PROGRAMMA **NAAR EEN RIJKE WADDENZEE**

DATA INVENTORY OF THE TIDAL BASINS IN THE TRILATERAL WADDEN SEA

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PHOTO: CWSS/Brockmann Consult

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PHOTO: KLAUS JANKE

1 SAMENVATTING

Het programma "Naar een rijke Waddenzee" (PRW) heeft als doel de kombergingen in de Deense, Duitse en Nederlandse Waddenzee te vergelijken op basis van abiotische kenmerken, ecologische ontwikkeling en historisch en vigerend beleid. Een dergelijke vergelijking kan inzichten opleveren in de effecten van natuurlijke en anthropogene factoren op de toestand van de kombergingen.

Dit rapport verkent de potentiële waarde van vergelijkend onderzoek op het niveau van kombergingen en de beschikbaarheid van data om vergelijkend onderzoek uit te kunnen voeren. Deze voorstudie, uitgevoerd tussen november 2010 en augustus 2011:

- presenteert een overzicht van de meest urgente beleidsvragen en de daarmee samenhangende wetenschappelijke onderwerpen,
- geeft een overzicht van de belangrijkste variabelen die nodig zijn om de fysische, chemische en biologische eigenschappen van de kombergingen in de Waddenzee te beschrijven,
- beoordeelt de kwaliteit en beschikbaarheid van bestaande gegevens, verzameld of georganiseerd binnen de belangrijkste monitoringsprogramma's in de Waddenzee,
- stelt methodologie voor aan de hand waarvan vergelijkingen gemaakt kunnen worden.

Wetenschappers en andere experts in Nederland, Duitsland en Denemarken zijn geïnterviewd om inzicht te verkrijgen in de relevantie en haalbaarheid om kombergingen onderling te vergelijken op basis van diverse kenmerken. Het vergelijken van kombergingen werd als zeer nuttig beschouwd voor verschillende beleids- en wetenschappelijke vragen. Een (digitale) atlas met daarin algemene informatie over kombergingen werd als vorm voorgesteld.

De belangrijkste beleids- en wetenschappelijke vragen waarvoor de beoogde aanpak nuttig zou zijn, werden ook met de experts besproken. Naast de experts, werden de literatuur, en databases geraadpleegd om een overzicht te verkrijgen van beschikbare data om de geïdentificeerde beleidsvragen te kunnen beantwoorden.

De belangrijkste beleidsvragen hebben betrekking op:

- klimaatverandering en zeespiegelstijging,
- biodiversiteit en de effecten van de aanwezigheid van exoten,
- de effecten van menselijk gebruik,
- ecosysteem functies en diensten.

Dit rapport presenteert verschillende nationale en internationale monitoringsprogramma's en initiatieven die voor de samenstelling van de atlas gebruikt kunnen worden. Verschillende harmonisatie-initiatieven (o.a. met betrekking tot bathymetrie, mosselbedden, vissen en vogels) hebben dataproducten opgeleverd die zeer geschikt zijn om kombergingen onderling te vergelijken.

Er zijn substantiële verschillen in de datadichtheid tussen kombergingen geconstateerd. Met name kleinere kombergingen zijn ondervertegenwoordigd in monitoringsprogramma's. De belangrijkste dataleemtes betreffen menselijk gebruik, schattingen van primaire productie en sediment budgetten. Het is vaak onduidelijk onder welke voorwaarden gegevens beschikbaar zijn voor algemeen gebruik.

In dit rapport worden verschillende kaarten met parameters op het niveau van kombergingen gepresenteerd. Om in geïdentificeerde dataleemtes te voorzien, wordt voorgesteld om gebruik te maken van kombergingstypen die representatief zijn voor andere kombergingen waar weinig of geen informatie voor beschikbaar is. Verder wordt voorgesteld om gebruik te maken van gegevens verkregen via remote sensing en van modellen voor het vergelijken van kombergingen en het opvullen van de leemtes. De grootste investering in de ontwikkeling van een atlas is het verzamelen van gegevens uit verschillende bronnen en deze op vergelijkbaarheid te toetsen, en, indien nodig vergelijkbaar te maken.

1 SUMMARY

The Dutch programme "Towards a Rich Wadden Sea" (PRW) proposes to compare all tidal basins in the Wadden Sea on the basis of their abiotic properties, ecological developments and the policies and management applied in each basin. Such a comparison may provide insight into the ways natural and anthropogenic factors influence the conditions of tidal basins. PRW has commissioned this prestudy with the aim of investigating the relevance and feasibility of comparing the tidal basins of the Wadden Sea.

The present study, carried out between November 2010 and August 2011:

- presents an overview of the most urgent policy questions and associated science topics,
- presents an overview of the main parameter groups needed to describe the physical, chemical, and biological properties of tidal basins and their use by humans,
- assesses the quality and availability of existing data collected or compiled by the most comprehensive monitoring programmes in the Wadden Sea,
- proposes methodology by which synoptic comparisons may be made.

Scientists and experts in The Netherlands, Germany, and Denmark were interviewed in order to gain insight into the relevance and feasibility of the proposed tidal basin approach.

The development of a tidal basin atlas was generally considered a potentially important contribution to the field. Comparison of tidal basins on the basis of general characteristics was considered helpful for various kinds of policy and research topics.

Additionally, the main policy questions for which this approach could be useful, including any related scientific questions and associated parameters, were discussed. The interviewees were consulted and literature and databases were searched to obtain an overview of data that were available to address the identified policy concerns.

The main policy questions relate to:

- Sea level rise
- Climate change, especially changing temperature
- Biodiversity, including the impact of invasive alien species
- The impact of human use, particularly seabedimpacting activities
- Conservation management in relation to ecosystem functions and services.

