factors such as water quality and the effects of the weather. Moreover, the effects may occur after different periods of delay. For example, deterioration of the food supply may not impact the bird population until time has passed, which at a later stage will have an effect on leisure and tourism. Moreover, the effects are often disproportionate, i.e. a brief interruption of one function may cause major changes in other functions.

There are different methods that can be used to study E-E-related themes, where a distinction can be made between direct and indirect methods. In the first category, the value is derived from the price of a nature or environment-related good which is negotiated on the market. For example, the price difference between two houses, one of which has a view of the Wadden Sea and the other does not, indicates the Wadden Sea's contribution to the amenity value, expressed in euro. The indirect methods derive the price from surveys. It should be noted that the direct methods can only be used to express use values in euros whereas the indirect method can be used to do this for both use and non-use values.

Interventions in the Wadden Sea Region's E-E system could lead to multiple chain reactions with feedbacks, which is a complicating factor for growth and policy. Although there is no shortage of legislation and regulations relating to the policy in the form of European and national nature conservation legislation, such as the Birds and Habitats Directives, environmental legislation such as Natura 2000 and the Water Framework Directive, and spatial planning, such as the PKB 2007, a number of interventions are surrounded by a high degree of uncertainty in terms of their impact, resulting in conflicts of interest and legal proceedings. The conflicts of interest are characterised by the differences in assessing the nature and extent of the positive and negative impact of interventions on the various functions in the E-E system.

3 Strategies for sustainable economic growth

Sustainable growth is about the optimum use of all of the economic, ecological and socio-cultural capital (people, planet and profit). The best-known form of sustainability relates to the distribution of prosperity over present and future generations, i.e. temporal sustainability. But durability also concerns the distribution of prosperity over regions, i.e. geographical sustainability. This means that sustainability is a spatial-temporal distribution issue with regard to the components of economic, ecological and socio-cultural capital. Almost every development issue in the Wadden Sea Region has a sustainability aspect, ranging from global problems such as adapting to climate change to developing business parks (landscaping, cradle-to-cradle strategies, the instrument of employment and quality of life), the development of salinated agriculture, the marketing of regionally produced products and housing.

Governance plays a major part in sustainable development. Whereas traditional top-down policy focusing on the division of labour was regarded as a means to increase productivity and prosperity, policy focusing on sustainability considers the integration of management, producers and consumers and of the actors in the production chain to be of essential importance. According to the Dutch Council for Housing, Spatial Planning and the Environment [VROM-raad], in this form of governance, integration means the need for multi-actor and multi-level cooperation. To put integration into practice, the various actors have to be identified and the benefits of forming an alliance have to be explained to them.

4 Knowledge gaps and research methods

From the perspective of social and spatial economics, the Wadden Sea Region challenges science to adapt existing economic ideas to a region with a very special economic, physical and spatial structure. Scientific knowledge can on the one hand contribute to the sustainability of the Wadden Sea Region's economic structure so as to provide sufficient employment and income and on the other hand contribute to a pleasant social climate for residents of the region and care for the region's natural and scenic values, which are also enjoyed by visitors. It is therefore vital to ascertain why firms, individuals and households decide to base themselves in the region and to develop sustainable forms of business. On the other hand, existing methods can be used and new ones developed to gain an insight into the policy considerations in which choices have to be made between conservation and the creation of natural values as against other interests such as employment and safety.

The knowledge gaps in the area of living, working and leisure activities mainly concern future developments as regards the socio-economic structure. In this connection, the following research questions present themselves:

- How can endeavours to create work, income and quality of life for the residents of the Wadden Sea Region be put into effect in a sustainable manner?
- What demographic trends can be expected in the Wadden Sea Region and what will the consequences be for the quality of life in the coastal villages?
- What sustainable developments can be expected in respect of the various economic sectors in terms of expansion or contraction, establishment of new businesses, structural changes and the related trends in employment and unemployment within the Wadden Sea Region and in the provinces within it?
- What will the impact be on the location choices of households and businesses as a result of the construction of new infrastructure such as the Central Axis or the availability of relocation destinations with good energy supplies such as those planned for the Delfzijl region?
- How can the Wadden Sea Region adapt to global trends in the economy and external developments such as climate change? How resilient is it to shocks such as the credit crisis?

A number of models (including REMI, RAEM 3.0, MOBILEC, DRAM, REGINA, TIGRIS and input-output analyses) have been developed in the regional economy with a view to answering these types of socio-economic research questions. However, none of these models is ready-made for application to socio-economic problems in the Wadden Sea Region. Moreover, each model has a number of strengths and weaknesses. This means that if specific questions are asked, not only does a choice have to be made from the supply of models but the models chosen also have to be adapted to the specific question. Moreover, data will have to be collected because data are not usually available on the desired scale. In order to fill this data gap, it would be advisable to set up a monitoring system which could be used to gain an insight both into trends in the region's social and economic structure combined with the economic centres within commuting distance and into the visitors who, via the tourism industry, contribute to the economic vitality of the Wadden Sea Region.

It would be an obvious move to link this monitor to trends in nature and landscape in the Wadden Sea Region as well as to trends concerning the climate. Sea-level rise can have an effect on the locations that businesses choose and on the profitability of investments. Higher temperatures could substantially change the Wadden Sea Region's competitive position as a holiday destination vis-à-vis the Mediterranean region and this would apply even if the Wadden Sea Region's natural environment and landscape were adversely affected.

The knowledge gaps in terms of the economics-ecology system are massive. Knowledge of each of the subsystems and, more importantly, of the interaction between the two subsystems is lacking. Many of the relationships within the Wadden Sea Region's economic subsystem are still unknown or only partly understood. Similar observations could be made with regard to the ecological subsystem. Where the relationships within the subsystems are unknown, the relationships between the systems are also unknown. Nothing is yet known about either the directions of many E-E system relationships or about the signs of their impact, let alone their orders of magnitude. In this connection, the following research questions present themselves:

- research into the consumptive and productive use values. Of special importance are the use values of functions which form the basis of the main forms of employment, particularly leisure and tourism. In addition, research into the residential function would be highly significant, with the focus on quality of life. However, various other use values such as those relating to different types of fishery have not yet been sufficiently well studied;
- research into the non-use values of the Wadden Sea Region as a whole and of its individual components. First and foremost, research into the non-use values of the Wadden Sea, with its wealth of flats, salt marshes, flora and fauna and its wealth of cultural history is required. Non-use values have repeatedly played a major part in conflicts between ecology and economics. Any knowledge of the non-use values of other parts of the Wadden Sea Region, such as its characteristic coastal area, is also almost entirely lacking. In this case, there are major unexpected connections with questions from both ecology and cultural history.

There are different methods for studying the E-E system, where a distinction can be made between direct and indirect methods. The indirect methods include the travel cost method, the hedonistic price model and the replacement production method. The best-known direct method is the contingent valuation method. Much is already known about the advantages and disadvantages of this method on the basis of its use internationally. However, the use of these methods in the particular situation in the Wadden Sea Region would mean that they would have to be specifically adapted to the region. An additional challenge is the need to combine the valuation of individual parts of the tidal flat system so that this information can be used for more general considerations of aggregated interests in analyses such as SCBAs for policy purposes.

The following research questions present themselves in the area of sustainable economic growth:

- What is the connection between the sustainable development of socio-cultural capital, ecological capital and economic capital?
- How sustainable and resilient is the Wadden Sea Region? This question can be answered with the aid of a sustainability balance sheet. And how can innovations and interventions to improve sustainability be encouraged?
- What overall growth prospects look promising and how can this be promoted via targeted policy measures?

An important policy and decision-making tool for assessing whether interventions in the Wadden Sea Region are permissible is the Social Cost-Benefit Analysis (SCBA). Worldwide, the SCBA is used in a large number of very different kinds of policy interventions because it provides a clear framework for ensuring the completeness and explicitation of theories and underpins and tests them scientifically. This makes the decision-making process more transparent and democratic. There is also a substantial gap in our knowledge in terms of integrating the above-mentioned research into the valuation of the elements of the Wadden Sea Region's ecological-economic (E-E) system as an input for the SCBA in various policy areas. A similar challenge is posed by the integration of information in the SCBA which can become available from the long-term monitoring of both socio-economic trends and trends in the areas of nature, landscape, ecology and climate.



2.5 Urban and rural planning: balancing risks and opportunities

Introduction

The Wadden Sea Region is in a continuous state of change, in different ways and at different rates. The region is the result of a continuous interplay of natural and human processes. The relationship between man, economics, ecology and geo-ecology is closely interwoven due to the presence of both natural values and economic potential. However, processes of (economic) growth often go hand in hand with friction and tension, mainly because of divergent, conflicting spatial claims.

This is felt not only in various nature reserves but also in tourist centres on the islands. Whereas the focus for nature reserves is on conservation, the centres for tourism and leisure are sources of development. Because these developments are limited by space constraints, the pressure increases here as well. Spatial strategies may be able to steer these developments in the 'right direction' within the actual centres but also by offering 'escapes' to locations elsewhere.

From a spatial point of view, the Wadden Sea Region contains a few locations in which a substantial degree of dynamism can be encountered, both seasonal and otherwise. These pressure points are situated in and abruptly alternate with extensive areas with a pronounced monofunctional character. If these are nature reserves, economic interests are derived from them, but there is – logically – a minimal amount of dynamism in the areas themselves. Agricultural areas are also relatively undynamic. Although less attention is paid to these areas, it is there where substantial spatial issues are at play. Examples include the quality of life in villages, the consequences of contraction for spatial planning, economic growth lagging behind, declining quality of the region, measures for tackling the consequences of sea-level rise, etc.

The fragmented diversity of spatial functions in the Wadden Sea Region, the interconnection and interdependence of these functions and the way in which they are developing, the risks and opportunities associated with these developments and the resulting spatial-functional contributions to the different region-specific qualities of the Wadden Sea Region will be closely examined in this contribution. The Wadden Sea Region has been analysed by means of a regional analysis which shows that there is a 'sustainable' separation of spatial functions in the region. This diagnosis gives rise to a number of questions, including the following. Under what conditions can functions be interwoven? Can this also support regional development? If so, which spatial strategies are desirable? How can policies be tailored accordingly? This will then form the basis for drawing conclusions and for formulating relevant knowledge demands.

1 Regional analysis

The Wadden Sea Region is diverse in many respects. It varies widely between areas of ecological value and areas of economic value. As well as tensions, there are also functional-spatial relationships between these areas. Extensive monofunctional natural and man-made areas alternate with pressure points. In functional-spatial terms, these pressure points are highly dynamic centres that seem to live in a symbiotic relationship with the surrounding natural environment and the seasonal changes to which this natural environment is subjected. Occasionally, pressure points are bursting with activity while nobody appears to be around in many places elsewhere in the Wadden Sea Region. This may be desirable for nature reserves but the situation is different when they are areas which we have forgotten, are

'of no significance' and are consequently undervalued in ecological, cultural, spatial or economic terms or remain underused. These subtle distinctions are an initial step towards a further analysis of the spatial diversity and spatial coherence of the Wadden Sea Region. Generally, the Wadden Sea Region can be split into three parts: the islands, the Wadden Sea and the area on the mainland, situated behind the sea dykes. From a functional-spatial point of view, these three areas are very different from each other with the sea as their common denominator.

The sea

The Wadden Sea forms part of the largest tidal area in Europe and is renowned for its unique natural qualities. Although the natural landscape is a changeable landscape, man's attitude is to focus strongly on preserving existing natural qualities. Shared human use is and will continue to be possible. But human activities should not cause lasting damage to the natural environment and landscape. From a functional-spatial perspective, the Wadden Sea is little more than a transitional area with no functional-spatial connections. This situation is changing, for instance the Wadden Sea has become a valued link in the routes used by a growing water sport sector.

The islands

The Wadden Islands form a natural buffer between the North Sea and the tidal area. This buffer is also a powerful tourist attraction. However, the tourism is confined to people who feel a bond with the region's ecological values. The main attractions are the scenic values of the islands, the wide variety of leisure facilities in the centres, the small-scale and cultural-historical nature of these centres and the magnificence of the North Sea beaches. Tourism and leisure have now become the largest source of income for the Wadden Islands. This spatial pressure is apparent in various ways. In recent years, the growing need for short-stay tourism has resulted in an increase in apartment complexes, which stand out in stark contrast to the characteristic appearance of the villages and have an effect on the quality of life.

The vast agricultural area behind the sea walls

Land reclamation operations in the past have shifted the Wadden Coast far into the Wadden Sea by adding a new 'skin' to the coastline with each operation. A man-made landscape has been created on top of an age-old landscape of terps and mounds. Land reclamation has enabled agriculture to develop in response to globalisation in a continuous process of expansion, upscaling and automation. Some processes aim for multifunctionality and expanding business activities, such as the increasing demand for the preservation and development of ecological, scenic and cultural-historical qualities. The interest in living, leisure and tourism in rural areas is also increasing. In agriculture, the production of biological products, the development of nature reserves and agricultural landscape development are already common processes. More recently, initiatives have been set up in the area of tourism, such as farm camp sites and social care farms, and in the area of energy production in which landscape maintenance and leftover crops are used as biofuels.

Social and economic trends

For some time, socio-economic factors and demographic contraction in the different regions have resulted in a decrease in the population, a changing composition of households and a less favourable age structure. These contractions will have consequences for the traditional spatial organisation and the quality of life of the region, which poses a threat of declining demand for functions and vacant property. The obvious solution is to strengthen the centralising function of a limited number of centres. This will then result in a hierarchy of centres, with the idea that, despite the contraction, public and retail functions and infrastructure can continue to serve the region as efficiently as possible. However, is this the only strategy

or are there interesting alternatives? Against a background of these concentration tendencies, issues concerning the conservation and development or redevelopment of scenic and cultural-historical elements such as village conservation areas, old sea walls, allotment patterns, 'one-man terps' and elements from the history of water management also play a part.

The entire coastal area has a strong inward focus, except for a couple of locations with industrial and port activities and the Lauwersmeer area. The Lauwersmeer has become a concentration point for natural and ecological qualities. In this area, spatial dynamics are confined to nature and ecology. At the border of the area, there are developments in the leisure sector, including marinas, holiday villages such as Esonstad and Villapark Lauwerssee and the planned Lauwershage resort for people requiring care. These developments have only a slight effect on surrounding areas, if any. Examples in which the development of nature reserves is combined with economic or leisure-related functions, are few along the Wadden Coast. Despite the proximity of the Wadden Sea and the pressure of tourism on the Wadden Islands, the terp areas of Groningen and Friesland are still failing to derive much benefit from the leisure sector. Locations on the water which are relatively accessible (Den Helder, Harlingen, Holwerd and Delfzijl/Eemshaven) mainly act as staging posts on the way to the Wadden Islands. Many people regard the area as a distant outpost of the Netherlands and little more than an area that has to be crossed to get to one of the Wadden Islands.

The industrial sector is mainly concentrated round the port areas. The port areas have relatively high spatial-economic dynamics without any significant spatial-functional connections with the area immediately inland. They are contrasting parts of an otherwise vast agricultural area.

The regional analysis has highlighted a number of imbalances. The Wadden Sea Region is a fragmented region containing considerable spatial-functional contrasts between mono-functional areas which have little if anything in common. There is also a lack of spatial connections which could possibly support sustainable development. An example would be connections between areas with an excess and shortage of leisure business, between the functions of agriculture, nature and leisure and between sea and land.

2 The policy

The spatial dynamics of the Wadden Sea Region are embedded within a context of formal and informal rules on conduct and use and legal rules. It is essential to gain an insight into the changing perspectives in policy and regulations as regards the likely effect on urban and rural planning considerations, policy action and ultimately the spatial situation. In the 1960s, plans for damming up the Wadden Sea were blocked because people recognised its unique qualities. Since then, national and international legislation, regulations and directives have been drawn up to protect the region's flora, fauna and physical condition. The largest proportion of legislation and regulations relates to the 'wet areas' and to (parts of) the Wadden Islands and, to a lesser extent, to the 'dry areas' of the inland communities (except for a few peripheral areas such as the ports and the Main Ecological Structure around Lauwersmeer). Land and sea are 'sustainably' separated by the solid line of the sea dykes. In the Third Coastal Policy Document [*Derde Kustnota*], the Dutch Ministry of Public Works and Water Management pointed out that the different parts of the Wadden Sea Region form an indivisible whole. Other policy documents, hold to the concept of a static transition between sea and hinterland, even where a flexible and interactive relationship between land and sea could be adopted as a principle.

From sectoral to area-specific

In addition to sectoral policy, the Dutch government is increasingly focusing on area-specific policy. However, this is hardly the case for the Wadden Sea Region. The vast (monofunctional) agricultural areas behind the sea dykes and the nature reserves do not require an integrated and area-specific approach immediately. Yet there is an increasing demand for multifunctionality. In the Wadden Sea Region, this mainly occurs at the interface between nature and leisure/care and between agriculture and leisure/care. In this case, a defensive strategy focusing on the separation of functions and preservation or restoration is not always desirable. Opportunities can also arise particularly where combinations of protecting values and developing functions are possible in the same area.

Peak policy and local initiative

With a change in political and administrative thinking at national level, a new course will be set from approval planning (no, unless...) to development planning (yes, provided that...). This does not mean that protection and risk-avoiding behaviour are becoming outdated: habitat regulations, climate management, maintaining sea defences, etc. are still high on the agenda. However, protection 'per se' and protection 'no matter what' will no longer be practised in all cases and will more frequently be weighed against potential possibilities for area-specific development. Government policy largely decentralises actions to exploit opportunities. By introducing the 'peak policy' (both nationally and regionally), the Dutch government is beginning to exploit and invest in the most promising spatial-economic activities of a region, area or location. Everything that has potential in 'The North' is summarised by the Ministry of Economic Affairs as a 'knowledge and energy region'. The emphasis is different in 'Het Kompas van het Noorden' (SNN, 1999) and 'Lila en de planologie van de contramal' (Hermans and De Roo, 2006) and the advisory 'Koersvast' published by the Social and Economic Council for the Northern Netherlands. In these publications, the North is regarded as 'Relaxation and Open Space' the counterpart to the 'Randstad' [the Amsterdam - The Hague - Utrecht - Rotterdam conurbation], having complementary qualities instead of competitive qualities. In 'Lila' and 'Koersvast' the leisure-related qualities of the Northern Netherlands in particular are regarded as an opportunity for regional development and this is of course highly appropriate for the Wadden Sea Region.