Various national and international initiatives in which data from different sources are being compiled and distributed have been identified and are presented in this report. Some trilateral harmonization initiatives have led to very useful data (e.g. birds and mussel beds), suitable for comparative research. There are substantial differences in the data density between tidal basins; smaller basins are particularly underrepresented. In addition, it is often unclear whether some datasets carry conditions of use which either forbid widespread publication or restrict the details that can be disclosed in public documents. The biggest gaps exist for human use parameters, measurements of primary production and sediment budgets.

Several recommendations on how to use the tidal basin approach are presented. To overcome the current problem of insufficient data coverage, it is recommended that a selected set of indicative basins be used, that models be applied and that remote sensing data be integrated into the approach. It is further recommended that the data be presented via an easily accessible information system comprising a digital atlas of the trilateral tidal basins.

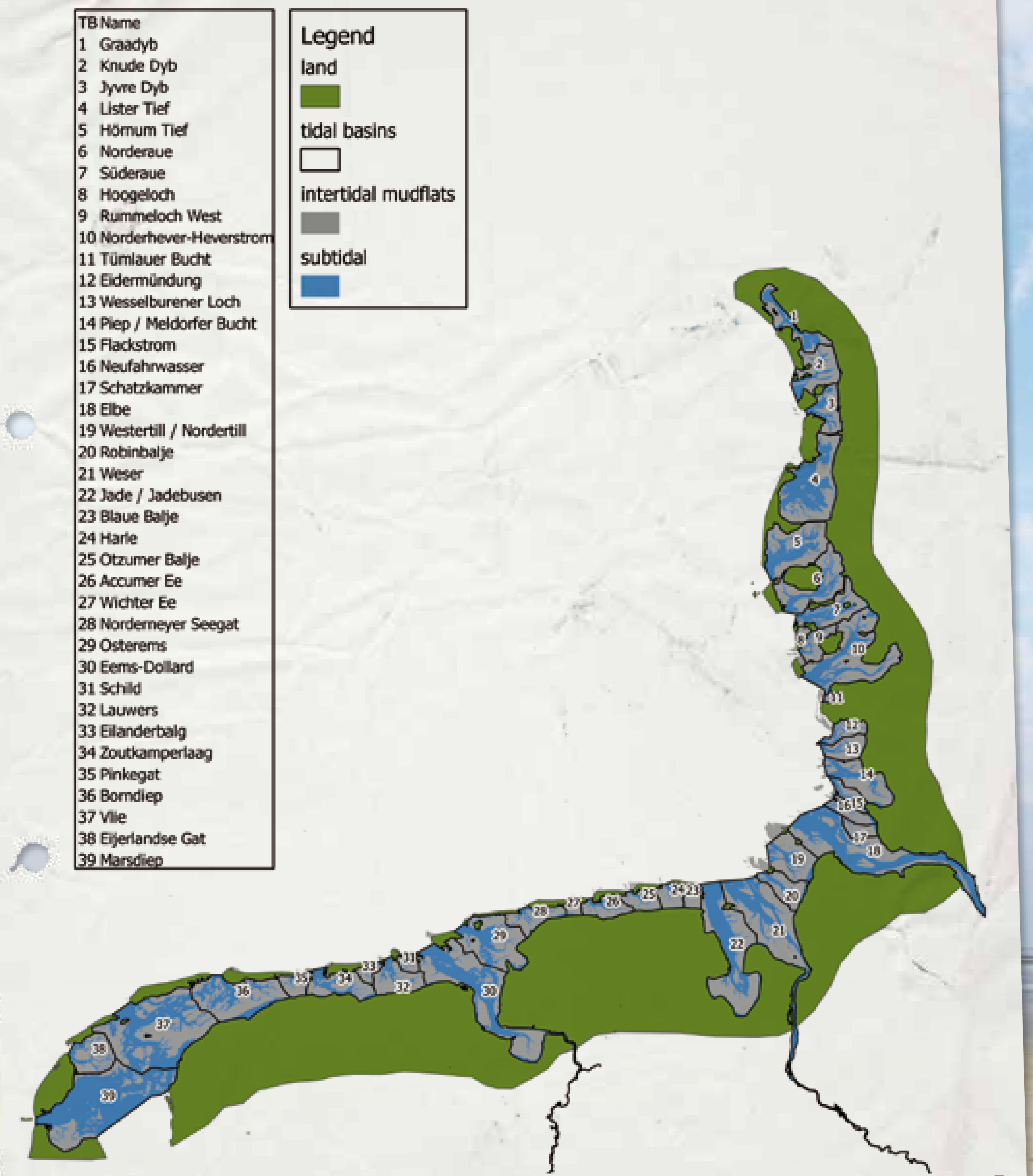


Figure 1: Tidal basins of the Wadden Sea.

2 INTRODUCTION

2.1 BACKGROUND

Starting point for this pre-study is the proposal from the Dutch programme "Towards a Rich Wadden Sea" (PRW) to compare all the tidal basins in the Wadden Sea on the basis of their abiotic properties, ecological development and applied policy and management. For instance, Herman et al. (2009) plead for a focus on large-scale comparative and integrative research. A comparison on the level of tidal basins may provide insight into how natural and anthropogenic factors influence the Wadden Sea. This knowledge may contribute to sustainable governance and management of the Wadden Sea ecosystem.

2.2 TIDAL BASIN LEVEL

A tidal basin is a body of water in a semi enclosed coastal area that is subject to tides. Tidal basins are useful for comparative research because they are logical units from morphological, hydrodynamic, and ecological perspectives. In this report the mean high tide lines, tidal divides, and the lines representing the shortest distance between islands are taken as boundaries of tidal basins (*Figure 1*). (See Appendix 9.1 for a detailed description of the demarcation of tidal basins and correspondence with previous estimations.)