There is an increasing interest in highlighting and exploiting opportunities at local and regional level. Instead of relying on government subsidies, regions will have to exploit their own strengths to the maximum. In this context, regional parties will have to increase their efforts to jointly identify these opportunities and consider how best to exploit them, in view of the qualities of an area or region. This means that government bodies, private parties such as property developers and farmers, and nature conservation organisations will have to join forces to implement regional coordination.

The shift of emphasis in spatial-economic policy means an increasing focus on 'development' and 'areas playing to their strengths'. This requires the region to think in terms of development, based on the potential opportunities of the area itself. The Northern Netherlands has responded to this by concentrating spatial-economic developments interwoven with industry and services in core areas, including the Eems Region. This is a successful policy as economic and employment growth in the North as a whole has now been equal to national development for a long time. However, economic growth in the Wadden Sea Region still lags behind. Areas with ecological values such as the Lauwersmeer, the Wadden Sea and the Wadden Islands are protected by strict national and international legislation and regulations from the undesirable effects of the drive for growth. This suggests a balance between development areas and areas that have policies to protect them. The reality is more diverse, less easy to classify and somewhat unruly. For example, the development of the

agricultural sector is restricted by policy rules. This includes intensifying cultivation and business expansion, but also generally, with connections to water-based and leisure activities. More flexible relationships between land and sea may also provide opportunities but developments at this interface are still made more difficult by policy. The result of this is that in physical-spatial terms there are only limited options for further developing the Wadden Sea Region on the basis of existing and potential area-specific qualities, even though the principle is explicitly to continue to strengthen existing area-specific qualities.

In view of the above, a spatial perspective on separating and interweaving functions in and on monofunctional and multifunctional use of the Wadden Sea Region is highly desirable. Inevitably, this also has consequences for the way in which the perspective on separation and interweaving of functions is turned into policy, which underlines the need for spatial regional coordination. Instead of functional allocation alone, it has more and more to do with the qualitative embedding of functions. Spatial functions should be in line with the landscape characteristics and should continue to strengthen existing qualities. This assumption may become an important spatial precondition for urban and rural planning actions. With the advent of concepts such as sustainability and quality of life and the focus on cultural history, the urban and rural planning debate has started to consider quality aspects besides and in addition to the functional aspect. But it must be said that by no means all planners and administrators are convinced by this principle. And the 'protectors' therefore have right on their side if they remain critical of the 'policy-makers'. Although a great deal still needs to be done in this respect, the benefits may be substantial. However, further and more intensive study will be required.

Adaptive governance

It can be inferred from the regional analysis that, besides vertical control by the government, more attention is being paid to horizontal and regional control strategies. The underlying arguments are the increasing interconnection of spatial issues, multiple claims on the available space and the desire for an area-specific approach. Increasing the interconnection of spatial issues also increases the number of relevant stakeholders who want to and will have to form part of decision-making processes. This means that, in addition to the government, semi-private parties, market players, interest groups and individual citizens will participate in decision-making and planning. This decision-making can be characterised as 'multi-level', 'multi-actor' and 'adaptive governance', in which the interests and positions of the parties involved are also a basis for the decision-making process. A number of complex issues in the Wadden Sea Region require 'adaptive governance'. This therefore involves decision-making that can adapt to continuously changing conditions at different levels and with variable structures. In addition to a dynamic structure of parties involved and interests, account must also be taken of different geographic and time scales resulting from socio-economic and natural trends. It is therefore relevant to connect area-specific knowledge and area-specific processes and involve science, the scientific debate on policy-related discussions, from which all the parties involved and the Wadden Sea Region can benefit.

3 Gaps in knowledge

The regional analysis has shown that the region operates a strict separation of functions and functional areas. As a result, 'conservation' and 'development' are on opposite sides. This situation does not necessarily produce a positive result on all fronts for the future development of the Wadden Sea Region. There are also ongoing trends which, in a number of cases and in the right conditions, justify a different position. In this case, strategies focusing on conservation and avoiding risks may clash with strategies more focused on development and exploiting opportunities. Against this background, the following knowledge demands have been formulated:

Interweaving of functions and multifunctional area-specific development

- Under what conditions can multifunctional area-specific development contribute to the development of the Wadden Sea Region?
- Which spatial functions and ecological and economic qualities can reinforce each other within multifunctional area-specific developments and which counteract each other? How can area-specific qualities be safeguarded?
- Which 'multi-level' factors can be combined to form a consistent and robust strategy for multifunctional area-specific development?
- What conceptual perspective can be developed to come to an 'ex-ante' judgement on a possible balance, competition and complementarity between monofunctional and stable areas with multifunctional and dynamic areas within a functional region? Examples of this are the opportunities and conditions for allowing the Wadden Sea to play, for example, a stronger connective role, both physically and in the perception of the Wadden Sea Region. Whether to relieve the leisure-related pressure on the Wadden Islands by means of developments behind them on the 'mainland'. What does this mean for the regional and local quality of life?
- Do developments in peripheral areas and transitional areas have to remain as they are or can they be used as crystallisation points and dynamos for future spatial developments?
- What are the spatial consequences of the apparently unstoppable process of expansion on the one hand and the demand for multifunctionality on the other hand in the agricultural areas?
- Is it possible to improve spatial arrangements and results by adopting a tailor-made, area-specific approach and with local support?

Spatial quality and spatial strategy

- What does the trend in urban and rural planning towards qualitative embedding of spatial functions mean for the development of policy, the area-specific approach and regional coordination in respect of the Wadden Sea Region?
- How can the qualitative embedding of spatial developments contribute to a higher evaluation of the everyday environment?
- How can strategies combine the best of two worlds: what are the opportunities and conditions for combining the need for protection and for risk-avoiding behaviour with the possibilities of taking risks and area-specific development, e.g. in terms of climate, energy and space, housing and nature and agriculture, water and leisure?

Housing and quality of life

- Can the demand for housing on the Wadden Islands be facilitated in such a way that it supports and, if possible, strengthens the local qualities?
- To what extent are housing and nature management compatible?
- What part can bi-residentiality play in eliminating empty property and preserving cultural history?
- Can the 'wintering' of leisure craft in the Wadden Sea Region help to preserve functions?
- What differentiates the Wadden Sea Region in terms of demographic contraction and what does this mean for the community structure, the structure of facilities in residential centres and the situation with regard to the supply and demand of facilities?

Regional coordination and adaptive governance

- To what can regional coordination lead and what underlying conditions are desirable?
- How can regional coordination help to create regional harmony in which regions do not compete with each other but actually complement each other?
- How can regional coordination be organised, given the different interests and views?
- What preconditions must regional coordination satisfy, from a multi-level, multi-actor and adaptive governance perspective, which takes account of the adaptive capacity of the parties involved?



2.6 Climate and water; climate change and the Wadden Sea Region

Introduction

The climate varies over timescales ranging from decades to millennia. However, since the 19th century, changes have been taking place at a much faster rate, mainly due to man-made emissions of greenhouse gases. These developments are expected to continue at an even faster rate over the decades to come. It is the speed of change that is forcing society to anticipate pro-actively. However, uncertainties associated with future greenhouse gas emissions and expected climate changes make it difficult to develop effective policies and to acquire the necessary support.

A number of subjects connected with climate change are of specific relevance to the Wadden Sea Area, i.e.:

- causes of climate change, such as greenhouse gas emissions in estuaries, in the Wadden Sea Area in particular, and the contribution to ocean acidification by processes in coastal systems;
- region-specific climate scenarios;
- expected consequences of climate change in the Wadden Sea Region;
- 'climate-proof' options for development in the region.

Each of these aspects is discussed in detail below.

The most obvious consequence of climate change for the Wadden Sea Area is that due to sea-level rise "the continued existence of the Wadden Sea as we know it can no longer be guaranteed"². Geomorphological processes, which keep tidal flat systems in balance with a rising sea level, may fail if the rise is too abrupt, resulting in the region being swamped. However, in addition to these dramatic consequences, a number of other more subtle but no less important changes can be expected. Examples include changes in the salt content of the water, the morphology of the tidal flats, populations and food web in the water and on land as well as tourism and economic activity. Climate change and its consequences will therefore be relevant to almost every sector when developing an outlook for the long term.

² Delta Committee Report
'Samen werken met water', 2008

In all these areas, the Wadden system will to some extent adapt autonomously. However, it will also need assistance to adapt and may also have to be defended. Policy focusing on protection (e.g. Natura 2000) and restoration (e.g. NRP 2009) will have to be evaluated regularly – perhaps more frequently than if climate change was not happening – to ensure that its objectives are attainable and its measures are effective. Adaptation measures could be taken reactively and should be updated continuously. However, we will also have to anticipate climate change and improve the sustainability of current investments by making them robust enough to cope with future changes anticipated in scenarios. This can and must be done without adversely affecting the basic assumption that the natural values of the Wadden Sea have primacy while tolerating only economic activities that are not in conflict with these. Climate adaptation will have to be embedded in the spatial planning of the Wadden Sea Area. However, this also provides opportunities for innovative, climate-proof and sustainable development in the region.

1 The Wadden Sea as an actor in climate change

Shallow coastal areas and estuaries are disproportionately important in the production and conversion of organic matter and nutrients. This applies to an even greater extent to the production of greenhouse gases, particularly CO₂, methane (CH₄) and nitrous oxide (N₂O). For example, a simple extrapolation of CH₄ emissions measured recently in the German Wadden Sea Region to the Dutch Wadden Sea Region suggests that CH₄ emissions could amount to some 750 kilotonnes a year. This is of the same order of magnitude as total Dutch anthropogenic CH₄ emissions. Moreover, human actions (affecting the supply of nutrients, changing the function of the Wadden Sea Region) could cause shifts in emissions or absorption of greenhouse gases which could be significant in relation to the total emission balance of the Netherlands.

There are several factors that contribute to the disproportionately large contribution of estuaries to global greenhouse gas production and emissions. First, the concentration of organic matter from rivers and coastal waters into estuaries is high. Second, because of their shallowness, both anaerobic and aerobic decomposition processes play an important role (particularly relevant to CH₄ and N₂O emissions). Finally, the high concentrations of nutrients which make estuaries extraordinarily productive also stimulate decomposition processes considerably. In particular, the emissions of N₂O from coastal waters may contribute significantly to the global balance for this gas, but also considerable amounts of methane are produced by benthic organisms. However, global estimates are not yet sufficiently supported by regional studies. The situation is even more complex in salt marshes due to the effect of plants and episodic inundations, and greenhouse gas emissions from salt marshes in the Dutch Wadden Sea Area are presently unknown.

It can be concluded from the above that the production of greenhouse gases in the Wadden Sea and their emission to the atmosphere and their export to the North Sea are potentially very substantial. We have limited sets of flux measurements from Zeeland and the Wadden Sea and from concentration profiles in the Eems. Recently, detailed research was conducted in Germany into greenhouse gas emissions in the Wadden Sea. However, a more detailed study of the Dutch Wadden Sea Region is required. In this respect, the Wadden Sea – where measurements of greenhouse gas production and emissions can be combined with existing and planned ecological studies – provides a unique opportunity for further research.

The absorption and emission of CO₂ is first and foremost determined by the balance of production and decomposition of organic matter. Measurements of the primary production in the Wadden Sea in the past have been incomplete (see section 2.2, Ecology). From the nutrient balance we can deduce that decomposition of organic matter exceeds its production. CO₂ concentrations in coastal waters were measured during a number of cruises. Along the Dutch coast, the undersaturation or oversaturation of the CO₂ concentration in the water and other properties such as salt content were extremely variable over time and space. There is a noticeable influence from the Rhine, Meuse and Schelde rivers, as well as from the production and consumption processes in the Wadden Sea.

CO₂ absorption by seawater is determined not only biologically but also, strongly, by the acidity of the water. This produces a powerful feedback: additional CO₂, dissolved in the water as a result of the increased atmospheric concentrations increases the acidity (and lowers the pH), thereby inhibiting further absorption by physical-chemical and ecological effects. In this way, the ability of the sea to absorb net CO₂ from the atmosphere is impaired. In addition, the increased acidity may have a harmful effect on organisms with calcium skeletons.

It has recently been shown that the Wadden Sea Area may be important in countering the above effect due to the disproportionate role it plays in regulating the alkalinity of the North Sea. Anaerobic decomposition processes are very important in the shallow Wadden Sea because a great deal of decomposition takes place in the (anaerobic) sea bed. The increased alkalinity generated by these processes increases the buffer capacity of the water.

The potential total emissions of greenhouse gases to the atmosphere from the Wadden Sea Area and adjacent areas are such that a reduction in the uncertainties in the estimates is required. New measurements of all three greenhouse gas fluxes and the underlying processes are needed. These measurements preferably have to be made all year round and covering the whole region. Production or absorption in water and soil must be linked to water flow models to quantify the transport of greenhouse gases to the North Sea in order to quantify the total balance sheet without double counting or omissions.

2 Recent changes in the climate of the Wadden Sea Region

Until now, the warming of North West Europe has been greater than the global average. In the Netherlands, the warming rate has been more than twice this global average. This is due to an increase in the number of situations with westerly winds in late winter and early spring and to an increase in solar radiation in spring and summer. The water temperature has also increased much more rapidly in shallow coastal seas (such as the North Sea) than in the ocean. The temperature of the Wadden Sea is in line with air temperature trends; over the past three decades the water temperature has risen by approximately 1.5°C (figure 21).

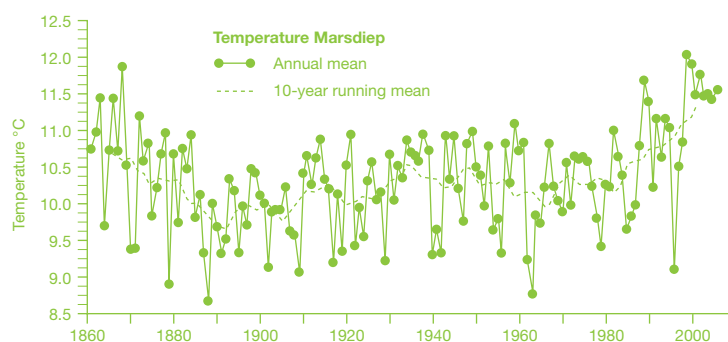
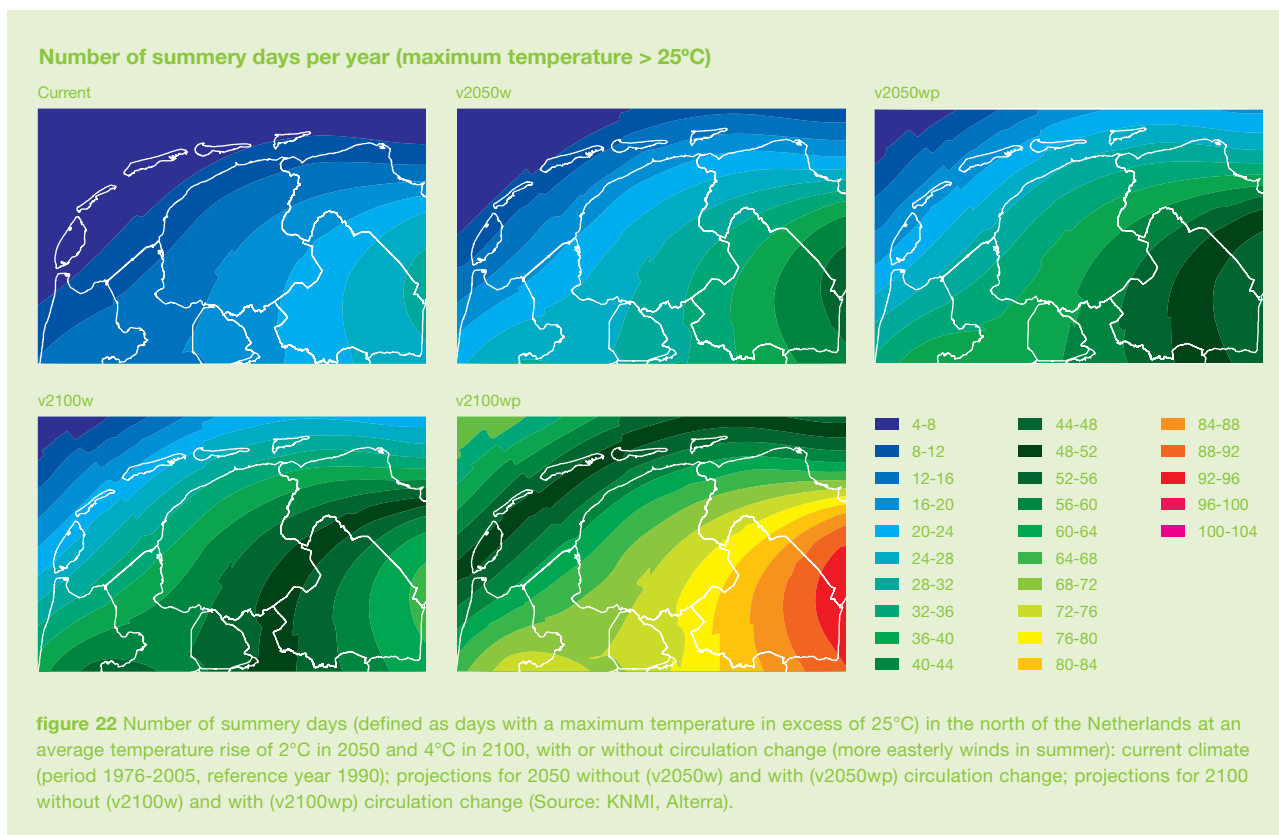


figure 21 Water temperature in the Marsdiep (Source: NIOZ).

The annual rainfall in the Netherlands has increased by 18% since 1906, mainly in winter and to a lesser extent in autumn and spring.

In the Wadden Sea Region, spring is on average drier than in the rest of the Netherlands and autumn wetter. In recent years, there seems to have been an increase in the number of days of heavy rainfall in the Netherlands. On the coast, the intensity of the rainfall may be influenced by the temperature of the North Sea water, particularly in late summer and early autumn. In the Dutch coastal area, the intensity of showers has increased by 15% per degree seawater temperature increase as opposed to 5% per degree further inland. Some of the rainfall evaporates. Only general estimates of evaporation are available for the Netherlands based on a simple model which does not take account of (regional) differences in wind speed and in the characteristics and condition of soil and vegetation. The rainfall deficit is the difference between rainfall and evaporation. Trends in this deficit are an indication of trends in the freshwater balance of the islands. Available data suggest that there is no national trend in the rainfall deficit. However, the maximum rainfall deficit in the dry years 1976 and 2003 was 20% greater near the coast than in the rest of the Netherlands, because the coastal region is relatively dry in spring.

Wind has consequences not only on land. It is also important on the tidal flats, mainly because of its influence on the formation of waves and swell during storm surges. Whenever high swell and surge are combined, there is an increased risk of inundation. Together with sea level and tidal movement, swell and wave energy play an important part in the creation of a dynamic geomorphological balance in the tidal flats due to their effect on the distribution of sediment material and the development of channels and sand bars. As storms in the Netherlands have been monitored only for a relatively short period, any trends are hard



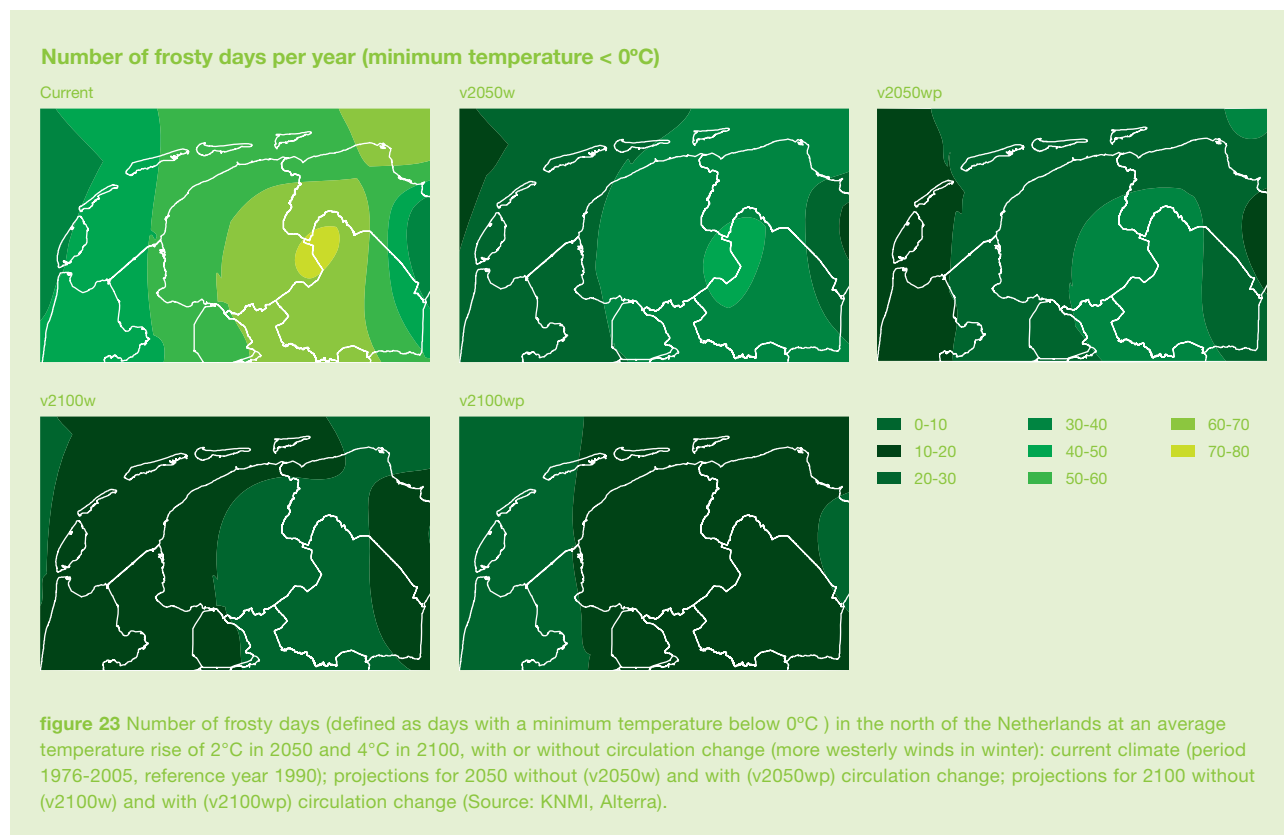
to discern. In any case, the observations on storm swell in the Dutch coastal area (including the Wadden Sea) do not show a clear trend, unlike observations in the German Bight which suggest a rising trend in the annual maximum water levels.

The sea-level rise relative to local land level is of particular importance to the Wadden Sea Region because of the considerable effect that it has on the geomorphological processes in that area. This relative sea-level rise is determined by the global absolute rise in sea level, taking account of regional effects, and the vertical movements of the land. Depending on the location, the land is sinking by 0-4 mm per annum in the Netherlands. In the last century, the sea level in the North Sea rose by an average of 1.8-1.9 mm per annum, which comes very close to the global average rise. From 1993 to 2003, satellite measurements indicated a global average rise of approximately 3 mm per annum, which would seem to suggest an increased trend. This increase has not yet been satisfactorily explained and is not yet clear from in-situ measurements along the Dutch coast.

3 Climate scenarios specific to the Wadden Sea Region

Climate change in the Wadden Sea Region depends first and foremost on global trends, but also involves region-specific effects. The IPCC's insights on global climate change were transformed into Dutch climate scenarios by the Royal Netherlands Meteorological Institute (KNMI) in 2006 (KNMI'06), which allows more regional projections to be made. In this process, changes in both the averages and the variability are prescribed by the selected KNMI'06 scenario. On the basis of these changes, several historical series of observations by the KNMI monitoring network were scaled. After interpolation of these scaled results, a future spatial pattern could be produced, based on the pattern in today's climate (for example, see **figs. 22 and 23** as discussed below).

Climate change for the next few decades (up to about 2050) more certain than for the period that follows. After all, the climate in the near future is mainly determined by the



known greenhouse gas emissions to date. Changes in the more distant future will also depend on the emission policies pursued in the decades to come and on links between climate and greenhouse gas emissions or absorption by the oceans and on land, about which there is currently much uncertainty. The uncertainties also vary widely between the different variables. For example, the projected temperature changes are much more certain than the changes in rainfall, wind and sea-level rise. Finally, it is important to note that future changes become more uncertain when the observed scale becomes smaller.

The KNMI'06 climate scenarios for the Netherlands assumed either a moderate world-wide temperature rise (1°C in 2050) or a somewhat higher rise (2°C). In addition, it made a distinction as to whether a change in circulation patterns will occur over Western Europe, thus resulting in four different scenarios.

In current climate scenarios the temperature will continue to rise. By 2050, the summer temperature in the Netherlands may have increased on average by 0.9-2.8°C. This is accompanied by an increase in the number of summery and tropical days. On the coast, as many summery days may occur each year as presently occur inland (**figure 22**). The average winter temperature also rises in all the scenarios, ranging from 0.9-2.3°C. At the same time, the number of icy and frosty days decrease, particularly if the wind will be blowing from the west more frequently (**figure 23**). A rise of around 2°C is expected for the seawater temperature at the coast.

Rainfall is, to a large extent, determined by possible circulation changes. There is a great deal of uncertainty with regard to the future total summer rainfall as the scenarios show conflicting trends. However, the likelihood of extreme rainfall in summer increases in all scenarios. In the coastal area, the trend in extreme rainfall in late summer and autumn may be reinforced by the increase in seawater temperature. However, the precise mechanism behind this phenomenon and the consequences of it are still unclear. The precipitation

scenarios provide a more consistent picture for the winter period: a 4-14% increase in rainfall. The KNMI'06 scenarios also suggest the possibility of changes in evaporation but the projections of a slight increase in evaporation are highly uncertain.

In the KNMI's 2006 scenarios, the absolute sea-level rise will be between 15 and 35 cm at the Dutch coast around 2050, rising to 35-85 cm in 2100. These projections describe the range of the most probable scenarios from the fourth IPCC report. In 2008, the Delta Committee commissioned additional scenarios based on guaranteeing long-term safety in the Netherlands. These are plausible but less probable upper limit scenarios for the period after 2050. These projections are also based on the fourth IPCC report but they assume the upper limit given in that report of a 6°C global average temperature rise around the year 2100. New information on ice cap dynamics has also been incorporated. According to the additional estimates for the upper limit, the absolute sea-level rise along the Dutch coast may reach a maximum of 120 cm around the year 2100 (**figure 24-A**). To all these projections for absolute sea-level rise, the effects of land subsidence along the Dutch coast, averaging about 11 cm per century must be added. This land subsidence varies locally, e.g. due to gas extraction.

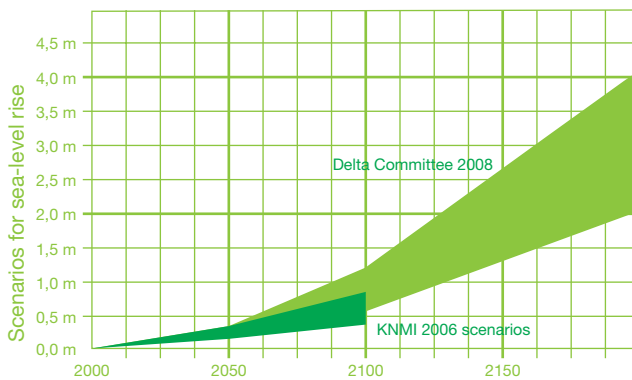


figure 24-A Scenarios for sea-level rise. Top: The projected sea-level rise for the Dutch coast relative to reference year 1990. The effects of land subsidence are not taken into account in the graph (Source: Delta Committee).

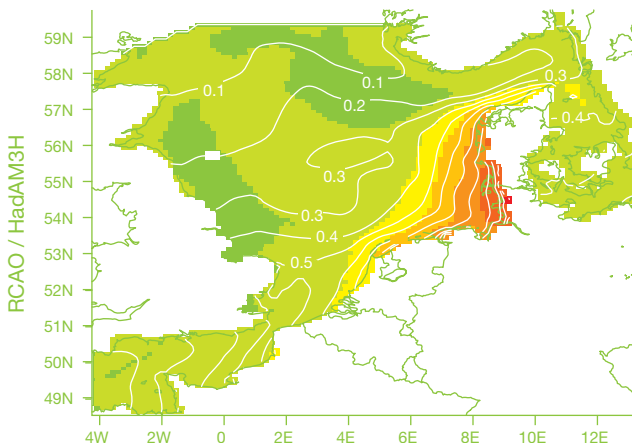


figure 24-B Bottom: In colour, the simulated additional swell that may occur once or twice a year at the end of the next century. Contours show the measured values for the period 1961-1990 (Source: Institute for Coastal Research, GKSS Research Centre, Germany).

Apart from sea-level rise also swell is important. The climate models show a slight increase in the maximum daily average wind speed per annum and in the strength of the severe south-westerly storms. Some models show an (additional) increase in the number of westerly winds but no increase in northerly winds. For these reasons, the scenarios do not expect an increased frequency of the number of situations involving an extremely high swell. However, recent projections of swell by German researchers do suggest an additional increase in the German bight that extends into the Dutch Wadden Sea Region (**figure 24-B**). This shows that important details of changes in wind climate and interactions with the geomorphology in the Wadden Sea are still unclear. The consequences for processes associated with the wave climatology such as the transport of sand and coastal formation are thus also uncertain.

4 Climate and safety

Safety in the Wadden Sea Region is a function of relative sea-level rise, storm swell and wave force on the one hand and defensive measures on the other. With regard to sea-

level rise, it is essential to establish the geomorphological 'threshold', i.e. the level of sea-level rise above which the Wadden will be flooded and therefore will cease to exist in its present form. Below the threshold sedimentation is in pace with sea-level rise and the Wadden will survive more or less in its present form. Currently, this threshold value is estimated at some 60 cm per century but it varies between the various morphological elements. For example, the threshold value is lowest (3 mm per annum) for large tidal basins, higher for small basins (6 mm per annum) and highest for salt marshes (9 mm per annum) but the quantitative evidence for this is weak (see Geoscience section before). Surprisingly, the threshold value seems to rise if the storm frequency increases, which can be explained by the increased sand transport during storms. Here too, confirmation or otherwise is urgently required.

Recent insights into sea-level rise as summarised in the Delta Committee report produce a range in rise from 0.65 to 1.30 m by 2100, taking account of land subsidence. This range is smaller in the shorter term (0.2-0.4 m by 2050) and larger in the longer term (2-4 m by 2200). The range is mainly determined by uncertainties with regard to the behaviour of the major ice caps (Greenland and Antarctica) and long-term emission scenarios. It is clear that even the conservative estimates of sea-level rise come close to the geomorphological threshold values.

In the Netherlands, every five years the primary water-defense structures are checked to ensure that they still conform to standards. These checks are based on 'hydraulic constraints', i.e. the forces acting on the water-defense structures. An update of these constraints is published every five years. Current knowledge in the area of wave predictions indicates that the representative wave loads used until now are too low at some points along the coast. Higher wave constraints in a future check of our coastal defense structures could result in dykes being disapproved. Because the financial consequences could be particularly serious, new measurement-based insights must be properly substantiated.

Options for adapting the coastal defences involve not only 'hard' interventions such as dyke reconstruction and sand suppletion but also less drastic options such as adapted dune, salt marsh and summer polder management, erosion and sedimentation control using 'bio-builders', spatial planning, disaster management, etc. What constitutes the most effective mix of adaptation options for the Wadden Sea, including international aspects, requires substantial further study.

5 Expected impact of climate change in the Wadden Sea Region

Ecology, nature and fishing

The combined impacts of warming, an increase in extreme rainfall, sea-level rise and salt reduction due to increasing discharge from rivers have consequences for the environment, directly on the physiology, the phenology and the behaviour of organisms and indirectly as a result of the major geomorphological changes that could occur. The consequences of this for biomass and productivity, species composition and behaviour will put pressure on the structure and functioning of the food web, with an impact on sustainable use and robust nature conservation measures. A couple of examples are given below to illustrate the diversity of effects. For a more complete list of the environmental impact of climate change, please refer to the background document.

The salinity of the water in the Marsdiep has declined in recent times (**figure 25**). A large part of this trend can be attributed to an increased flow of fresh water to the sea as a result of human interventions to control the water level in the Rhine and the discharge of fresh water from Lake IJsselmeer. The effect of rainfall on river discharge largely determines the year-to-year variations in salinity. The average reduction of salinity in the Marsdiep is not very relevant in ecological terms. This is because most species in the Wadden Sea Region can live quite happily in moderately brackish situations. However, surges of almost completely fresh water that last a few days, e.g. in the case of record discharges from the Rhine and IJssel, do have a major impact. If the surplus water cannot be contained in Lake IJsselmeer but has to be discharged on to the tidal flats, this can cause massive mortality among the benthos. Such effects are regularly observed in the Westerschelde and off Haringvliet in the North Sea. The recovery of populations of benthic organisms can take years.

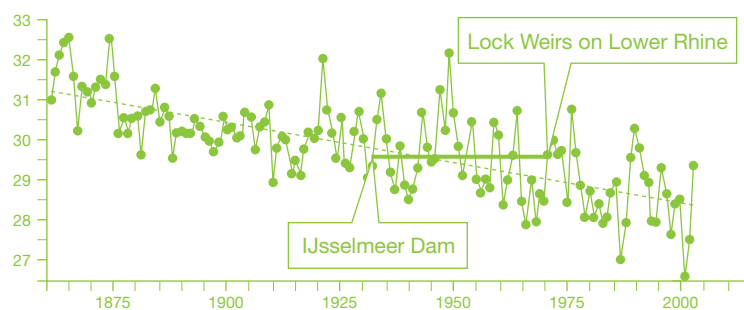


figure 25 Annual mean salinity as measured in the Marsdiep (Source: NIOZ).

Harsh winters appear to be a prerequisite for a healthy recruitment of shellfish. In such winters, predators like shrimps and crabs do not enter the tidal flats until later in the season which gives young shellfish the chance to grow to a size at which these predators are no longer able to eat them. The absence of cold winters in recent decades has had a negative impact on the growth of mussels, cockles and Baltic clams. By contrast, the Pacific oyster and the common slipper limpet thrive during warm summers and mild winters.

Research into the eelpout, an indicator species for fish in the North Sea and Wadden Sea, has shown that an increased water temperature reduces the amount of oxygen absorbed by fish. This then reduces the growth and abundance of this species, which will eventually result in its extinction or migration when the seawater becomes too warm. A reduced oxygen content resulting from temperature rise also has an effect on shellfish and their predators.

Over the past 50 years, the North Sea climate has exhibited two major anomalies. In the 1970s, the water temperature, salinity and Atlantic inflow were lower than usual. The trends have reversed since the 1980s. Both periods were characterised by rapid and large-scale changes in plankton, benthos and fish populations, with significant regional differences. For example, over the past few decades, the spring bloom of phytoplankton has occurred increasingly later in the Wadden Sea but earlier in the North Sea. Fish larvae and young shrimp appear earlier in the Wadden Sea. These kinds of changes in seasonal dynamics result in a mismatch between peaks in phytoplankton and zooplankton, between shrimps and shellfish larvae, between zooplankton and fish, and between fish and seabirds.

A clear northward expansion of 'warm' species has been observed for plankton and fish in the North Sea, sometimes over 1,000 km, whereas cold-water species have disappeared. For example, the population of anchovies and sardines has grown since 1995, while plaice move to deeper waters earlier in the year.