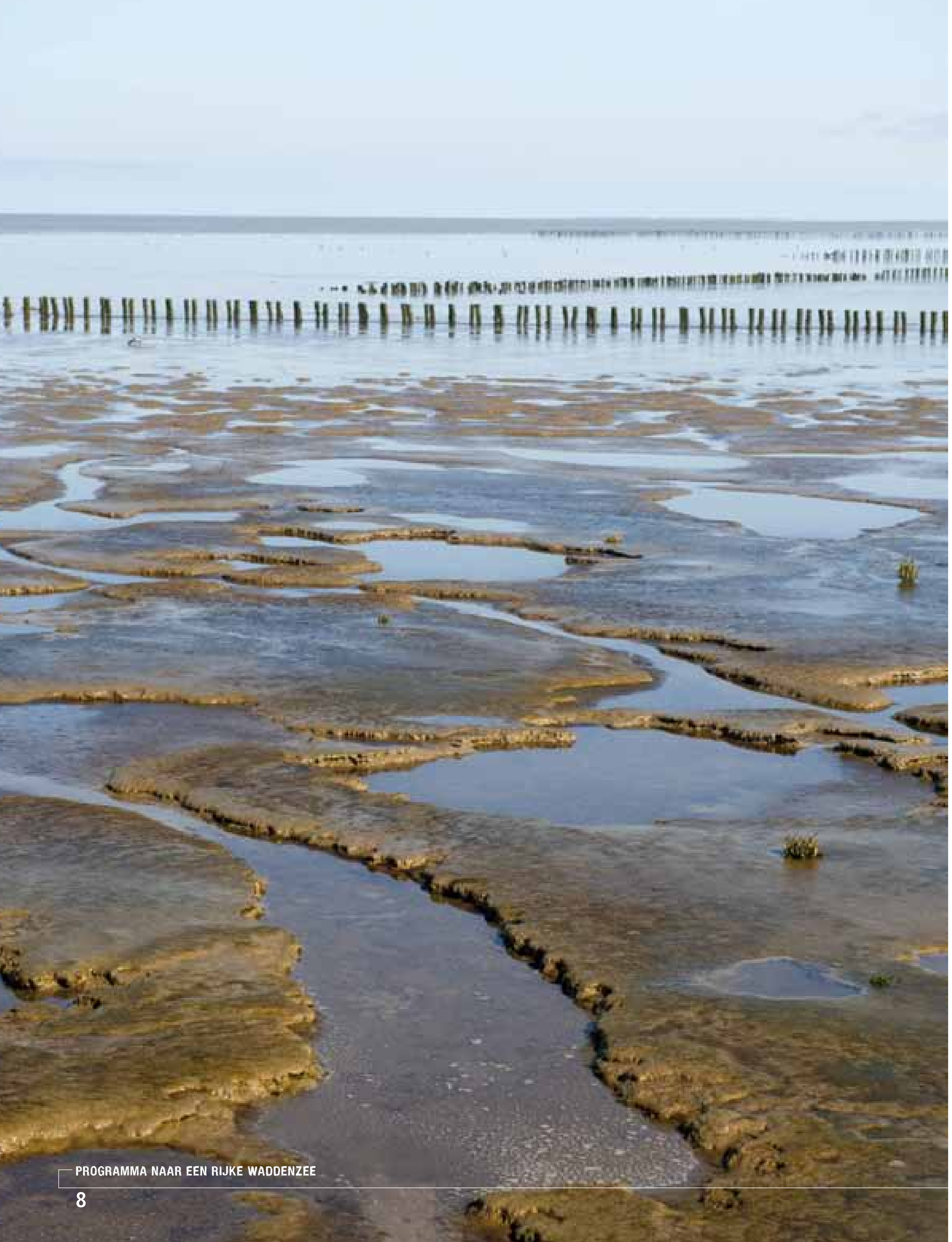
2.3 OBJECTIVES

The objectives of this study are

1. To investigate if comparative research at the level of tidal basins is considered useful and for which policy questions this approach is most promising.
2. To judge requirements, quality and availability of data to conduct a comparative analysis.
3. To investigate the the opportunities to construct an atlas which includes information on morphology, physical and chemical properties, ecology, anthropogenic disturbance, and management practices on the level of tidal basins, which would enable assessment of changes in the Wadden Sea in relation to natural and human factors. As such, the atlas would be an important reference for policy and research.

2.4 STRUCTURE OF THE REPORT

Chapter 3 describes the methodology and presents the contractors and steering committee. **Chapter 4** describes the most urgent policy concerns and related scientific questions identified in the interviews. It furthermore presents the parameters that are required to deal with the questions. **Chapter 5** describes the demand for, quality and availability of (historical) data based on the interviews, literature and database research. In some cases, project based measurements are also presented. It concludes with a description of important gaps in the data. As a precursor to a tidal basin atlas, **Chapter 6** presents a basic map relating the size of intertidal mudflat and a map with the average depths of the basins. **Chapter 7** makes a number of recommendations about the application of the tidal basin concept and suggests additional follow-up activities.



3 METHODS

3.1 CONTRACTORS AND STEERING COMMITTEE

Contractors of this study were ecologists from Germany and The Netherlands.

- Dietmar Kraft, HWK (D), WIMO
- Jürgen Meyerdirks, ICBM – University of Oldenburg (D)
- Thorsten Stiehl, ICBM – University of Oldenburg (D)
- Eelke Folmer (NL), (Ecospace and NIOZ, Royal Netherlands Institute for Sea Research)

Dietmar Kraft, Jürgen Meyerdirks and Thorsten Stiehl interviewed German experts and compiled the information from German and Danish projects and databases. Eelke Folmer compiled information from The Netherlands and interviewed Dutch experts.

The study was supervised by a steering committee consisting of:

- Justus van Beusekom, AWI Sylt (D)
- Norbert Dankers, IMARES (NL)
- Morten Pejrup, University of Copenhagen (DK) with the support of Bruno Ens (SOVON, NL) and Katja Philippart (NIOZ, NL).

Overall coordination: Folkert de Jong (PRW, CWSS).