Migration patterns of birds are determined by differences in temperature and food availability between different staging areas. In the Wadden Sea, there are significant differences in numbers of wintering birds between severe and mild winters. Changes in migration patterns can also be expected alongside climate change but it is difficult, if not impossible, to predict in which direction. This will have to be taken into account when interpreting bird count data over the longer term, especially as an alternative or additional explanation to local disturbances or changes in the Wadden Sea Region. The diversity of effects requires much better integrated and continuous monitoring of the tidal flat system, better knowledge of the vulnerability and adaptability of key species and the development of models for managing the marine and tidal flat ecosystems.

Climate and fresh water supply

The Dutch Wadden Islands obtain their fresh water partly from the mainland and they are partly self-reliant in this regard. Texel obtains all of its fresh water from the mainland. Terschelling and Ameland are 30-40% self-sufficient and Vlieland and Schiermonnikoog entirely so. The aim is to make all the Wadden Islands as self-reliant as possible in future. The surplus rainfall that accumulates in fresh water lenses under the dunes and in the agricultural areas already plays an important part in the islands' fresh water management system and it is expected that this role will only become more important in future. The rainfall surplus is partly determined through evaporation by the response of the vegetation to climate change. For this and other reasons, it is extremely difficult to predict future changes in the fresh water balance. Sea-level rise may also increase salt seepage. The result is a possible acceleration of salinisation which will have a negative impact on water quality.

The drinking water supply will become more complex by increased groundwater dynamics as well as surface water dynamics. Extremes of rainfall cause peak discharges which are often accompanied by peaks in pollution levels. Temperature rise has a major impact not only on the microbiological load of surface water but also on water treatment and in the mains system. Adaptation measures in the sewage, water treatment and water supply systems on the islands must be studied.

Agriculture in the coastal zone is ultra-sensitive to drought and salination. The risk of water shortages during dry periods is greater in elevated parts of the coastal area. Low-lying areas will have a greater risk of flooding in winter and an increase in salt seepage (**figure 26**). A shift in the choice of crops may be expected, not only with regard to more traditional varieties, but also as a result of new opportunities for brackish agriculture, including land-based aquaculture.

Groundwater quality (salinity, nutrient and calcium content) and gradients are of great importance to the ecology of the islands and agriculture in the northern regions. But the impact of climate change on groundwater quality through the combined effects on the chemical dynamics and on quantity of groundwater has received little attention until now and is poorly understood. Major questions arise with regard to the dynamics of small or recent freshwater lenses in washovers, the calcium balance and the consequences for agriculture and the natural environment.

The impact of climate change on the quality of the surface water (inside the dyke) is caused by (in order of importance) changes in temperature, rainfall and wind. More research will be required, particularly with regard to the impact of climate change on biological water quality parameters, such as cyanobacteria and phytoplankton and with regard to the impact of the changing water quality and quantity on different functions, including agriculture, nature, leisure and fishing.

Other sectors

Tourism and leisure are sensitive to the weather and therefore to climate change. Higher temperatures, fewer rainy days in summer and more hot days are generally considered favourable. The reduced likelihood of there being an Eleven City Ice-Skating Race [*Elfstedentocht*] is less favourable to the northern region. The likelihood of an Eleven City Ice-Skating Race has already receded since 1960 and is expected to continue to decline in future. Climate change can also pose health risks related to tourism, e.g. exposure to UV rays and the risk of cyanobacteria and plagues of ticks and mosquitoes.

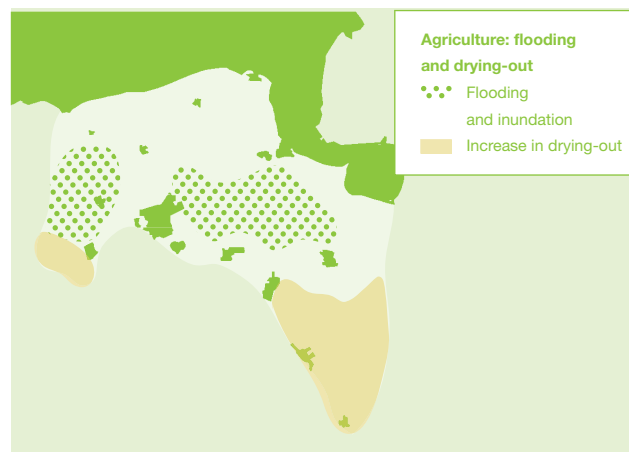


figure 26 Example of the possible spatial impact of climate change on agriculture in the Province of Groningen: flooding and drying-out (Source: DHV).

6 Knowledge gaps

Knowledge demands relating to climate change in the Wadden Sea Region can be classified into four groups. First, detailed studies are required into the role of the region in the emission of greenhouse gases. Combined region-wide estimates of emission balances of CO₂, CH₄ and N₂O over the seasons can only be compiled when they are linked to the hydrodynamic (tidal currents as the transporter of greenhouse gases) and ecological (primary production and decomposition) studies from the relevant domains. This should result in a far more comprehensive picture of the fluxes and underlying processes which will enable us to better estimate how management can (unintentionally) influence these emissions. Second, there is great interest in producing good regionalised climate scenarios for impact studies and for designing adaptation measures. For the decades to come (until about 2050), the uncertainty in global climate scenarios is small enough to make downscaling them to the Wadden Sea Region worthwhile. It is of particular interest to have a good understanding of effects which are specific to the coastal zone and have to do with the transition between land and sea, such as the effect of seawater temperature on rainfall intensity. The design of no-regret adaptation measures benefits from a thorough examination of extremes. Third, much more knowledge is required with regard to the possible impacts of climate change on the morphology, water management and ecology of the Wadden Sea Area and the robustness and resilience of existing natural and human systems. Fourth, development of innovative adaptation measures will have to be based on all of the above. Creative ideas will have to be evaluated based on their overall impact on the future situation. Robustness and resilience are also key words in this context. In these two themes, impacts and adaptation, knowledge development can only take place in close cooperation with other domains, where climatological and meteorological knowledge interacts directly with knowledge concerning ecology, geomorphology and society.

Below are examples of knowledge demands in each of these three areas. Behind the knowledge needs stated here, there are other, more specific questions. For a more exhaustive list, please refer to the position paper.

Greenhouse gas emissions and balance sheet

- How big are the emissions of carbon dioxide, methane and nitrous oxide from the Wadden Sea Region?
- What are the main natural mechanisms that determine the greenhouse gas emissions from the Wadden Sea Region?
- How and to what extent are the emissions of carbon dioxide, methane and nitrous oxide from the Wadden Sea Region affected by human activities in the region itself, on the mainland and in our rivers?
- How and to what extent does the Wadden Sea Region help to counteract the acidification of North Sea water?

High-resolution climate scenarios

- How will the climate of the Wadden Sea Region change in the century to come and how will extremes of temperature, rainfall, drought and wind change?
- What are the differences between nation-wide climate changes and the regional climate changes in the Wadden Sea Region?
- What are the effects of the North Sea and the geographical and geomorphological properties of the Wadden Sea Region on regional climate change?
- How do climate change and geomorphological characteristics determine changes in the temperature of water and land and changes in swell, wave heights, storm frequencies and salinity?

Sectoral and cross-sectoral impact studies

- How will tidal channels and flats respond to climate change and what are the consequences for their morphology and ecosystem?
- What are the consequences of climate change for water balance and quality in the Wadden Sea Region?
- How will the food web in the Wadden Sea respond to climate change and how will changes in the food web affect the abundance and species composition of shellfish, fish and birds?
- How serious will possibly harmful impacts of climate change be on tourism, leisure, agriculture and other economic sectors?

Design and impact studies for sectoral and cross-sectoral adaptation options

- What are the options for guaranteeing safety in the Wadden Sea Region?
- How can the sustainability and resilience of the various sectors be measured and compared?
- How can agriculture and fishing adapt to the changing climate and what new options are feasible in the Wadden Sea?
- What new opportunities does climate change offer for leisure and tourism?
- How can insights from the natural sciences concerning climate change be usefully combined with insights from the social sciences concerning perception and human actions?

The infrastructural prerequisite for answering the above questions is the creation of a database supplied by the consistent and integrated monitoring of operational and demand-specific measurement data. From the climate domain, this involves in particular meteorological, physical-oceanographic and greenhouse gas emission data with sufficient spatial coverage to interpret the main gradients in the Wadden Sea Region. A second database would have to provide all parties upon request with relevant climate scenarios, model data on climatological variables which can be used as input for impact studies and in the evaluation of adaptation measures. Both generic and more tailor made scenarios and tools can be developed in this way.

3 Wadden Sea Region: an international perspective





3 Wadden Sea Region: an international perspective

Introduction

The international Wadden Sea is one of the last remaining natural, large-scale intertidal ecosystems in Europe. The tidal flats in the Wadden Sea form the largest unbroken stretch of sand and mudflats worldwide, accounting for 50% of all tidal areas in Europe and North Africa. They provide an unrivalled space for natural biogeomorphological processes. As such it is 'the only one of its kind' and the Wadden Sea is a textbook example of intertidal habitats and the rich and diverse flora and fauna they sustain.

An ecosystem of international importance

There are numerous interactions between the Wadden Sea tidal basins, between tidal basins and the adjacent North Sea and between the Wadden Sea and rivers. Sediment, substances and plankton are exchanged with the North Sea and are transported with the dominant current along the Wadden Sea from southwest to northeast. Several major rivers are a source of fresh water, fine sediments and chemical substances. Biological processes, including primary and secondary production, as well as food web interactions, all over the Wadden Sea are influenced by these hydrological and geomorphological processes. The international Wadden Sea shows much stronger gradients in the relative impact of the main sources of mud and nutrients (the English Channel, the Rhine and the Elbe) than the relatively small part of it that is the Dutch Wadden Sea.

There is a vast exchange of species between the different parts of the Wadden Sea, and between the Wadden Sea and the North Sea. Moreover, there are interactions between the Wadden Sea and ecosystems not directly bordering the Wadden Sea. According to the 1% criterion of the Ramsar Convention (which is an internationally recognised measure to identify wetlands of international importance) the Wadden Sea is of outstanding international importance as a staging, moulting and wintering area for at least 52 populations of 41 migratory water bird species that use the East Atlantic flyway and originate from breeding populations as far away as Northern Siberia or Northeast Canada. Numbers of 44 populations of 34 species are so high, that the Wadden Sea is indispensable to these birds and often their main stepping stone during migration or their primary wintering or moulting habitat. Therefore the Wadden Sea is essential for the existence of these bird species (see **figure 27**). Serious damage to the Wadden Sea would mean a loss of biodiversity on a global scale and could have a significant effect on ecological processes in far-off regions. Because of these internal and external ecological connections, the Wadden Sea is at the centre of a network of international importance.



figure 27 The East Atlantic bird migration route connects breeding grounds in the Arctic Region with wintering areas in the tropics. The Wadden Sea fulfils an essential role as a 'rest and recreation' stop on this route. Changes in the Wadden Sea also have an impact on the other areas on the migration route, and vice versa (Source: T. Piersma, RUG).

A unique man-made landscape

The Wadden Sea Region is not only a very special nature reserve but also a unique man-made landscape. The islands and districts have a long shared history which dates back to the late prehistoric period and which is partly determined by the fact that a similar configuration of the landscape is recognisable everywhere along the coast. It is not only in Friesland and Groningen that terps originating in the Iron Age, Roman Iron Age or early Middle Ages can be found, they also exist in the German provinces of East and North Friesland. Great similarities can also be discovered throughout the coastal area in terms of the history of dyke building, the exploitation of peat beds and the organisation of water management systems. Since the early Middle Ages, the indigenous, international marine and coastal shipping trade has formed a link between all parts of the Wadden Sea Region and with far-off countries. In the late Middle Ages and Early Modern Era, this produced a common, prosperous maritime culture. The region lost its prominent political and economic position in the 19th and 20th centuries and became an agricultural – and later also a tourist – area on the periphery of the new nation states of Denmark, Germany and the Netherlands. Despite these common aspects of the region's historical development, the island communities and the coastal districts have a distinctive character of their own (see **figure 28**). The economic

structure and development of the Wadden Sea Region shows major differences but also similarities. Where tourism in the Netherlands is mainly confined to the islands, the coastal area is also an important economic factor in Germany and Denmark.



figure 28 The island communities and coastal districts of the Wadden Sea Region (Lancewad).

Three countries, one goal, many approaches

The three Wadden Sea countries have outlined national and regional policies to protect the major natural values in the region. Joint initiatives (Lancewad) have been developed to make an inventory of the region's cultural and scenic heritage. Not only the natural values but also the rich history of human use of the region played a part in the nomination of the Wadden Sea as a World Heritage Site.

At European level, the three countries are bound by common EU legislation, such as Natura 2000 and the Water Framework Directive. Agreement on principles and a common legal framework does not detract from the fact that there are regional and national differences in the way the region is managed in practice. These differences generate interesting comparative material for studies of the impact of policy on natural values. Until now, only limited use has been made of this material. Coordination of policy is at a fairly advanced stage as regards 'old' environmental problems, such as eutrophication or combating the emission of toxic substances. However, new policy areas have to be opened up where joint policy is not so well developed, such as nature conservation policy, the installation of wind and other energy systems, port development and the climate issue.

A shared infrastructure for science and monitoring

At the trilateral level, much has already been achieved regarding common monitoring and assessment via TMAP (Trilateral Monitoring and Planning). As part of this process, a common database of monitoring data is being maintained and regular reports are published on the quality of the environment and nature in the international Wadden Sea. Recently, initiatives have been started to intensify and computerise the monitoring of nature and the environment and to extend this to the monitoring of social impacts. This creates completely new possibilities for gaining an insight into processes that previously escaped 'standard'

monitoring systems. The harmonisation and integration of these efforts could create a 'shared workspace' for the Wadden Sea as a whole which will be an additional stimulus for all participants to perform excellent research. In addition, common European legislation makes it necessary to develop common, scientifically sound preservation objectives and assessment methods. A particular challenge in this respect is the expected changes in the ecosystem as a result of climate change impacts.

A new boost for scientific cooperation in the Wadden Sea

There is a wide variety of institutes in Germany and Denmark engaged in Wadden Sea research. The majority of them focus mainly on natural science-based research into biotic and abiotic processes (mainly morphodynamics, the pelagic zone and material and nutrient cycles). There has been much less research into the socio-economic and cultural aspects (see **figure 29**). The Common Wadden Sea Secretariat (CWSS) merits a special mention as far as cooperation on international Wadden Sea research is concerned. Over the past twenty years, the CWSS has developed into a central and valued hub concerned with integrating and aggregating research data (including socio-economic and socio-cultural data). The Wadden Academy is pleased to have had beneficial contacts with CWSS over the past few months. For example, the CWSS has provided substantial input for this section.

The Wadden Sea Forum (WSF) is a major player in the interaction between science and policy relating to international Wadden Sea research. The WSF is a platform for stakeholders in the Wadden Sea Region and consists of representatives from the main sectors of the economy, nature conservation organisations and local and regional government. The WSF's objective is to encourage the sustainable development of the Wadden Sea Region. The CWSS and the WSF work closely together and have set out this collaboration in a covenant.

There are many valid reasons for organising research on the international Wadden Sea Region across national boundaries, such as the common responsibility for the Wadden Sea as a key element in the world ecosystem, the important exchanges within the (international) Wadden Sea and between the Wadden Sea as a whole and the surrounding area, the existence of substantial and interesting gradients within the Wadden Sea, the diversity of management issues and instruments in the region, the need to continuously update policy instruments to take account of new needs, common legislation, added values of shared infrastructure and scientific exchange.

For all these reasons, scientists from the three Wadden Sea countries began to make the available information accessible to everyone as long as fifty years ago. They also took the initiative in drawing up an international research agenda with the aim of describing the ecosystem as fully as possible and finding solutions to the consequences of human activities. A milestone in this process was the work done on the 'Wadden Sea ecosystem' series in 1973-1978 (better known as the Veth series), which was published in 1983.

Almost thirty years after the publication of this standard work, major changes have occurred in the global environment, human activities, the legal regime and the socio-political situation. All of these changes have had an impact on the Wadden Sea ecosystem and require new

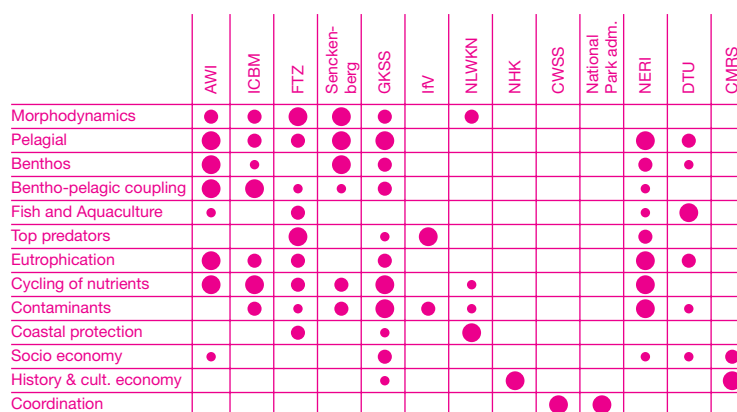


figure 29 Overview of the expertise of 14 institutes (10 from Germany and 4 from Denmark). The size of the circles in each column denotes the intensity of research for each subject (Source: P. Schwemmer, 2009).

international research which focuses not only on ecology and the consequences of human activities but also on the socio-economic, legal and cultural-historical dimensions of the Wadden Sea Region.

1 Trilateral research perspective

Most of the knowledge demands and gaps highlighted in this research agenda apply not only to Dutch research or research into the Dutch Wadden Sea Region, but also to the international Wadden Sea. In addition, a lot of research would benefit from being embedded at international level and this embedding is to a large extent already in place, particularly in terms of natural science-based research. The research agenda places the emphasis on those research questions for which an international approach is an absolute necessity. This involves opportunities for international comparative research and research which should examine the Wadden Sea as a whole in its interactions with the rest of the world. The main points are as listed below:

1. Subsurface and natural resources

For many decades now there has been effective coordination and cooperation in relation to geoscientific data, information and cross-border mapping programmes relating to the soil/subsurface of countries in the European Union. This also relates to the Wadden Sea Region. The responsible parties are the Geological Surveys of the Netherlands, the relevant German federal states, and Denmark, which parties also handle the implementation.