3.2 INFORMATION SOURCES

Various sources of information were considered and the following steps were taken to meet the objectives (2.3):

1. **Workshops and interviews** were conducted with 44 academic scientists, policy makers and one consultant from 12 different institutes to identify the most important current and future policy concerns, related research topics and associated parameters. The experts were asked which data would be required to evaluate the main questions and to comment on methodological issues.
2. **Current monitoring programmes, datasets and scientific programmes** were screened by means of literature and database research.
3. **A quick scan** was made of the relevant research projects and related literature to find out whether these projects produced data on the scale of tidal basins that could be of use for comparative research. To curb the amount of information, the authors limited their research to projects not older than ten years.

4 POLICY CONCERNS, SCIENTIFIC QUESTIONS AND REQUIRED PARAMETERS

This chapter presents the main policy and management questions identified in the interviews and from literature, together with related scientific questions and required parameters. The chapter furthermore provides some insight into how the tidal basin approach might help to identify important causes of differences and change. It should be noted that there may be overlap between scientific questions and required parameters between the different policy concerns.

4.1 SEA LEVEL RISE AND SEA FLOOR SUBSIDENCE

Policy question:
Will the Wadden Sea drown with the predicted acceleration in sea level rise and sea floor subsidence?

There is general concern and much uncertainty about the impact of sea level rise and sea floor subsidence on the morphology of the Wadden Sea. In particular, it is not known to what extent mudflats and barrier islands will be able to keep up with accelerating sea-level rise. Whether or not sea level rise will become a problem depends on the actual rates of sea level rise and the rate of sediment accretion. In order to mitigate sea level rise and sea floor subsidence and to prevent coastal erosion, nourishments are carried out. The morphological and ecological consequences of nourishments are largely unknown.

4.1.1 SCIENTIFIC TOPIC: WHAT IS NEEDED TO PREDICT THE IMPACTS OF SEA LEVEL RISE?

To gain insight into the effects of sea level rise on the Wadden Sea, geological, hydrodynamical and geomorphological processes have to be understood and models should predict sediment fluxes correctly. Current sediment transport models, however, do not predict the fluxes of sediment in the Wadden Sea accurately on short time scales. It is therefore uncertain whether natural sediment fluxes are sufficiently high to compensate for sea level rise and sea floor subsidence in all tidal basins. It is therefore important to know whether and to what degree sediment nourishments can mitigate these effects. Differences in properties between the tidal basins are relevant in this context (Louters and Gerritsen 1994), as is the role of bio-engineers. Also of high relevance is the influence of large-scale physical activities such as coastal protection constructions.

4.1.2 PARAMETERS OF MORPHODYNAMICS

Bathymetry is important because it describes an essential aspect of the geomorphology and it is a central component of geomorphological models. Sediment transport results from moving water (hydrodynamics). Hence tidal range (the tide is the driver of currents) and wave-climate (distribution of wave heights and directions caused by wind) are important parameters for predicting geomorphology. As the movement of sediment also depends on shear stress, it is also important to know grain size distribution. It should be noted that the above parameters have profound direct or indirect impact on the presence and abundance of most, if not all, species of benthos.

4.1.3 METHODOLOGICAL CONCERNS

A number of experts stressed the importance of extreme events that shaped the morphology of the tidal basins – with large differences from basin to basin. It is therefore important to have accurate maps of extreme wind events. This is a challenging task because these are difficult to interpolate spatially.

4.2 HUMAN USE

Policy question:

What are the main anthropogenic disturbances and what are their impacts on the Wadden Sea ecosystem?

Scientific knowledge is important for developing sustainable human use. However, identifying the main anthropogenic drivers and their impacts is difficult due to the complexity of the Wadden Sea system. There are several types of exploitation and anthropogenic disturbances going on in the Wadden Sea. Fisheries directly affect the biota and the food-web and several types of fishery have an impact on the seafloor. Because of the spatial extent and regular occurrence it can be seen as a chronic impact. Mining of sand and shells affects the morphology of the seafloor and may lead to increased turbidity of the water. Similarly, dredging and dumping of sediment is often thought to have a profound impact on the ecosystem in that it influences hydrology and increases the turbidity. In addition, pollutants from human activities enter the system via rivers and the atmosphere.

4.2.1 SCIENCE TOPIC: HOW IS TURBIDITY OF THE WATER COLUMN AFFECTED BY HUMAN USE?

From a scientific and management point of view, there is strong interest in the turbidity of the Wadden Sea. An important factor is related to the hydrodynamic regime which is affected by dikes (causing 'coastal squeeze') and dredging of channels which may have led to increased turbidity. Measurements of turbidity and silt-content in the Dutch Wadden Sea are poor because there is high spatio-temporal variability due to tides and waves. These constantly changing variants make it difficult to detect long-term changes. The questions of whether the Wadden Sea has become more turbid (and if so, where), and what contribution anthropogenic disturbances have made, are open.

The turbidity level of the water is considered an important factor in the restoration of seagrass meadows because of the high light requirement of the different seagrass species. In the past it has been particularly difficult to establish new seagrass meadows in the Dutch Wadden Sea. Also other factors, such as hydrodynamic conditions and morphological properties of the seabed (consolidated vs. bioturbated), affect restoration. It should be noted that seagrass stands may interfere with local hydrodynamic conditions and thus indirectly affect the turbidity of the water.

PHOTO: ROOS KENTIE

4.2.2 SCIENCE TOPIC: WHAT ARE THE IMPACTS OF FISHERIES ON ECOSYSTEM FUNCTIONING?

There are various kinds of fisheries in the Wadden Sea. Shrimp fisheries are relatively important because there are many active ships and their activities disturb the bottom which affects the development the biological community including ecosystem engineers. Shrimp fisheries will also affect the food-web by altering trophic interactions.

The effects of mussel cultivation on the structure and development of the food-web is an open question. Furthermore, the impacts of musselseed fisheries (bottom dredging) on the ecosystem is not well known.

Hand-cockle fisheries are expanding in scale but not much is known about their impacts on the ecosystem. The quantities fished and the extents of the fished areas are currently unknown.