There are three subjects in which – in addition to the existing programmes – closer international cooperation has an added value. They are research into processes, the interaction between these processes and the properties of rocks, faults and fluids deep below the earth and close to and at the surface, transnational reconstructions of the development of the Wadden Sea Region from about 8000 BC and the development of modelling tools for the entire trilateral Wadden Sea Region and for modelling sediment balances.

2. Ecological interactions within the Wadden Sea ecosystem and between the Wadden Sea, the North Sea and the rivers

The dominant sources of nutrients, mud and organic matter for the Wadden Sea are the English Channel and the Rhine and, to a lesser extent, the Elbe and smaller rivers. The dominant residual current runs from southwest to northeast. Because of this, the region has a natural gradient in concentrations of mud and nutrients and therefore also in the extent to which they determine the dynamics of the ecosystem. Research must take maximum advantage of the existence of these gradients to establish causality.

The existence of these gradients means that the options for natural development are not the same all over the Wadden Sea. For example, although it has not been possible to reintroduce eel grass in the Dutch Wadden Sea for years, eel grass is doing reasonably well in the north-eastern part of the German Wadden Sea. Then again, the reverse seems to be true for mussels. An international perspective may lead to a situation where a regional approach to organisation and management is taken with regard to those elements of the ecosystem that have the best chances, particularly if compromises are not the best solution for any individual element. Maximum biodiversity in the region as a whole is not by definition the same as maximum diversity within each subregion, although such considerations will have to be handled with great care.

Important populations in the Wadden Sea, e.g. marine mammals and birds, move about a lot within the international Wadden Sea. At the same time, their numbers have been observed to show different trends in different parts of the Wadden Sea. Identifying the reasons for this may provide a lot of insight into the factors that are the most relevant to maintaining or boosting these populations.

3. Comparative research between the Wadden Sea and estuaries elsewhere; research into the global importance of the Wadden Sea

According to the Wadden Academy, comparative research between the Wadden Sea and estuaries elsewhere in the world should be explicitly regarded as Wadden Sea research. The management of the Wadden Sea and the connection between human and natural values in the region could be studied as an example for other ecosystems of global importance. Tensions between preserving and developing internationally important natural values on the one hand and the regional or subregional development of a sustainable and just society on the other hand are a typical aspect of this problem. There are considerable differences between areas in terms of population density, human pressure and methods for managing them. To a varying extent, exploitation and habitat loss have resulted in the 'decapitation' of the food web or altered the geomorphology. As such, an international comparison could produce a sort of 'chronosequence' of human impacts and form the basis for a broader perspective on the management of such internationally important ecosystems.

Those studies taking place on a global scale should consider the Wadden Sea in its entirety. This implies that this research should ideally be organised in conjunction with international colleagues involved in Wadden Sea research. Moreover, the logistics of such studies requires parties to combine forces to the maximum extent. It also provides an excellent platform for exchanging and supplementing scientific expertise.

4. Regional research into the causes and effects of climate change

The smallest scale at which it is possible to make a reasonable judgement on climate change is smaller than the scale of the international Wadden Sea. Within that area it is therefore possible to make judgements on new gradients and differences. It is an obvious move to combine and coordinate efforts aimed at regionalising climate models. In addition, many of the effects of climate change will be similar (e.g. sea-level rise, migration of populations, temperature change, acidification, etc.) and it is essential to conduct joint research into these effects. The possibility of combined mitigation measures may also be of interest in this (largely sand-sharing) system.

5. Comparative research into cultural history and society within the Wadden Sea Region

The man-made landscape of the Wadden Sea Region is a rich, complex and irreplaceable entity. It has great potential both with regard to its intrinsic value and its role in economic development. From an economic perspective the landscape of the Wadden Sea Region is, as with many other man-made landscapes today, changing from a production area into a consumption landscape. There is a growing need for distinctive and unique landscapes, for places with stories and histories that offer inhabitants and visitors new perceptions and experiences of life and reflection and that offer inhabitants and entrepreneurs new opportunities in income production. The question is: where will new forms of human use of the region conflict with the preservation of the Wadden Sea Area as a nature reserve? To answer this question, it is essential to know how residents of the region live their lives and earn their living and how visitors regard the region and make use of it. And how did this way of living in and making use of the region develop historically? With its unity in regional diversity, the Wadden Sea Region offers interesting options for comparison in this regard. It is interesting to study the factors in history and in the current world economy which have contributed and are contributing to differences in political and social development of the various regions and differences in the way in which the inhabitants of different regions deal with the natural environment and natural resources. Different answers to common questions could also be a source of inspiration and innovation.

6. Economic trends, developments and planning from an international perspective

Regional and national economies are becoming ever more closely interwoven because the specialisation of production processes is taking place globally in locations where the greatest benefit can be derived from economies of scale or cost advantages. As a result, international trade and transport flows have increased. Export, transit and transshipment for regions with an easily accessible port are therefore an important pillar of the regional economy. This is also true of the ports in the Wadden Sea Region. Globalisation is also raising its head in the area of energy generation as electricity and gas can be transported over long distances. Fishing, agriculture and tourism are also subject to international competition.

From an economic point of view, it goes without saying that production should take place in locations where costs are lowest. From the perspective of the Wadden Sea Region, it is very important that all costs and benefits should be taken into account when considering the matter. The costs also relate to negative external effects of damage to the natural environment, e.g. caused by gas extraction, electricity generation, port development or dredging activities. The benefits encompass employment, income, consumption and quality of life in the region. There is a wide choice of locations for global economic activities. When deciding whether the Wadden Sea Region is to play a part in the production or distribution of goods, it is essential to make an overall assessment of the costs and benefits of alternative locations inside and outside the Wadden Sea Region that serve the same sales market and of locations all over the world when the production of transportable goods is involved.

International planning can also highlight important aspects of scale. For example, concentrating wind farms in a particular area can produce both economies of scale in terms of the maintenance and transport of electricity and diseconomies of scale if the barriers to bird migration become too high. Much research into sustainable development has been conducted at national level. In working towards making human use more sustainable, it may be worthwhile developing common trilateral sustainability standards, based on a common vision for the whole Wadden Sea Region. The Wadden Sea Forum (WSF) has already in 2005 made a start with its report 'Breaking the Ice'. Certain non-commercial human activities, in particular coastal defence, also have an important international dimension when it comes to developing more sustainable practices, in particular in the light of increasing sea-level rise.

7. Comparative research into policy, management and methods and, where possible, harmonisation of the approach

Most research into management in the Wadden Sea is done at national level and the research area is confined within national boundaries. However, also here there may be advantages of doing comparative research. For example, the evaluation of Dutch shellfish fishery policy (EVA II), would certainly have gained added value if there had been a parallel and comparative study in other parts of the Wadden Sea. Also, comparison with Wadden Sea-like ecosystems in other parts of the world could provide added value, e.g. in the case of sustainable fishing.

Moreover, all three Wadden Sea states are subject to the legal EU framework regime (N2000, Water Framework Directive) and have, to a great extent, the same requirements regarding monitoring, assessment and reporting. Harmonising the approach (e.g. evaluation systems, profile documents, etc.) and monitoring would provide significant advantages in this case, both in practical terms and with regard to consistency.

2 Trilateral knowledge gaps

On the basis of the above points, it is possible to identify the following trilateral knowledge gaps:

Ecology/habitats/species

- research into the Wadden Sea's role as a mating, resting, breeding or nursery area for populations of fish, marine mammals and birds that are important to the North Sea; interchange of populations within the Wadden Sea;
- research into the exchange of water, mud, sand and nutrients between parts of the Wadden Sea, the North Sea and rivers; analysis of significant gradients in the international Wadden Sea;
- harmonisation of methods, data storage and processing and assessment of existing and newly developed monitoring programmes; creation of a shared workspace;
- research into the state of maintenance or restoration of different ecological elements in different parts of the Wadden Sea; optimisation of maintenance and development goals within the realms of what is ecologically feasible;
- jointly established comparative research into the Wadden Sea and comparable estuarine regions elsewhere;
- jointly established research into the role of the Wadden Sea within the global ecosystem.

Subsurface and natural resources

- (continuation of) transnational mapping programmes on the soil/subsurface of the Wadden Sea Region and the natural resources present within it;
- exchange and coordination of data and information on the physical-chemical properties of rocks, fluids and fault systems;
- (continuation of) research into and monitoring of land subsidence, land rise and seismicity over different space and time scales;
- cross-border reconstruction of the development of the Wadden Sea Region since approx. 8000 BC;
- development of tools for modelling processes in the entire trilateral Wadden Sea Region and modelling of sediment balances.

Climate change

- research into the effects of regional climate change on the scale of the international Wadden Sea and the consequences for geomorphological and biological processes;
- research into the effects (benefits, impacts) of large scale sand suppletion just outside and inside the Wadden Sea;
- integrated research (ecological, socio-economic) of potentials, feasibility and benefits of increasing the resilience of mainland coast (agriculture, tourism, nature, industry, energy, culture) to combat the impacts of climate change.

Sustainable development

- research into the further development and operationalisation of (Wadden Sea-specific) sustainability indicators;
- research into the economic prospects on a regional scale, e.g. for tourism, agriculture, fishing and port development;
- research into economies of scale and environmental impact of energy production projects.

Cultural history

- identification and evaluation (in addition to Lancewad) of cultural heritage in an international context and, on the basis of this, determining what specific features could be further developed;
- comparative research into the development of the natural, social and man-made landscape of the various islands and districts of the Wadden Sea Region from the beginnings of human habitation until the 20th century;
- comparative research between countries and regions into forms of recollection and history as a factor in creating a sense of identity and community;
- comparative research into images of the natural and man-made landscape of the Wadden Sea Area and Wadden Sea Region in the 19th and 20th centuries.

Governance

- comparative research into policymaking and management methods in the three countries in relation to different issues; harmonisation of methods, particularly when implementing common European legislation.

4 Integrated research agenda





4 Integrated research agenda

Introduction

The Wadden Academy attaches great importance to its role as a 'broker and intermediary' between scientists and between science and government and policymaking. The essential part of this role is helping to develop integrated and well coordinated scientific programmes which will lead to innovation and will be applied in policy.

It is the ambition of the Wadden Academy to develop the Wadden Sea Region into an incubator for widely applicable integrated knowledge of sustainable development of a coastal area, in which natural values are a key element and form the foundations of the local and regional economy. The region is a meeting place for scientists from the Netherlands and elsewhere, administrators, policy makers and management agencies. Together, they develop sustainable and innovative solutions based on interdisciplinary knowledge. By 2020, the trilateral Wadden Sea Region will be the best monitored and best understood coastal system in the world.

Sections 2 and 3 have shown that the various disciplines have considerable knowledge of the Wadden Sea Region, but major gaps still remain. This section summarises the main lines of force of these knowledge gaps. It has also been noted that the existing knowledge and expertise is, to a large extent, fragmented and compartmentalised. The lack of an interdisciplinary approach is a limiting factor when it comes to understanding how the Wadden Sea Region functions as an integrated system, e.g. in the context of the preservation and development of natural values, sustainable shared use or climate change and sea-level rise. The Wadden Academy therefore advocates the setting-up of a limited number of integrated research programmes. This argument is set out in detail in this section.

1 Identifying gaps in our knowledge

The Wadden Academy has identified a number of gaps in our knowledge. The table below provides a brief summary of the main gaps as identified in Section 2 and the relevant thematic background reports, which should be referred to for further details of and background to the key points below.

Geosciences

- *Subsurface of the Wadden Sea Region:* 3D detailing of the current geological composition and structure and of the physical-chemical properties of rocks, faults and fluids in the subsurface. Modelling and quantifying processes in the subsurface as a basis for understanding and predicting dynamic behaviour. Optimisation of present and future use of subsurface natural resources such as gas and salt, groundwater, storage of gas and CO₂ and exchange of heat and cold.
- *Evolution of the Wadden Sea Region:* Reconstruction of the morphological development of the Wadden Sea Region in the Holocene and the role of deeper structures within it. Dynamics of salt marshes, flats, channels and outer deltas at different rates of sea-level rise. The role of man as a "geological force".
- *Morphodynamics of the Wadden Sea:* Detailing in data and understanding of the sediment balance for both sand suppletions and silt, including the effects of sand suppletions and the role of ecosystem engineers. Quantifying and modelling of the dynamics of the (components of) tidal inlet systems on an engineering timescale. Predicting the impact of sea-level rise, changing storm regimes and coastal defence options on the morphology of the tidal flats.

Ecology

- *Food web as a binding element:* Understanding the processes on which the food web is based requires improved monitoring, modelling and focus on qualitative aspects, as well as paleo-ecological reconstruction. Too little is known about the effect of (partially extinct) predators at the top of the food web. At the bottom, too little is known about the role of primary producers and consumers.
- *Non-trophic interactions:* The dynamics of ecosystem engineers in silt and sand systems connect the ecological domain to the geomorphological domain, both on the dry and on the wet tidal flats.
- *The tidal flats as an open system:* Exchange with coast and rivers also determines the concentrations of nutrients and organic material. International interconnection with breeding grounds and wintering areas of migratory birds.
- *Paradox of (nature) conservation in an ever-changing world:* The Wadden Sea is a dynamic, coherent, open and valuable ecosystem, but global changes will substantially alter it. Values should not be considered the same as conditions; a more detailed reflection on this problem requires cooperation with the humanities.
- *Comparative research with other tidal inlet systems:* This is an important element in each sub-theme above, e.g. for a better definition of terms such as 'natural' and 'undisturbed' functioning.

Society and cultural history

Formulation of questions with regard to people, their way of life (profit), their social organisation, their relationship to the past and the significance and value they attach to their natural and man-made environment (planet), how they deal with it and their impact on it.

- *Historical development of the Wadden Sea Region's natural and man-made landscape:* insight into the way in which residents of the region lived their lives, earned their living and made use of the region. Insight into the impact of this on the region's climate, soil, subsurface and natural values.
- *Image and evaluation of the Wadden Sea Region:* Interpretation of the role of various manifestations of recollection and history in the individual, social, (tourism-related) economic and political domains. Contextual definition of natural and man-made scenic values and their development in past, present and future.
- *Social and political organisation:* A just and sustainable future for the Wadden Sea Region requires insight into groups formed by inhabitants and outsiders, their organisation and manifestation (formal and informal) and processes of individualisation and community-forming.
- *Systems for documenting, evaluating and selecting cultural-historical values:* strengths and weaknesses of existing systems, development of best practices.

Economics

From the perspective of social and spatial economics, the Wadden Sea Region challenges science to adapt existing economic ideas to a region with a very special economic, physical and spatial structure.

- *Trends in the regional economy:* Accumulating data in production, sector structure, employment, working population and sustainability in the present, past and future. Regional economic modelling which can be used to forecast how the Wadden Sea Region can adapt to global trends and shocks in the economy and external trends such as climate change.
- *Contributing to the sustainability of the Wadden Sea Region's economic structure:* Analysing synergy and conflicts between work and income on the one hand and quality of life and natural and scenic values on the other. It is therefore vital to ascertain why firms, individuals and households decide to locate themselves in the region and how to develop sustainable forms of economic activities.
- *Social cost-benefit analysis:* SCBA as a policy- and decision-making tool for interventions in the Wadden Sea Region. Developing a full and clear framework which makes it possible to consider in a more transparent and democratic manner material and non-material use values and non-use values in decision-making processes concerning the Wadden Sea Area.

Urban and rural planning

The Wadden Sea Region maintains a strict separation of functions and functional areas, where 'preservation' is countered by 'development'. This situation is not always positive for the continuing development of the Wadden Sea Region. Against this background, knowledge development is required in respect of

- *The acquisition of functions and multifunctional area-specific development* with the focus on ecological and economic area-specific qualities. Alternative conceptual perspectives are required to strike a balance in competition and complementarity between monofunctional and stable areas and multifunctional and dynamic areas within a functional region.
- *Qualitative embedding of spatial functions*: Valuation problems relating to functions as an issue in developing policy for the Wadden Sea Region.
- *Contraction*: Consequences for the structure of communities and facilities in residential areas. Possible mitigation options.
- *Regional coordination and adaptive governance*: Improvement will facilitate an analysis of underlying conditions, coordination issues and requirements from a 'multi-level', 'multi-actor' and 'adaptive governance' perspective.

Climate change

- *The Wadden Sea Area as an actor in climate change*: Quantifying and understanding greenhouse gas emissions. Linking emissions to primary production and decomposition (Ecology) and transport by tidal currents to the North Sea (Geosciences). Assessment of (unintended) effects of the management of rivers, coastal zone and the Wadden Sea on these emissions.
- *Regional climate scenarios* as a basis for impact studies and designing adaptation measures. Over the decades to come, the uncertainty is small enough to allow downscaling of global climate scenarios to 2050 to the Wadden Sea Region, taking account of meteorological effects which are specific to the coastal zone. Identifying extremes in climate and sea-level scenarios.
- *Impacts of climate change on the Wadden Sea Area*: Knowledge development of observed and expected impacts of climate change on morphology, water management and ecology of the Wadden Sea Area. Assessing the robustness and resilience of existing natural and human systems.
- *Innovative and robust adaptation measures* must be developed. Creative ideas will have to be worked out on the basis of overall impact on the future situation. In the impacts and adaptation themes, knowledge can only be developed in close cooperation with other domains.

The following cross-disciplinary research themes have been identified:

- people as a geological force;
- sediment balances of sand and mud and the role of ecosystem engineers;
- sea-level rise, changing storm regimes, tidal flat morphology and the use of natural processes as coastal defences;
- paleo-ecological reconstructions of the food web;
- reflections on the paradox of (nature) conservation in a changing world, from the points of view of natural and social sciences;
- the impact of people and their activities on climate, land, water and nature over the past 2,500 years, as well as in today's Wadden Sea Region;
- regional economic developments in the light of external trends such as climate change;
- development of employment and income in relation to conservation of natural and cultural-historic values;
- sustainable economic development, the culture of entrepreneurship and social cohesion;
- economic valuation of use (consumption and production) and non-use values of nature and culture in the Wadden Sea Region;
- tidal flows, geomorphology, ecology and greenhouse gas emissions;
- human management of rivers, the coastal zone and the Wadden Sea and greenhouse gas emissions;
- (conceivable extremes in) climate trends and the design of robust adaptive measures;

- climate change effects on geomorphology, water management and ecology;
- governance and the design and implementation of adaptive climate measures.

2 An integrated system approach

In a system approach, different elements, features and processes of a (linked natural and socio-economic) system are explicitly brought into contact with each other. The emphasis is on the following aspects: feedbacks between different subsystems (e.g. geomorphological, biological, cultural-historical and economic aspects) and the specific dynamics following on from these feedbacks; consistency of the descriptions (e.g. respecting the mass balances: mud that is not there cannot be recorded; organisms cannot function as ecosystem engineers if they do not have a place in the food web, etc.); coherence of different process descriptions on several space and time scales (e.g. processes may be intense but vary widely with the seasons and therefore contribute little to long-term budgets, or indeed vice versa); completeness of the descriptions (e.g. industrial development cannot be viewed in isolation from its effect on the non-use value of the natural environment and its effect on natural processes); verifiability of the descriptions and the availability of the necessary data and/or experiments.

In the Wadden Academy's view, an integrated approach is required to enable us to understand the Wadden Sea Region in the short, medium and long term at system level. The research agenda therefore proceeds from the notion of integrality. To avoid any misconceptions of this term, we state briefly below what the Wadden Academy considers to be the main features of integrality.

Combination of more than one scientific discipline, with the emphasis on interactions between the natural science, social science and humanities

Problems which at first sight are purely scientific (although crossing domains) such as 'water clarity' also have significant social aspects, especially as regards the impact of port activities (dredging, construction of the Maasvlakte development) and coastal defence (suppletions, sand extraction). Other examples are: the inclusion of natural values in economic analysis and the linking of scientific, cultural and historical analyses when determining 'natural values' and how they are to be evaluated; the use of cultural-historical values in the region for sustainable development in tourism and lifestyle.

Focus on space and time scales

It is very important to make explicit the space and time scales to which process descriptions or problem analyses relate. A few examples: When considering climate change, the spatial scale is what mostly determines the uncertainty of the predictions; it is easier to make predictions about the global climate than about the climate in the Wadden Sea. An uncertainty analysis based on scale must always be included. In natural development or projects for facilitating geomorphological processes, the scale of development measures is often the key to (potential) success. In addition, consideration should be given as to whether the maximum diversity of habitats and species should be viewed on the scale of a basin, the Dutch Wadden Sea, the international Wadden Sea or the world. Considerations of shared human use can also differ greatly depending on the scale on which the effect of the use is being analysed. Regulations and legal frameworks are on a scale of time; interventions must be consistent with current regulations but take account of future developments.

Focus on the cumulation of processes, interventions and impacts

Observing a single intervention in isolation can produce a completely different picture than when it is observed in conjunction with other interventions and processes. Cumulative impacts of human interventions in the system must be explicitly taken into account in current legal frameworks but this poses serious problems in practice.

Focus on the process of knowledge co-production

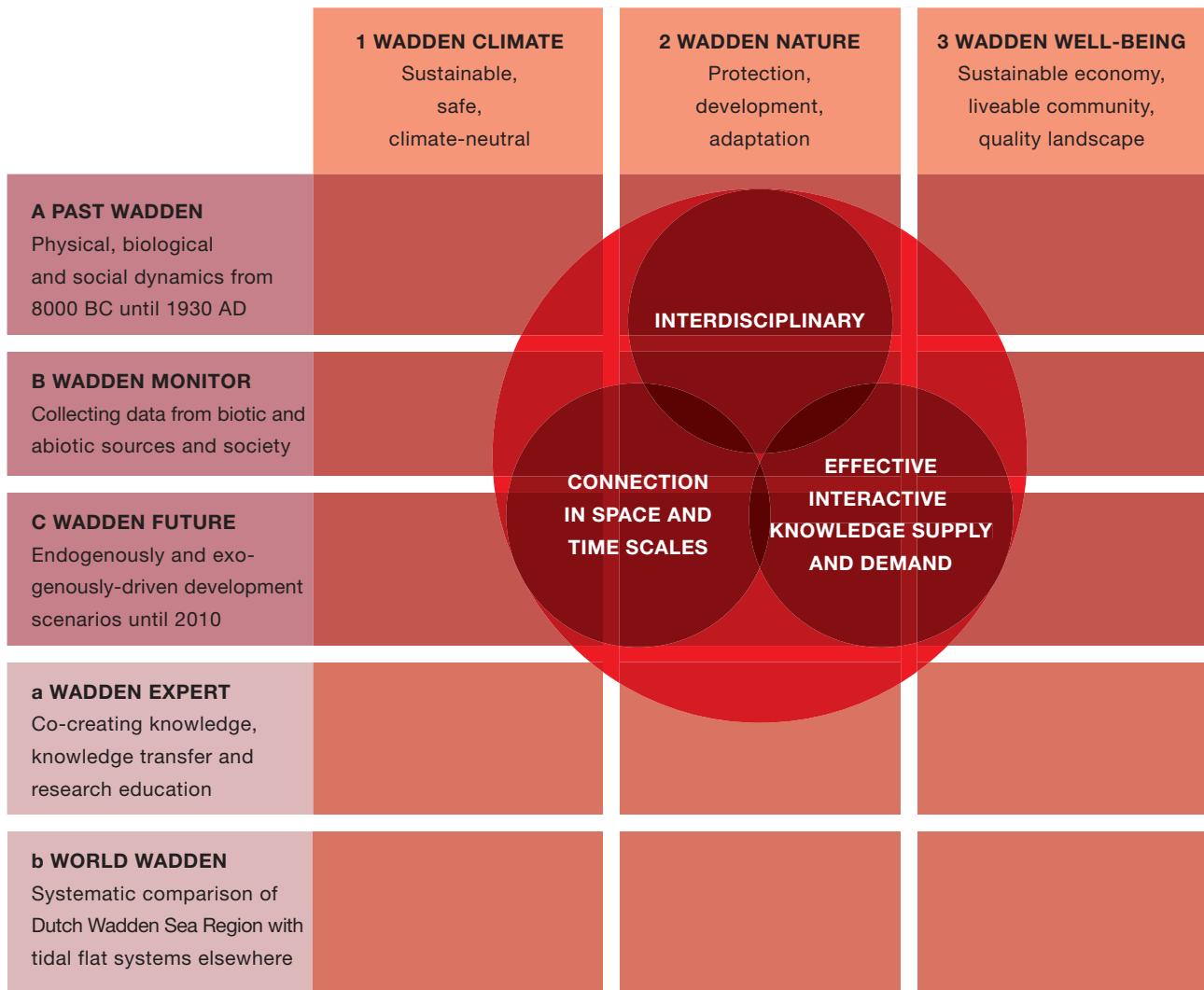
When formulating questions and hypotheses, finding answers to the questions and translating knowledge into practical applications, many researchers from the fields of policymaking and fundamental and applied science are engaged in constantly iterating issues, limiting uncertainty and applying new insights. This aspect is an essential component of an integrated approach.

The emphasis on an integrated approach in the Wadden Academy's research agenda does not mean that there will be no place for discipline-enhancing and curiosity-driven scientific research in the Wadden Sea Region. A quick scan of the Web of Science reveals that the number of scientific publications explicitly addressing the Wadden Sea system has declined considerably in recent years. Although this is primarily the task of the universities and scientific institutes of NWO and KNAW, the Wadden Academy also intends to encourage this segment of knowledge development, e.g. by improving the way in which the results of relevant dissertations are disseminated. By interpreting these sometimes ground-breaking results as part of wider knowledge demands concerning the Wadden Sea Region, it is possible to re-invigorate the valorisation of these scientific results. The Wadden Academy will be working closely with universities and national research schools in this regard.

3 Knowledge and research programmes

To guarantee the integrated nature of the research agenda and the associated research programmes, a limited number of large, umbrella programmes is proposed in this research agenda in which interdisciplinary research should be undertaken. There will be three generic knowledge programmes plus three integrated research programmes supported by two conditional themes, as illustrated in the diagram below.

The six programmes have been chosen and formulated so that they can serve the entire field of knowledge concerning the Wadden Sea Region. They are semi-permanent in nature, so that only gradual updates of priorities in activities and – to an even lesser extent – in objectives are required. For all programmes, whether generic or demand-based, the Wadden Academy is arguing for the required level of integrality and system thinking (the circles) that it considers essential if significant leaps forward in knowledge are to be achieved.



The horizontal generic knowledge programmes generate basic data and basic insights into the operation of the tidal flat system. They involve research which is extremely relevant to a wide range of social issues but often falls outside the scope of more demand-driven research.

In the horizontal, generic theme, Wadden Future scenarios are developed of regional and supra-regional climate change, sea-level rise, demographics and economic growth, where possible interrelated. These can be used to develop and assess coastal defence options in the vertical Wadden Climate project which is an attempt to contribute to policy dossiers such as that of the Delta Committee or concerning the renovation of the IJsselmeer Dam. The same scenarios can be used to analyse the robustness of natural values and biodiversity in the vertical Wadden Nature project which is an attempt to be relevant in a more visible way to policy dossiers such as the *Wadden Sea Area Nature Recovery Plan*.

The vertical integrated research programmes attempt to fill the gaps which are relevant to policymaking and policy evaluation without lapsing into single-issue approaches or an excessively restricted temporal or spatial perspective.

Data, information and expertise are exchanged at the intersections between horizontal, generic programmes on the one hand and vertical, demand-related projects on the other. One example of this is explained in a little more detail opposite.

All six programmes are supported by two conditional themes. These themes will assist the authors and implementers of the programmes to interact with policy and management to co-create knowledge and to have an effective knowledge transfer and to train a new generation of Wadden Sea experts who have internalised concepts such as integrality and engaged scholarship. The second theme has a supporting role in the internationalisation of research planning and implementation.

Each of the horizontal and vertical programmes is discussed below in terms of objectives, building blocks and relevant (to the vertical programmes) policy dossiers. First and foremost are the horizontal generic knowledge programmes.

A Past Wadden: reconstructing the development of the Wadden Sea Region

The aim is to gain an understanding of the climatological, geological, ecological, economic and sociocultural dynamics of the tidal flat system between the end of the Pleistocene (8200 BC) and the construction of the IJsselmeer Dam (1932). Of necessity, the programme uses proxies for climatological, paleo-geographical and paleo-ecological reconstructions and those of man-made environments.

Building blocks

- *geoscience*: 8000 BC until 1932, development of the Wadden Sea system (rocks and fluids, geomorphology and dynamics) in time and space;
- *ecology*: 8000 BC until 1932, paleo-ecological reconstructions and historical ecology;
- *social and cultural history*: 8000 BC to 1932: development of the Wadden Sea Region's landscape;
- *economics*: Middle Ages until 1932, historical economics;
- *climate*: 8000 BC until 1932, paleo-climate (proxies);
- *data and information*: organising and safeguarding data and information relevant to the reconstruction of the development of the Wadden Sea Region.

B Wadden Monitor: monitoring the development of the Wadden Sea Region

The aim is to gain an understanding of the natural and social dynamics of the tidal flat system from 1932 (the closing off of the Zuiderzee) up to and including 2015 (the date on which several of the current monitoring programmes end).

The programme focuses on the systematic collection and long-term supply of quantitative data which are relevant to the various disciplines. These include: harmonisation and organisation of the monitoring of the condition of the natural environment, society and climate in the Wadden Sea Area and (where possible) in comparable regions elsewhere; increasing the efficiency of relatively isolated monitoring efforts by providing a more complete context; improving the technological monitoring facilities; joining in with similar efforts in the international Wadden Sea Region; transparent management, verification and dissemination of data. Supporting research by providing relevant, reliable and complete data sets; analyses of historical time series for developing scientific knowledge and for complying with policy and management.

Building blocks

- *geoscience*: monitoring and analysis of topography and bathymetry, sediment composition, groundwater levels, groundwater quality, seismic data, aerial photographs, etc.;
- *ecology*: monitoring and analyses of the benthic, pelagic and terrestrial system, use of modern monitoring technologies with high resolution in time and/or space; measurement of process rates (e.g. primary production, grazing rate) as well as concentrations and population densities;
- *social and cultural history*: monitoring and analyses of demographics, faith, culture, politics, etc.;
- *economics*: monitoring and analyses of economic activity (Statistics Netherlands information, etc.);
- *climate*: monitoring and analyses of rainfall, temperature, hours of sunlight, evaporation, greenhouse gas emissions and hydrodynamic transport, swell, wave patterns, etc.;

- *data and information*: organising and safeguarding data and information relevant to the monitoring of the development of the Wadden Sea Region. Development of data structure and facilities for supplying data. Exchange of databases with trilateral partners in the international Wadden Sea Region.

C Wadden Future: predicting the development of the Wadden Sea Region until 2100

The aim is to understand and predict the development of the tidal flat system between 2010 and 2100. Conceivable, diverse scenarios for the development of the Wadden Sea Region will be based on multiple trend analyses and quantitative process models and will be updated as new information comes to light.

Building blocks

- *geoscience*: forecasts and scenarios for the natural development of the Wadden Sea Region, including natural resources (groundwater stocks and improving groundwater quality, natural gas stocks, etc.) and the effect of extracting them, e.g. land movement, seismicity, etc.;
- *ecology*: forecasts/scenarios for trends in food web, biodiversity, etc.; scenarios for changing species composition, impact of temperature on ecophysiology of organisms, change in seasonal patterns of important processes, invasions by new species;
- *social and cultural history*: forecasts and scenarios for demographics, faith, culture, politics, etc.;
- *economy*: forecasts and scenarios for economic growth of the Wadden Sea Region as driven by endogenous and exogenous factors;
- *climate*: forecasts and scenarios for climate trends and sea-level rise based on statistical and dynamic downscaling of global models that take account of specific regional influences, effect of this on safety, etc.

The three vertical integrated research programmes are set out below in terms of objectives, building blocks and relevant policy dossiers.

1 Wadden Climate: the Wadden Sea Region sustainably safe and climate-neutral

Reason and urgency

Recommendation of the second Delta Committee (2008) and its follow-up in the National Water Plan. The Delta Committee states that the continued existence of the Wadden Sea as we know it is in doubt. Sand suppletions contribute to the rise in the Wadden Sea bed that occurs with sea-level rise. The protection of the islands and mainland coast must continue to be guaranteed in future. This requires further research and monitoring.

There is great pressure to save energy and generate energy sustainably. Initiatives such as Energy Valley could make the Northern Netherlands a national and international trail-

blazer in the field of sustainable energy. The North Netherlands Energy Agreement [*Energieakkoord Noord-Nederland*] focuses on energy-saving at all scale levels. The specific values of the Wadden Sea Region will be taken into account in the development of methods for sustainable energy generation. On the other hand, the greatest potential for sustainable energy generation (CO₂

storage in gas fields, exploitable geothermal energy, tide and fresh-salt transition (osmosis, wind energy) is in the Wadden Sea coastal zone. Many questions still need to be answered in order to find a balance.

Relevant reports

Delta Committee report; NWP; Afsluitdijk; ARK; Léven in de Wadden, Management and Development Plan of the RCW, Part A; Grounds for Change; Omgevingsplan Groningen (POP); Streekplan Fryslân; KvR Hotspot A18 reports and presentations.

Sustainably Safe

How can the safety of the Wadden Sea Region and its population be guaranteed in the long-term, also taking into account the possible harmful effects of climate change and sea-level rise? Can this be achieved in a way that preserves the natural and dynamic character of the region? Can large-scale interventions in the coastal zone – such as sand suppletions – make a positive contribution to the development of marine and terrestrial natural values?

Climate-Neutral

How can a sustainable energy balance for the Wadden Sea Region be realised, taking into account the region's specific values? There is a desire to exploit the potential of the Wadden Sea ports for transporting energy and bio-energy raw materials and for energy production, also making sensible use of residual heat, as well as the options for CO₂ storage in gas fields, the exploitable geothermal energy in the region and the energy potential of tidal and fresh-to-salt transitions. The most promising options, from the point of view of electricity generation and heat exploitation, is found in the coastal zone of the Wadden Sea Region. At the same time, the vast, open landscape, the natural environment and the tidal dynamics are values that must be cherished and protected. There are many knowledge gaps in the tension between the desire to create innovative 'energy landscapes' and to preserve natural and cultural-historic values.

Building blocks and examples of research questions

Coastal safety

- What is the effect of an increased relative sea-level rise, whether or not combined with a change in wind, wave and current conditions, on coastal accretion and erosion of the North Sea coast and the Wadden Islands?
- How can the preconditions for dynamic coastal management be achieved on a sufficiently robust spatial and temporal scale and with an acceptable environmental impact?
- What role can ecosystem engineers fulfil in capturing and depositing sediment and what is the effect of climate change on the ecosystem engineers?
- What are the opportunities for building wide, multi-functional delta dykes in the region?
- How can the present and future economic significance of some parts of the Wadden Sea Region be better and more fully integrated when determining safety standards?

Monitoring and piloting

- Large-scale, long-term monitoring (on a trilateral basis) of sediment transport and sand suppletions, including large-scale pilot experiments.

Climate-Neutral

- Options for sustainable energy and energy-saving for the islands and in various regions in the Wadden Sea Provinces.
- Sustainable energy: tides, wind, osmosis (fresh-to-salt), geothermal energy, use of heat from conventional power stations in market garden greenhouses and aquaculture, CO₂ storage.
- Effect of climate change and sea-level rise on mineral extraction (gas extraction and storage, heat) in the region (e.g. 'one hand on the stopcock' principle) and any adaptations that may be required.
- Optimum mix of local energy potentials versus energy-saving and importing energy by economical and sustainable means (SCBA).