4.3 BIODIVERSITY, CLIMATE CHANGE AND NEOBIOTA

Policy questions:

How and to what extent will climate change and neobiota affect the ecology of the Wadden Sea?

What are possible measures that can be taken to sustain biodiversity and what is their effectiveness?

Sustaining the characteristic biodiversity of the Wadden Sea region is a central objective of policy. Various factors, including climate change and invasive species, may cause basic changes in ecosystem functioning (e.g. fluxes between different trophic stages), species distributions and overall biodiversity. Identification of the most effective managerial measures to maintain or improve biodiversity and resilience in relation to (inevitable) change is important.

4.3.1 SCIENCE TOPIC: WHAT ARE THE SPATIO-TEMPORAL DISTRIBUTION PATTERNS OF BIOTA AND WHAT ARE THE DRIVERS?

In order to study how productivity and biodiversity are related to environmental factors and anthropogenic disturbance, it is important to have an overview of the distribution of species, food-webs and ecotopes. Below, fundamental food-web dynamics, impact of neobiota on native communities and the distribution of shorebirds are presented as examples of topics related to biodiversity in the Wadden Sea:

1. Understanding species richness and population dynamics requires basic understanding of the structure and the fluxes of energy in food-webs. Estimation of fluxes from primary to secondary producers requires knowledge of the densities and population dynamics of zooplankton and macrozoobenthos. It is therefore important to understand the diets of, and competitive interactions between, secondary producers. Better understanding is required

to predict future population dynamics among secondary producers in response to changing conditions. To estimate fluxes from secondary producers to top predators, a comparative analysis of tidal basin density and dynamic levels could provide insight into several important determinants of population densities.

2. The Wadden Sea has always been exposed to invasion by exotic species but no evidence for the exclusion of native species has been documented. However, invasive species like the Pacific oyster (Crassostrea gigas), razor clam (Ensis americanus), and – currently expanding in range and density - the common slipper shell (Crepidula fornicata) are bound to have an impact on the distribution of native species. Buschbaum (at the Waddenacademie symposium, 2010) suggests that the pathways of establishment of neobiota and the impact on the native community in one area may be indicative for the development of populations of neobiota and the native community in other areas. Comparative research at the level of tidal basins may allow identification of the impacts on species native to the ecosystem under varying environmental conditions. Furthermore, the role of artificial structures (seaports, marinas, navigation buoys, offshore infrastructure, hard coastal defences, roads, canals, cultural landscapes) as corridors requires analysis.

3. Despite a long history of research on population dynamics and the diets of shorebirds in the Dutch Wadden Sea (van de Kam et al. 2004, Laursen et al. 2010), regional and temporal distributions are still poorly understood. The trends in numbers of several species of shorebirds vary widely between the three countries (Ens et al. 2009). Questions as to which extent differences in bird numbers and trends are due to natural causes and management practices remain unanswered.

4.3.2 SCIENCE TOPIC: WHAT PROMOTES AND WHAT THREATENS BIODIVERSITY AND RESILIENCE?

To understand how biodiversity (and related ecosystem functioning) may be protected, basic ecological issues such as the relationship between diversity and stability would need to be addressed. While these are challenging kinds of topics, there are ways in which comparative research may provide insights. In particular, the properties of rich and resilient tidal basins may be indicative of desirable conditions for other tidal basins. Likewise, the potential impact of an activity may be assessed by investigating patterns of biodiversity in tidal basins where similar activities have taken place.

4.3.3 SCIENCE TOPIC: HOW DOES CLIMATE CHANGE AFFECT THE MAIN ECOLOGICAL PROCESSES?

The effects of climate change on the Wadden Sea ecosystem will be related to changes in water temperature, sea level, rainfall, wind and carbon dioxide levels (and thus pH). These changes may cause shifts in habitats and species distributions (and food-web structure); biological rates (e.g. metabolism, reproduction); community level phenologies (Philippart et al. 2003)and thus in overall ecosystem functioning (nutrient recycling, primary production) (Harley et al. 2006).

A key challenge is to identify the main biological processes that will be affected by climate change and invasive species. One way to address this question is by considering variations in biological processes between the tidal basins.

4.3.4 PARAMETERS OF BIODIVERSITY, CLIMATE CHANGE AND NEOBIOTA

The distributions and abundances of organisms (ranging from plankton to mammals) are required in order to define biodiversity and to describe communities. As populations and communities fluctuate under natural conditions, long term ecological data are required to asses systematic ecological changes in the Wadden Sea ecosystem.

As mentioned above (4.1), climate change involves changes in various climatological and related parameters. Sea level, wind and waves are important factors for the morphology of the Wadden Sea. Water temperature, rainfall, CO_2 concentrations and associated variables (e.g. seawater acidity and salinity) are important to ecosystem functioning. Independent of other factors, such as human use, changing temperature ranges may lead to different effects in different tidal basins.

4.4 ECOSYSTEM SERVICES

Policy question:

Which are the most important ecosystem services provided by the Wadden Sea?

Ecosystem services are the multitude of benefits that natural ecosystems supply to humankind. The following categories are distinguished by the Millenium Ecosystem Assessment (MEA):

- provisioning services (e.g. food, water, minerals energy),
- regulating services (e.g. waste decomposition, carbon sequestration, water purification, pest control),
- supporting services (e.g. nutrient cycling, seed dispersal) and
- cultural services (e.g. recreation, artistic and intellectual inspiration) (Costanza et al. 1997, de Groot et al. 2002).

Identifying the manifold functions that the Wadden Sea ecosystem fulfils, and evaluating the weight of these services for the users of the ecosystem, is one of the biggest challenges facing politics and management, as well as the research community. Examples of ecosystem services in the Wadden Sea are the coastal defence function of marshes and mudflats, the production of fish for fisheries, purification of water and sediment fixation. Other important values are related to recreation and cultural and intellectual inspiration.

4.4.1 SCIENCE TOPIC: WHAT ARE THE VALUES OF THE SERVICES PROVIDED BY THE ECOSYSTEM?

The services and uses of the Wadden Sea are complex and many interactions have to be considered. Moreover, several of the impacts are long lasting but may show up not only until quite some time has elapsed. Valuation of ecosystem services is difficult as it often requires monetarisation (expressing value in currency) of natural and cultural goods for present and future generations.

The relevance of a trans-disciplinary approach, especially in the context of management, was highlighted several times in the interviews.

4.4.2 PARAMETERS OF ECOSYSTEM SERVICES

Valuation of the services of the Wadden Sea region requires identification of their main functions and of their dominant users. For instance, the value of fish requires the demand by the current and future demand for fish. Another important service is related to coastal defence by mudflats and marshes. The main value of this function may be calculated by considering the cost of replacing this natural barrier by an artificial coastal defence infrastructure. An important value of the Wadden Sea region is related to tourism and leisure. Many visitors enjoy the natural and inspirational values which lead to jobs in the tourist sector. Determining the value of a tidal basin requires insight into how the intrinsic resources of the basin enable biodiversity and ecosystem functions, and also how they influence and facilitate human activity.

Parameter Group / *Parameter*	demand	quality	effort	availability NL	availability D	availability DK	spatial coverage NL	spatial coverage D	spatial coverage DK	sources NL	sources D	sources DK
General												
bathymetry	H		L	H	M	M	A	A	A	RWS	*BSH*	*DMSA*
hydrology[k]	M		M	H	M	M	A,P	A	A	RWS[Lit]	COASTDAT	COASTDAT
sea water level	H	H	L	H	H	H	P	P	A	LMW	*BSH*[f]	TMAP
sediment[l]	H		M	H	M		A,P	A		RWS	*BSH*	
weather, climate	H	H	L	H	H	H	P,A	A	A	KNMI, Cesar	*DWD*	DMI
land cover	M	H	L	H	H	H	A	A	A	CLC	CLC	CLC
Physical												
temperature	H	H	L	M	H	H	P	P,A	P,A	RWS	BLMP[d], TMAP[e]	MADS
salinity	H	H	L	M	H	H	P	P,A	P,A	RWS	BLMP[d], TMAP[e]	MADS
currents	H	M	L	M	H	H	A,P	A	A	HMCN, COASTDAT	COASTDAT	COASTDAT
waves	H	M	L	M	H	H	A,P	A	A	HMCN, COASTDAT	RA[g],COASTDAT	COASTDAT
Chemical												
chlorophyll	H	L	M	H	L	H	P		P	RWS		MADS
nutrients	H	M	H	H	M	H	P	P	P	RWS, TMAP	BLMP, TMAP	MADS, TMAP
turbidity	H		L	M	H		P	P		RWS, TMAP	BLMP, TMAP	c
organic matter	H	M	H	M		H	P			RWS, TMAP	c	c
pH	H		L	H	H		P	P		RWS, TMAP	BLMP, TMAP	c
oxygen	H	L	L	H	H	H	P	P	P	RWS, TMAP	BLMP, TMAP	MADS
toxins[b]	L	M	L		H	H	P	P	P	RWS, TMAP	BLMP, TMAP	TMAP, MADS
Biological[o]												
dolphins	H		M	H	H	H	P	P	P	NIOZ, IM, TMAP	TMAP	TMAP, MADS
seals	H		L	H	H	H	P	P	P	TMAP	TMAP	TMAP
birds[p]	H			M	H	H	P	P	P	SOVON, RWS, TMAP[e]	TMAP	TMAP
fish	H		L	H	H	L	P	P		NIOZ, IM, TMAP[e]	vTI, TMAP	
macrophytes	M		L	H	H	H				TMAP[e]	TMAP	TMAP
macrozoobenthos	H		M	H		M	P,A	P	P	RWS, IM, NIOZ	TMAP	MADS
phytoplankton	H		M	H	M	H	P	P	P	RWS	*BLMP*	MADS[a]
microphytobenthos	H			L			P			ZKO[q]		
zooplankton	H			L			P	P		ZKO	AWI-sylt	
neobiota	H		L	H	H	H	P	P	P	TMAP	TMAP	TMAP
Habitat[h]												
tidal area[j]	H	H	L	H	H	H	A	A	A	TMAP	TMAP	TMAP
salt marshes	H	H	L	H	H	H	A	A	A	TMAP	TMAP	TMAP
dunes	M	H	L	H	H	H	A	A	A	TMAP	TMAP	TMAP
blue mussel beds	H	H	L	H	H	H	A	A	A	TMAP	TMAP	TMAP
seagrass beds	H	H	L	H	H	H	A	A	A	TMAP	TMAP	TMAP
Human use												
fishing	H	L	M	H	M	M					scattered	scattered[n]
dredging	H		H	M								n
dumping	H		M	L								n
mining (shells and sand)	M		H	H								

[a] in total 144 stations
[b] water, sediment, bird eggs, flounder, bleu mussel
[d] probably available according to obtained parameter list; not covered TBs 8,9,15,16,17,27
[g] regional authorities responsible, data scattered and hard to obtain
[h] adopted from QSR 2004 and 2009
[j] intertidal, sublittoral; including rivers and deltas
[k] including emersion time, tidal amplitude, tidal prism, residence time
[l] including sediment compostition, silt concentrations, organic material
[o] numbers and densities
[p] high tide roost counts

A: Real data
P: Point measurements

H= high
M= medium
L= low

[Lit] Literature
[c] probably add-on at all contaminants stations
[e] TMAP: no information for SH/HH (TB 30-39), Data units off-line
[f] 5 stations in the German Bight only
[n] use restricted by law
[q] only since recently one location in Western Dutch Wadden Sea

5 DATA

Based on the policy questions, the related scientific questions and the associated parameters, identified in Chapter 4, an investigation into the demand for, the quality and the availability of data was undertaken. Data sources and research programs were screened and experts were asked for advice and opinion. The focus was on relatively large (in terms of temporal and spatial extent) monitoring programmes and compilations of data. This implies that several site-specific programmes and data have not or only partly been considered.