Governance and economics

- Exchange of knowledge and experience between municipalities, provinces, water boards, etc.
- Perception and appreciation test for newly designed energy landscapes, e.g. Eemshaven and Dollard area.
- Optimum forms of multi-level governance in collaboration between the Dutch government and the northern provinces and municipalities with regard to spatial scheduling of new initiatives.
- Business-case development in Eemshaven: (1) Process for effecting change, (2) Business decisions and choices, (3) Roles for different stakeholders, (4) Preconditions for assuming these roles, (5) Deadlines.

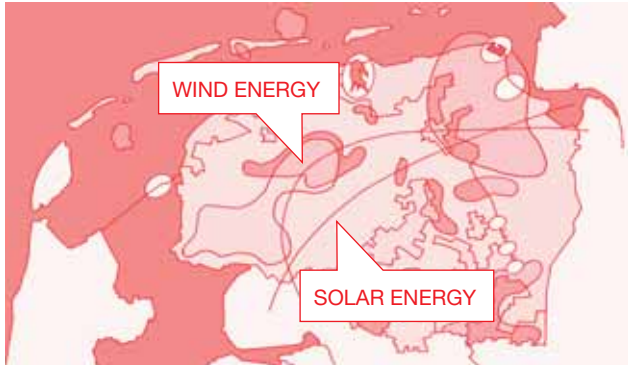


figure 30 Map showing energy mix of the Wadden Sea Provinces: combined regional energy potential (Source: Roggema et al., 2006).

2 Wadden Nature: protecting, developing and adapting the natural environment

Reason and urgency:

National and international legislation lays down that the natural environment in the Wadden Sea Area must be protected but requires specific and enforceable objectives to be set. The Nature Recovery Programme [*Natuur-HerstelProgramma*] is an initiative which has been started to reintroduce or strengthen species and natural processes in the Wadden Sea, with the ambition of creating 'a rich sea'. The RCW's Management and Development Plan is a guide for local, regional and national policymaking levels on how to put policy objectives into practice.

Agreements in the trilateral consultation, initiatives to register the Wadden Sea as a World Heritage Site and sectoral policy of government departments all require(d) detailed knowledge of natural processes.

Relevant policy documents:

PKB Third Wadden Sea Policy Document; Nature Recovery Plan (in development); the Regional Wadden Sea Region Board's Management and Development Plan; EU legislation (Natura 2000 and the Water Framework Directive); Trilateral Agreement.

Overarching knowledge demands

Relevant reports

PKB Third Policy Document on the Wadden Sea; Nature Recovery Plan (under development); *Léven in de Wadden*, Management and Development Plan of the RCW; EU legislation (Natura 2000, Kaderrichtlijn Water); Trilateral Agreement.

Protection

What forms of (shared) use will affect the development of the natural environment and will it be possible to adjust them if they are found to be harmful? How can the value of the Wadden Sea in the world ecosystem be safeguarded?

Development

How can the management and landscaping of the Wadden Sea Region make an optimum contribution, on a scale of decades, to the natural quality of water flows, geomorphology, benthic processes, water, air and soil quality, and flora and fauna? Which developments will guarantee the highest natural values in the long-term, what are the essential characteristics of the natural values and which developments are possible within the (altered) constraints?

Adaptation

How will global change (climate change, introduction of invasive species, changes in the global economy) affect the natural environment in the Wadden Sea and how can the direction of the development of nature be adjusted?

Building blocks and examples of research questions

Based on policy objectives, attention is being focused mainly on the following groups of problems:

- the natural development of water flows, geomorphology and benthic processes. This mainly concerns the 'abiotic' aspects of nature, although biogeomorphological processes are equally important. There is also a problem of timescales, with climate change being a major driving force in the longer term;
- the quality of water, soil and air. Both pollutants and nutrients (eutrophication) are relevant in this regard. Eutrophication is closely connected to the production of organic matter in the system and therefore also to the carrying capacity of the system;
- the flora and fauna. Species-oriented approaches will be adopted for flora and fauna (red list of species, top predators and typifying and structuring species), approaches based on a general improvement in the quality of the surrounding area and the habitats and approaches that focus on reducing exploitation and/or disturbance. The effects of exploitation and disturbance are not always well known, research is also required to ascertain whether more sustainable methods (e.g. of fishing) can prevent disturbance;
- developing habitats and the landscape: space for dynamic processes, ecological transitions at the boundaries. Both technical development issues and much more generic issues will be raised concerning the region's optimum ecological richness and dynamics, compatibility with its landscape and cultural heritage and compatibility with the regional economy;
- upscaling and internationalisation. Specific issues within the Wadden Sea Region will give way to the more general question of how a region with a relatively high population density and of global ecological importance can best be managed for the population and the natural environment.

Approaches

- systematic, well organised and open monitoring. It is very important that the various efforts of many parties to monitor the Wadden Sea Area are brought together soon and that an open data structure is available. Such an initiative ('LTER: Long Term Ecological Research Site') will be initiated and embedded into a broader interdisciplinary monitoring effort and into an international context;
- integrated modelling of the ecosystem's abiotic and biotic characteristics to improve knowledge of processes at the bottom of the food web and to investigate consistently the preconditions for habitat development;
- modelling of the food web, focusing specifically on the (potential) importance of top-down regulation;
- innovative surveys to quantify relationships within the food web in estuarine systems;
- experimental studies for model validation and for demonstrating causal links;
- comparative studies with other tidal flat systems subject to different regimes of human influence. The objective is to put the Wadden Sea's current position and condition into perspective, to help to outline future developments and be a means of evaluating the importance of the Wadden Sea in the (changing) world.
- interdisciplinary (natural science, social science and humanities) studies of the costs and benefits (in the broadest sense, see Section 2, Economics theme) of different policy options with regard to (shared) use and development; research into (more) sustainable forms of shared use;

- research into the (cultural, social, historical) basis of natural values as an underlying framework for future policy.

3 Wadden Well-being: sustainable economy and liveable communities in the Wadden Sea Region

Reason and urgency

Sustainability is a key word frequently referred to in documents such as the PKB and the RCW's Management and Development Plan. The region contains a wide diversity of economic activities. Almost every development issue in the Wadden Sea Region has a sustainability aspect but lacks an integrated overview of the sustainability of current and proposed economic activities.

Natural gas production in the Wadden Sea Region will probably continue until about 2050. The Wadden Sea Region's subsurface also contains a lot of thermal energy and part of it is also suitable for storing heat and cold, natural gas and CO₂. Salt production also takes place. The use of the subsurface, particularly for natural gas and salt, is associated with land subsidence and seismicity.

About a quarter of a million people live around the Wadden Sea Area. Lack of employment and demographics threaten the social cohesion of local communities. The threat to the quality of life is also a spatial planning issue: an attractive living environment is inconsistent with lack of maintenance and urban sprawl blighting the countryside. At the same time, concerns are being raised about the loss of function and the maintenance of our (built) heritage which is of great value not only in terms of tourism and leisure but, more importantly as a source of a sense of identity and community. Quality of life, landscape development and care of heritage are the subject of reviews, policymaking, financing and interventions by a complex amalgam of governmental and non-governmental organisations.

Overarching knowledge demand

Sustainable economy

How can work, income and quality of life for the residents of the Wadden Sea Region be guaranteed in a sustainable manner? How do we take account of the resilience within the system and of exogenously-driven changes in the regional and global economy? Is it possible to use minerals and geothermal energy sustainably in the light of climate change and sea-level rise, and if so, how?

Relevant reports

Nota Ruimte, Léven in de Wadden, Management and Development Plan of the RCW; Akkoord van Apeldoorn over Nederlands Landschap; Modernisering Monumentenzorg; Nationale Landschappen.

Liveable community and quality landscape

How can the residents of the Wadden Sea Region be guaranteed a pleasant social environment, in view of the priority given to natural values in the region and in view of radical demographic, economic, socio-economic and cultural processes that extend far beyond the region? In this context, quality of life is interpreted in terms of social cohesion, a recognisable and vital man-made landscape and living heritage.

Building blocks and examples of research questions

Sustainable economics

- What is the connection between the three components of sustainability socio-cultural capital, ecological capital and economic capital, also with regard to the resilience of these three components?

- What is the connection between the temporal sustainability that relates to the distribution of prosperity over present and future generations and the sustainability that relates to the distribution of prosperity over regions? In essence, this is an issue relating to the distribution of economic, ecological and socio-cultural capital.
- How sustainable are current economic activities in the Wadden Sea Region? What overall development prospects are promising and sustainable?
- How can innovations to foster sustainability and resilience be encouraged in areas such as tourism, energy, agriculture and fishing, aquaculture and saltwater fish farming?

Mineral extraction in the Wadden Sea Region

- How can gas extraction (continue to) take place with a minimum of negative effects on the natural, dynamic tidal flat system, if any?
- Can thermal energy production contribute to a climate-neutral energy management system?
- Can safe and economically viable systems for storing heat and cold, natural gas and CO₂ be created in the coastal zone?

Social cohesion

- What demographic and socio-economic trends since the Second World War have characterised the Wadden Sea Region and what future trends can be expected?
- What organised groups in the social midfield are discerned by residents, how are they organised and how do they develop?
- What part do the natural environment, the man-made landscape, heritage and historic recollection play in the well-being of individual residents and in the construction of social cohesion? How does this contribute to creating a sense of community and new sources of income (e.g. tourism)?

Vital and valuable landscape

- How well have man-made landscapes been described and mapped?
- How can/will a vital and valuable man-made landscape develop under the influence of the growth in the agricultural sector and the spatial demands of housing and employment?
- How can knowledge and information on heritage be expanded and made easier to understand and more accessible? Can people from outside the professional heritage conservation sector become involved in defining, reviewing, describing and valuing heritage?
- What is the best way to maintain archaeological, man-made scenic and built heritage and develop it in a meaningful way?

Finally, the two conditional themes are described below.

a: Wadden Expert: Knowledge co-creation, knowledge transfer and training a new generation of Wadden Sea experts

Reason and urgency

In the research agenda, it has been concluded that to date the relationship between policy and science is largely fragmented and ad hoc and that there is room for a substantial improvement in knowledge valorisation. The aim is to develop a sustainable knowledge infrastructure in which knowledge demands are formulated and knowledge and expertise are developed on the basis of intensive interaction (co-creation) between scientists, governmental experts and policy makers at all stages in the knowledge development cycle.

Building blocks

The Wadden Academy sees its role in knowledge co-creation, transfer and valorisation as

- the central knowledge broker that passes the knowledge demands from central and regional governments to the relevant experts or expert teams;
- a facilitator of multidisciplinary expert teams such as those that already exist for the Wet and Dry Tidal Flats. These expert teams constitute a wide-ranging network of experts around the Wadden Academy and can be effectively mobilised to tackle specific knowledge demands;
- organiser of winter and summer schools for public officials and management bodies, organised as a series of courses and training sessions based on a multidisciplinary approach to knowledge;
- joint initiator of an investigation to develop a new information system on the Wadden Sea Region;
- acting as an intermediary with the general public by making contributions to Interwad, maintaining a social network and organising an annual public lecture on the Wadden Sea.

As a contribution to the training of a new generation of Wadden Sea researchers, the Wadden Academy will

- take the initiative to establish jointly with the relevant existing research schools an international Wadden Research School of Excellence;
- take the initiative to establish an inter-university, interdisciplinary Wadden master degree programme;
- establish an annual Wadden Academy Award for the best dissertation or master thesis;
- organise an international, interdisciplinary scientific Wadden Conference;
- hold an annual Wadden Academy Day for university and higher professional level students.

In all the initiatives, the Wadden Academy will seek to collaborate with other university, governmental and non-governmental partners and higher education establishments.

b: World Wadden: The international study of the Wadden Sea Region

The aim is to systematically compare the Dutch, German and Danish parts of the Wadden Sea Region and to compare the Wadden Sea with intertidal areas elsewhere in the world. To what extent does the local functioning of the tidal flat system depend on processes in other systems, via flows of materials, dispersion and migration of organisms, economic globalisation and climate change? And how do developments in the Dutch Wadden Sea affect the diversity and functioning of associated ecosystems elsewhere, such as the Danish and German Wadden Sea, the North Sea, the Arctic tundra and tropical coastal zones? The keywords are: cooperation, coordination, prioritising, fundraising and knowledge dissemination. The results of common comparative research can make a substantial contribution to the Wadden Sea Quality Status Reports.

Building blocks

- the continued specification and prioritisation of research for the whole trilateral Wadden Sea Region (see Section 3);
- the stimulation and coordination of Wadden Sea research, including common monitoring facilities;
- assistance with applications for international research projects;
- contribution to the creation of the Wadden Sea Quality Status Reports;
- comparative studies on international wetlands, within an international framework;
- the use of the tidal flat system as a 'test case' for managing globally important ecosystems.

5 Implementation





5 Implementation

By publishing this research agenda, the Wadden Academy has taken the first step towards developing a sustainable knowledge management system for the Wadden Sea Region. The Wadden Academy intends to update this research agenda regularly on the basis of the latest scientific insights and also in response to major new policy proposals.

The preceding sections have identified gaps in knowledge, explained which research themes are suitable for a more programmatic approach and discussed ways of disseminating knowledge effectively. Cooperation with and between government departments, research institutes, social organisations, consultancy firms and private parties is crucial to the implementation of the integrated research agenda proposed by the Wadden Academy. In the near future, the Wadden Academy will be encouraging and facilitating these parties to take part in the proposed research programmes.

In the run-up to the publication of the integrated research agenda, the Wadden Academy has been seriously interacting with a wide range of parties. Over two hundred players from research institutes, government and NGOs have assisted in drawing up the research agenda. This does not detract from the fact that the extent to which these parties are prepared to devote time and energy and above all to provide financial resources to cooperate on the future implementation of the integrated research programmes and the completion of the proposed research and knowledge dissemination activities will not become clear until the implementation stage. This will begin immediately after the publication of the integrated research agenda on the Wadden Open Day [*Waddentoogdag*] in May 2009.

This section on implementation provides an indication of how the Wadden Academy intends to carry out its work in the years to come.

Phase 1: Communication and feedback

This phase begins immediately after publication of the integrated research agenda on 30 May 2009. The Wadden Academy will disseminate the research agenda – in both printed and electronic form – as widely as possible among the relevant research institutes, government bodies and social organisations. This will be followed in rapid succession by the thematic reports on which it is based.

The Wadden Academy will begin a wide-ranging round of consultations, via its website and elsewhere, to discuss the issues raised in the research agenda. This round of consultations will consist of three parts: a digital discussion platform, a stakeholder symposium and finally a series of knowledge groups in government departments.

The digital discussion platform will be active until October 2009. The Wadden Academy will then summarise the results and present them at the Academy's autumn symposium.

On 1 and 2 July 2009, the Wadden Academy will organise a stakeholder symposium at which the integrated research agenda and the possible consequences for future research programmes will be discussed with representatives of research institutes, government departments and nature conservation and management organisations. At this symposium, a start will also be made on fleshing out the six knowledge and research programmes and the two conditional themes proposed in the research agenda (see Phase 2 below).

The Wadden Fund

The Wadden Fund is a fund that provides additional investment in ecological and economic projects in and around the Wadden Sea. The Wadden Fund has 800 million euro at its disposal. This sum will be spent over a period of 20 years.

The Rural Area Service (DLG) of the Ministry of Agriculture, Nature and Food Quality is the implementation organisation of the Wadden Fund and assesses the admissibility of projects submitted. Projects which have been judged to be admissible are passed to the Wadden Fund Advisory Committee which consists of independent experts. The Advisory Committee advises the Minister of Housing, Spatial Planning and the Environment on the order of priority of the admissible projects on the basis of legally established criteria for the effectiveness and the favourable prospects of the projects. The Wadden Fund Regional Committee, on which the RCW partners and social sectors are represented, gives its assessment of the support for the Advisory Committee's recommendation. Following consultation with the Minister who is also concerned, the Minister finally takes a decision on the subsidies to be granted.

In April 2009, the Wadden Academy and the Wadden Fund Advisory Committee reached agreement on the involvement of the Wadden Academy in admissible projects which the DLG passes to the Advisory Committee. The knowledge agenda of the Wadden Academy is used by the Wadden Fund Advisory Committee to assess knowledge projects submitted in order to determine whether these projects help to fill knowledge gaps. The Advisory Committee sees an important role for the Wadden Academy in matching and coordinating research proposals. With effect from the next tender, the Wadden Fund Advisory Committee will therefore seriously consider whether the parties submitting projects which have a knowledge component have sought to coordinate their content with the Wadden Academy at the preliminary stage. The Wadden Fund Advisory Committee will of course continue to be responsible for the ultimate decision-making process with regard to the advice given on submitted projects.

Knowledge group sessions will be organised by the Wadden Academy in the second half of 2009 at most of the ministries involved, namely Agriculture, Nature and Food Quality; Housing, Spatial Planning and the Environment; Public Works and Water Management; Economic Affairs and Education, Culture and Science. The aim is to achieve the maximum substantive coordination between the main ideas of the research agenda and those of the ministries and an initial exploration of the financial options.

Phase 2: Drawing up plans to implement the programmes and projects

In Section 4, three generic multi-disciplinary knowledge programmes are identified which focus specifically on the knowledge gaps at system level: Past Wadden, Wadden Monitor and Wadden Future. Three research programmes have also been identified that aim to provide a knowledge base for a number of highly topical social issues in the Wadden Sea Region: Wadden Climate, Wadden Nature and Wadden Well-being. Finally, two conditional themes are identified: Wadden Expert and World Wadden.

It is our intention for a multidisciplinary team to be formed around each of these research programmes/themes who will concentrate on elaborating in greater detail each programme/theme in specific implementation plans. The Wadden Academy will coordinate and facilitate the formation of these teams.

The proposed implementation plans will first address the relevance for society, the scientific rationale and the research strategy. This will be followed by a description of a cluster of interconnected projects and implementation strategies. Finally, details of the resources required will be provided in terms of financing, manpower and infrastructure. At a later stage, these programmes/themes can be presented – as a cluster or individually – for

financing to various potential funding bodies (see next phase). The general implementation plan for the programme/theme concerned will be used as an integration framework against which the goals, rationale and methods of individual projects proposed under the programme will have to be rigorously tested, one by one.

On completion of the implementation plans, a start will be made on the stakeholder symposium on 1 and 2 July 2009 in Leeuwarden. The intention is to have all the implementation plans fully worked out and published by December 2009 at the latest.

Phase 3: Mobilising financing frameworks

The third phase involves financing. Two categories of financing options are available for the implementation of programmes and projects. First and foremost, these will be funds and financing programmes which have a special relationship with the Wadden Sea Region, currently the Wadden Fund and the Dutch Marine and Coastal Research [*Zee- en Kustonderzoek*, ZKO] programme. Second, they are programme funding options provided by ministries, lower-level government bodies and knowledge institutions.

In the case of the funds, applications can be submitted in response to selective or open calls. The Wadden Fund Advisory Committee will include the Wadden Academy's integrated research agenda as a substantive assessment framework in its consideration and assessment of the knowledge projects submitted. The allocation or re-allocation of programme resources of ministries and knowledge institutions will involve an interactive and iterative process, in which the Wadden Academy has assumed the role of knowledge broker.

To date, most of the research relating to the Wadden Sea Region has been funded from the public purse, except for contributions from the Nederlandse Aardolie Maatschappij (NAM). The Wadden Academy is actively seeking opportunities to get more private market players involved in the Wadden knowledge infrastructure, including the major energy companies and the financial sector.

Phase 4: Internationalisation

In the fourth phase (from the second half of 2010), we will be actively seeking options for getting the research programmes accepted and funded as a trilateral arrangement and at EU level. The Wadden Academy will also have a facilitating role in this process. A trilateral knowledge forum is being organised with major public research funders in Germany, Denmark and the Netherlands in association with the international secretariat in Wilhelmshaven, Germany (see also Section 3). Together with German and Danish colleagues, we are also investigating opportunities in the EU framework programmes and in EU Interreg programmes.

Phase 5: Evaluation and summary

In the fifth phase (early 2014), an independent audit and progress evaluation will be organised, which is based on a summary of the objectives set by the Wadden Academy and its partners in the integrated research agenda which have been achieved.

NWO and the Wadden Academy

In 2006, the NWO launched the national Marine and Coastal Research [*Zee- en Kustonderzoek (ZKO)*] programme. This ZKO contains interconnected choices focusing on scientific analysis of five social challenges associated with the sustainable preservation and use of the marine and coastal environment. The five leading challenges are safety, economic return, nature, spatial planning and water quality. A start-up programme has been developed as part of the ZKO, specifically targeted at a very topical subject in Dutch coastal waters. Outline 1 of the start-up programme relates to (combinations of) research proposals focusing on answering policy questions. Outline 1 of ZKO has been jointly developed by the ZKO Programme Council and the Wadden Academy. The Wadden Academy has set aside 500,000 euro for this, which together with the 1 million euro available from ZKO makes a total of 1.5 million euro for this outline over a period of five years. The invitation to submit (preliminary) applications will be issued in 2009.

Appendix 1

Summary of position papers

The research agenda is based on the following papers which were published in June 2009 by the Wadden Academy:

position paper on Geoscience

De ontwikkeling van het waddengebied in tijd en ruimte

H. Speelman, A.P. Oost, J.M. Verweij, Z.B. Wang (editors)

position paper on Ecology

(Natuur)behoud in een veranderende wereld

Authors: Peter M.J. Herman, V.N. de Jonge, N. Dankers, B. J. Ens, W.J. Wolff, B. Brinkman, M. Baptist, M.A. van Leeuwe, J.P. Bakker, C.J.M. Philippart, J. Kromkamp, J. van Beusekom, M. van Katwijk, T. Piersma, H.W. van der Veer, E.J. Lammerts, A.P. Oost, J. van der Meer, H.J. Lindeboom, H. Olff, G. Jansen

position paper on Society and Cultural History

Geschiedenis, herinnering en beleving. Naar een cultuur-historische en sociaalwetenschappelijke onderzoeksagenda voor het Waddengebied

Author: J. Bazelmans

position paper on Social and Spatial Economics

Analyse van sociaaleconomische problemen in het waddengebied

Leading authors: Jouke van Dijk, Henk Folmer. Other authors: L. Broersma, M. van der Heide, W. Heijman, I. Horlings, O. Ivanova, W. Jonkhoff, O. Koops, F. Sijtsma, A. van der Veen

position paper on Climate and Water

Klimaatverandering en het Waddengebied

Authors: P. Kabat, C. Jacobs, R.W.A. Hutjes, W. Hazeleger, M. Engelman, J.P.M. de Witte, R. Roggema, E.J. Lammerts, J. Bessembinder, W. Hazeleger, P. Hoekstra and M. van den Berg

Op het Snijvlak van Risico en Kansen

Over ruimtelijke processen en ontwikkelingen van het Waddengebied

Authors: S. Hartman, G. de Roo

Metawad. De Waddenzee als zwakke schakel in een internationaal meta-ecosysteem

Authors: Th. Piersma, J.A. van Gils, H. Olff

‘Je hebt nooit genoeg kennis.’

Onderzoek naar de kennisbehoefte in het Waddengebied

Authors: J. Klostermann, H. Revier, E. van den Berg, J. Lamfers

The Wadden Sea in an international perspective

Authors: P. Schwemmer, S. Müller, F. Colijn

Paleogeografie van het Waddenzeegebied, een SWOT-analyse

Author: P.C. Vos

De late prehistorie en protohistorie van holoceen

Noord-Nederland (Version 2.0), Amersfoort

(Nationale Onderzoeksagenda Archeologie, hoofdstuk 12).

Authors: J. Bazelmans, H. Groenendijk, G. de Langen, J. Nicolai and A. Nieuwhof

“Man always contrives to neglect the things that are nearest to him”. Het ongekende verleden van een bekende regio: het Waddengebied.

Author: O. Knottnerus

Appendix 2

History of the Wadden Fund and Wadden Academy

The report of the Advisory Group on Wadden Sea Policy (Meijer Committee) was published in 2004. In its report, the committee noted that policy on and management of the Wadden Sea had reached an impasse and that the natural qualities of this unique region had deteriorated in a number of respects. The committee also found that a defensive policy and management style had been adopted in respect of the Wadden Sea Region, in which all the energy had been focused on prevention rather than creation and development. The committee felt that a major unintended consequence of this was that the development and improvement of the natural environment had been impeded and the economic development of the Wadden Sea Region and the northern part of the Netherlands had been blocked. The committee therefore argued strongly in favour of adopting an offensive strategy.

According to the committee, the main objective was to design a sustainable means of protecting and developing the Wadden Sea as a nature reserve and preserve the unique open landscape. The committee believed that an integrated perspective based on prioritising the natural environment which has limited shared human use was necessary to monitor and continue to develop the values and interests which are at issue. The offensive strategy that the committee envisaged included establishing a Wadden fund to finance additional investment in the Wadden Sea Region. With the establishment of this budget fund, it was intended to protect and develop the Wadden Sea as a nature reserve in a sustainable way. The aim was also to preserve the unique open landscape.

In October 2005, the then Dutch government decided, in response to a proposal from Sybilla M. Dekker, the Minister of Housing, Spatial Planning and the Environment, to approve the establishment of the Wadden Fund for which 800 million euro was made available over a period of 20 years (including compensation for cockle fishers). The Minister set up a Wadden Fund Advisory Committee under the chairmanship of L. Hermans. This Advisory Committee got off to an energetic start and, based on its advice, the Minister approved a first round of 19 projects with a total value of over 40 million euro.

The Wadden Fund has four objectives:

- To increase and enhance the natural and scenic values of the Wadden Sea Region;
- To reduce or eliminate external threats to the natural resources of the Wadden Sea;
- To achieve sustainable economic development in the Wadden Sea Region or to concentrate its efforts on a substantial transition towards a sustainable energy management system in the Wadden Sea Region and areas immediately adjacent to it;
- To develop a sustainable knowledge structure for the Wadden Sea Region.

The fourth objective in particular is relevant to the history of the Wadden Academy's development. The Meijer Committee found that much of the knowledge about the Wadden Sea Region was fragmented or incomplete and therefore not immediately available or of use for policymaking or management purposes. The committee also noted that there was too little coordination and integration of knowledge and research with regard to the Wadden Sea Region and that there was not a proper match between the demand for knowledge, the supply of knowledge and the establishment of knowledge development programmes. Finally, the Meijer Committee found that gaps existed in ecological monitoring and that there was a lack of (shared) knowledge with regard to the relationship between the Wadden Sea as a nature reserve and the socio-economic position of the people living in the Wadden Sea Region and the appeal of the Wadden Sea.

For all these reasons, the Meijer Committee advocated the establishment of an independent Wadden Academy. The then Dutch government decided to accept the Meijer Committee's recommendation to establish a Wadden Academy. During the period between the end of October 2005 and the formal inauguration of the Wadden Academy on 30 July 2008, the former Queen's Commissioner in Friesland, Ed Nijpels, led an intensive consultation process with all the parties involved in the Wadden Sea Region to decide on the most effective form of organisation. In these discussions, various alternative versions of the Wadden Academy were reviewed, ranging from a large research institute with its own annual budget of at least 10 million euro to an entirely virtual institute. Eventually, the current form was chosen: a compact and region-specific knowledge organisation which is a separate entity within the KNAW and which principally operates as a network organisation and knowledge platform.

Appendix 3

Analysis of knowledge demands in policy documents

The main principle for the Wadden Academy when setting up research programmes is that they must satisfy the knowledge requirements of management and policymaking bodies. For this reason, the Wadden Academy has ensured that the knowledge demands from the four documents below have been included in the research agenda:

- Preliminary Recommendation for the Dune and Coastal Landscape from the Ministry of Agriculture, Nature and Food Quality;
- PKB Third Policy Document on the Wadden Sea;
- The Management and Development Plan of the Regional Wadden Sea Region Board (RCW);
- Nature Recovery Plan.

Preliminary Recommendation for the Dune and Coastal Landscape

The preliminary recommendation highlights problems in preserving biodiversity in the dune and coastal landscape and places them within their scenic and ecological context. Research themes for the next five years will be formulated on the basis of this review. The largest part of the preliminary recommendation is devoted to a description of the way in which dynamics, the formation of landscape elements and ecology are interconnected. The preliminary recommendation states that returning dynamics to the coastal and dune landscape is the most promising measure for preserving biodiversity in the long term. The priority research for the next five years focuses on three themes:

Research questions for theme 1:

Dynamic coastal management: the engine of biodiversity?

- What effects occur in the soil, vegetation and fauna as a result of different sand-drift and inundation patterns and initial scenarios?
- What is the interaction between washover and salt marsh development?
- How can relic populations be preserved in the event of large-scale sand-drift and washover projects?
- What are the effects of the various methods of sand suppletion on the development of the dune ecosystem?

Research questions for theme 2: Gradients on salt marshes

- Does wetting reduce nutrient availability and therefore delay succession?

- What is the effect of the size of salt marshes on the presence of gradients and biodiversity?
- What is the effect of a more dynamic grazing regime on salt-marsh development, flora and fauna?
- In the case of mainland salt marshes, is it possible to preserve a wide and gradual transition between low salt marsh and the unvegetated flats by means of a long-term cyclical maintenance regime for the salt flat facilities?

Research questions for theme 3: Soil formation, particularly in the grey dunes: reverse the process or anticipate developments?

- What is the effect of the accumulation of organic matter in the soil on the availability of nutrients, vegetation structure and biocoenosis of plants and animals in dune grasslands?
- What is the effect of grazing (and other management methods) on the shifting of nutrient pools in the soil, vegetation and fauna and therefore the biocoenosis of dune grasslands?
- What is the ecological impact and sustainability of small areas of drifting sand?

The above research questions are recurrent themes in the knowledge gaps of Geoscience and Ecology (although sometimes phrased differently).

PKB Third Policy Document on the Wadden Sea

The PKB contains the main ideas of the Dutch government's policy on the Wadden Sea. The PKB is area-specific and integrates spatial planning and spatial planning-related government policy on the Wadden Sea. The main objective of the PKB is to design a sustainable means of protecting and developing the Wadden Sea as a nature reserve and to preserve the unique open landscape.

The policy focuses on the sustainable protection and/or the near-natural development of:

- tidal movements and the associated geomorphological and benthic processes;
- the quality of water, soil and air;
- the flora and fauna;
- and also the preservation of scenic qualities, i.e. tranquillity, vastness, open horizon and natural qualities including dark nights. Archaeological values in the soil and cultural-historic values in the region will also be protected.

The development perspective applied is offensive and describes the main ideas advocated by the government for the long-term development of the Wadden Sea until 2030. The development perspective is an expression of the effort to achieve sustainable development of the region in both ecological and socio-economic terms and in terms of the tourism economy. As regards the policy choices made, human activities have been permitted provided that they are compatible with the main objective for the Wadden Sea.

The PKB states that the government believes that there is a need for research into a number of fields of knowledge and that it is essential for programmes and priorities to be integrated. It also states that the government considers cooperation between the research institutes involved to be necessary and that the primary responsibility for this rests with the institutes.

The main knowledge gaps cited are as listed below:

- the development of the Wadden Sea over long timescales, also in the light of expected climate trends;
- a number of morphological and ecological processes are still insufficiently well understood, as is the interaction between morphology and ecology;
- the relationship between (declining) eutrophication and the carrying capacity of the system;
- insufficient knowledge of dose-effect relationships;
- there is insufficient knowledge of socio-economic and socio-cultural aspects to make a social cost-benefit analysis.

With regard to general monitoring, it is also noted that there is a need for an improvement in (international) cohesion between monitoring programmes for the various uses. With regard to specific monitoring, the government believes that it is advisable to have a separate and independent monitoring committee to oversee large-scale and socially sensitive activities, such as gas extraction, so long as no system of predetermined natural and scenic boundaries is available.

The Wadden Academy notes that all the knowledge gaps identified can be found in the research agenda. The same applies to the importance attached to an effective monitoring programme and the relationship between nature and economics.

Management and Development Plan of the Regional Wadden Sea Region Board

The ambition of the M&D Plan is to protect and develop a robust and resilient nature reserve in which it is also possible to live, work and pursue leisure activities. The M&D Plan is a joint plan for the Wadden Sea Region by the Dutch government, provinces, municipalities and water boards. The PKB has been the key influence in drawing up the M&D Plan.

The M&D Plan focuses on four interconnected categories:

- Ecosystems, habitat and species;
- Climate and energy;
- Landscape and cultural history;
- Living, working and leisure.

The main principles of the M&D Plan are:

- working on robust resilience;
- sustainability;
- development-oriented approach;
- tailored solutions.

The M&D Plan indicates what government bodies regard as opportunities for the region, what course they intend to take and what arrangements need to be made to this end.

In the M&D Plan it has been established that various arrangements which have been proposed require research before they can be developed or implemented. Although a lot of knowledge is available on the ecosystem of the tidal flats, sometimes there is no clear research question or specifically defined scenario. According to the RCW, the relationship between socio-economic issues on the one hand and ecological or landscape-related issues on the other sometimes requires further research to turn opportunities into reality.

All four categories identified by the RCW are elaborated in the integrated research agenda.

Nature Recovery Plan (NRP)

The main objective of the NRP is to place nature recovery at the ambition level as described in the PKB: a sustainable means of protecting and developing the Wadden Sea as a nature reserve and preserve the unique open landscape. The NRP is associated with the Implementation Plan for the mussel sector transition covenant, the binding element being the outright ban on bottom-disturbing seed mussel fishing in 2020 to ensure nature conservation in its widest sense.

The NRP is based on a thematic approach, with six themes:

- restoring clear water;
- improving the food web;
- large-scale recovery of ecosystem engineers;
- a climate-proof Wadden Sea;
- guaranteeing international cohesion;
- shared use: sustainable link between tidal flats and man.

The first three themes provide details of the ecological objective of the region whereas the last three themes are inextricably bound up with the ecological recovery of the Wadden Sea. The themes will be developed during the period April-June 2009 by theme groups in which skills in the areas of knowledge, policy and practice are represented.

Each of the six theme groups has the months of April, May and June in which to perform the task. In the approach to the task, attention must be focused on:

- problem analysis;
- analysis of existing policy and clear target definition;
- finding solutions;
- reviewing current initiatives;
- describing additional measures/initiatives required to achieve the recovery of the tidal flats within the theme;
- a portfolio of prioritised initiatives/projects to put solutions into practice, including approach, parties involved, organisation and financing;
- a summary of relevant research questions and monitoring required, also in relation to current research and monitoring projects;
- a time line with milestones that will make it possible to monitor and evaluate the progress of the chosen approach and initiatives.

The six themes of the NRP can be found in the integrated research agenda. It has been agreed with the directors of the Nature and Reinstatement Plan that the Wadden Academy will accept the directors' request to assume responsibility for ensuring that the plan has scientific backing.









Editorial details

'Knowledge for a sustainable future of the Wadden' has been produced under the auspices of the Wadden Academy-KNAW:

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The contents of the research agenda are based on a number of position papers (see Appendix 1 for a summary). These position papers contain contributions from a wide range of scientific researchers in the Netherlands, representing all the relevant disciplines. Containing comprehensive lists of references to the sources and literature used in this research agenda, the position papers were published separately by the Wadden Academy in June 2009.

This document can be referred to as:

Kabat, P., Bazelmans, J., van Dijk, J., Herman, P.M.J., Speelman, H., Deen, N.R.J. and R.W.A. Hutjes, (editors), 2009.

Knowledge for a sustainable future of the Wadden integrated research agenda of the Wadden Academy-KNAW, 2009.

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Production: Synergos Communicatie

Translation: Balance texts & translations

Lay-out: Supernova Ontwerp bNO

Photography: Jan Huneman, Hollandse Hoogte

Printed by: Platform P

ISBN 978-94-90289-15-7



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