Research institutes are spread over the three national states and between various European authorities. There is substantial variation in the spatial scale of the various projects, ranging from small pilot-site-oriented case studies up to investigations covering the whole North Sea.

A large number of programs and databases were considered. More than 40 projects, which represent the larger part of project-organised coastal research of recent years have been examined. A detailed review of all programmes, databases and projects was beyond the scope of this pre-study. For an overview of monitoring programs in the Dutch Wadden Sea we refer to Smit et al. (2010). Section 5.1 presents an overview and section 5.2 provides more detailed information on the monitoring programs and data while section 5.3 describes the gaps.

5.1 OVERVIEW: DATA DEMAND, QUALITY AND AVAILABILITY

The 'Data Demand' gives an indication of the importance of a variable for the research and management community. It is based on how often it was mentioned during interviews and in the literature. The 'quality' of data is related to the spatial and temporal resolution and the precision and consistency by which it is measured. It is, however, impossible to define 'quality' unambiguously because it depends on the way the data are used. Data Availability characterises the accessibility of the data. It varied widely between parameters. Accessing data via the internet is sometimes difficult due to dead links, off-line databases and lack of metadata (such as the position of the stations).

The parameters are grouped as in TMAP. It is worth noting that no single programme covers all tidal basins. Table 1 presents an overview and the sources are described in detail in 5.2.

< Table 1: Demand, quality and availability of key parameters. Sources represent the dominant data-provider; bold type have been checked in detail, italics most likely contain information about the parameter but have not been checked in detail. Spatial coverage gives information whether data are provided throughout the tidal basins or are restricted to some locations. Section 5.2 presents further information.

5.2 DATA SOURCES AND MEASUREMENT METHODOLOGY

5.2.1 GENERAL PARAMETERS

5.2.1.1 Bathymetry

The bathymetry of the Wadden Sea is important from various perspectives. RWS determines the bathymetry of the Dutch Wadden Sea. The BSH provides some basic bathymetry models for the German Wadden Sea. The Danish Maritime Safety Administration holds data for the Danish Wadden Sea. EMODnet provides a compilation of the bathymetries in a resolution of approximately 300 × 300 m of the German and Danish Wadden Sea in a web-GIS[1] which may be downloaded free (*Figure 2*).

The bathymetry of the Dutch Wadden Sea is determined every six years by RWS. Data are freely available and RWS distributes the data in 'tiles' which are constructed by interpolation. It takes RWS six years to determine the bathymetry of the Dutch Wadden Sea. A full bathymetry, therefore, does not represent a plain cross-section. An additional complicating factor is that the way the data is collected has changed, and therefore bathymetries are incomparable over longer time periods. Care should be taken when temporal variation is analysed.

Figure 2: Bathymetry of the Wadden Sea and part of North Sea. Data are compiled by EMODnet from various sources.

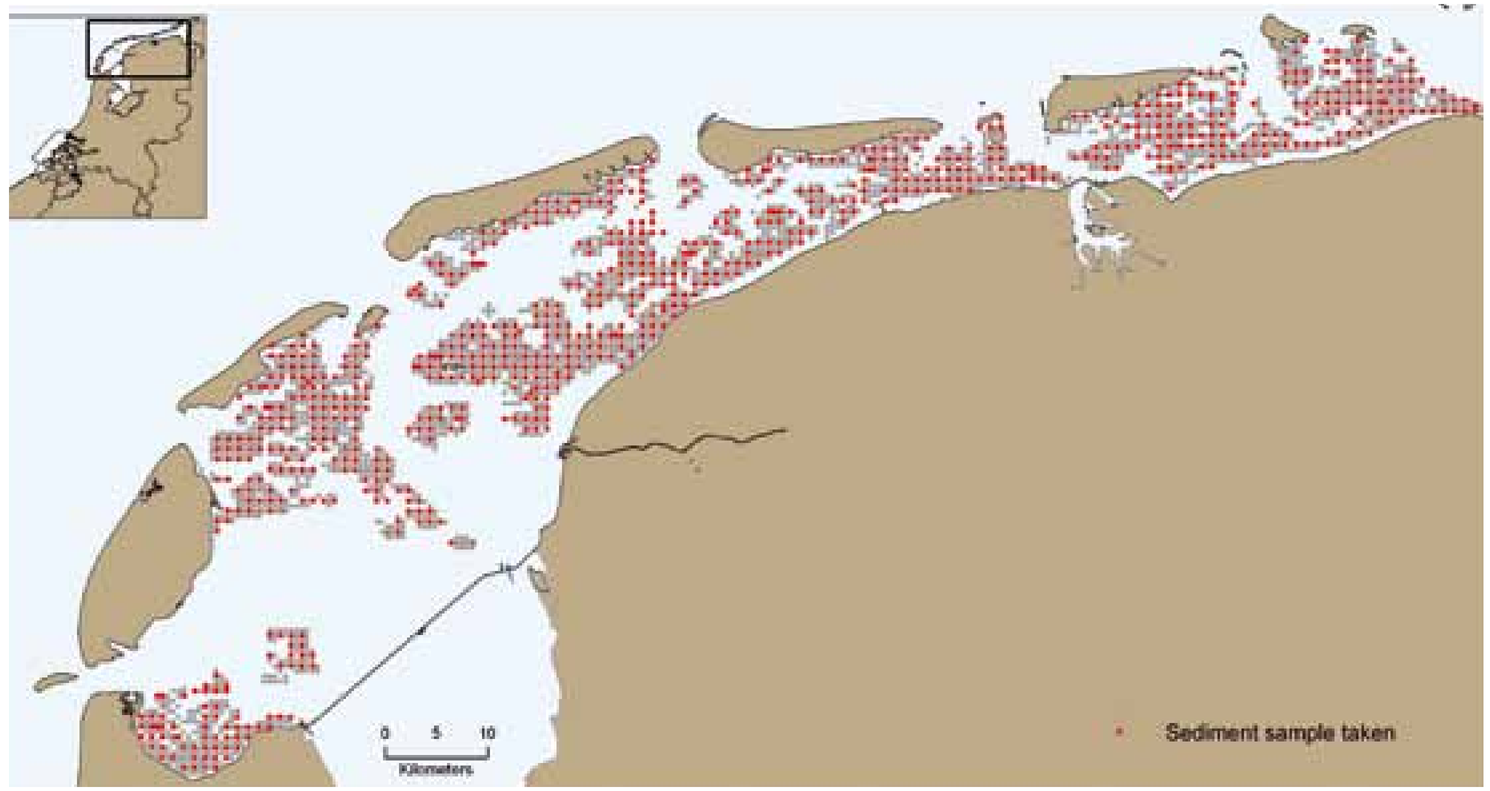


Figure 3: Spatial distribution of sampling stations in the SIBES 2008 monitoring program (reproduced with permission from Aarts et al. 2010).

5.2.1.2 Sediment

Sediment properties of the seafloor are determined in various Dutch programmes. No German or Danish programmes that monitor sediment properties were encountered.

RWS (MWTL program) provides data on grain size properties from several locations in the Dutch Wadden Sea. The following parameters are determined from the sediment samples: grain size distribution, mass concentrations of organic carbon (in which particles <63 µm are distinguished), concentration of metals, HCB, HAK, PCBs, Organotin, Bromine (Brominated flame retardant), Lutum, and organic content. It is not feasible to mention all parameters and we refer to the website from which the DONAR database may be freely accessed[2].

Grain size distribution is also determined in the macrofauna monitoring program (also MWTL) on several locations in the Wadden Sea where they serve as covariates. These data are also freely available but there is no online database from which the data may be downloaded. 'Helpdesk water' at RWS may provide the data. In addition to the standard monitoring of grain size distribution, measurements are made for more specific RWS projects of which an overview is hard to obtain.

Between 1989 and 1997 large scale measurements of grain size have been performed by RWS throughout the Dutch Wadden Sea. The data have been collected in the 'Sediment atlas' which may be freely downloaded[3].

In the yearly Synoptic Intertidal Benthic Surveys Wadden Sea (SIBES) monitoring program of the NIOZ, benthos and sediment are sampled throughout the whole Dutch Wadden Sea (Aarts et al. 2010). The primary goal of SIBES is to measure the abundance, composition and change of macrozoobenthos in response to natural gas extraction. Sediment samples are also collected in this program. The program has been running since 2008. The sampling stations are located on a rectangular grid with a distance of 500m between the stations (*Figure 3*). In earlier years, similar sampling

[1] http://gis.eucc-d.de/waddengis_mapfish/index.htm
[2] http://www.rijkswaterstaat.nl/water/scheepvaartberichten_waterdata/historische_waterdata/waterbase/index.aspx
Via the OpenDAP server in the Open Earth Tools (OET) developed at Deltares these data may be obtained effeciently.
[3] www.waddenzee.nl/Sedimentatlas.729.0.html The Sediment atlas comes with a viewer.
The data may also be accessed directly via dbf files and by means of a shapefile which contains information on the locations of the sampling points.

was performed by the NIOZ, but at a smaller scale (focus on Western Wadden Sea) and coarser resolution (Kraan et al. 2007). In previous years sediment samples were obtained on a 1 km grid.

5.2.1.3 Hydrology

Water levels: In the governmental programme LMW, water levels are measured continuously at several locations in the Dutch Wadden Sea. LMW provides constant and up-to-date information about water levels on the Dutch coast and further inland[4]. In Germany, the Federal States are responsible for collecting hydrologically important data, e.g. water levels and wave heights. To this end they maintain a network of measuring units. Not all tidal basins are covered. COSYNA is a noteworthy German model- and database project that aims to deliver real-time data on currents, waves, salinity, temperature, chlorophyll and oxygen for the North Sea.

Tidal prism, tidal amplitude, residence/turnover times, and outer deltas: Estimates of these relatively constant parameters for the Dutch tidal basins have been found in the literature. Tidal prisms and inward flood sand transport data are presented by Louters and Gerritsen (1994), turnover times by Ridderinkhof (1988) and channel circumferences by Cleveringa and Oost (1999). AWI-Sylt maintains data on the hydrography of the Sylt-Rømø Bight.

5.2.1.4 Weather and atmosphere

The KNMI, DWD and DMI collect basic weather data (temperature, irradiation, cloud and visibility, air pressure, wind force and direction and precipitation) at high temporal frequency. The stations in the Dutch Wadden Sea area are located at: De Kooy, Vlieland, Hoorn (Terschelling), Leeuwarden, Lauwersoog. Excerpts from the KNMI[5] and DWD data are available to the public via websites. No declarations on Danish weather data can be made. Precipitation is measured at 325 stations by the KNMI. (See the website for an overview of the locations[6].)

For the Dutch part of the Wadden Sea region, atmospheric parameters are determined at the Cesar Observatory. The measurements include wind, cloud, aerosols, greenhouse gases, surface-level and elevated fluxes, hydrology and infrasound. In addition, higher order products derived from the observational data are available via a data portal[7].

[4] The stations in and near the Dutch Wadden Sea are located at Den Helder, Den Oever buiten, Oude Schild, Texel noordzee, Kornwerderzand buiten, Harlingen, Vlieland, West-Terschelling, Terschelling Noordzee, Nes, Holwerd, Huibertgat, Lauwersoog, Wierumergronden Schiermonnikoog, Nieuwe statenzijl, Eemshaven, Delfzijl, Nieuwe Statenzijl. For some locations, data are available since the 19th century. All the above mentioned stations are currently operational.
[5] http://www.knmi.nl/klimatologie/daggegevens/download.html
[6] http://www.knmi.nl/klimatologie/monv/reeksen/
[7] http://www.cesar-database.nl/

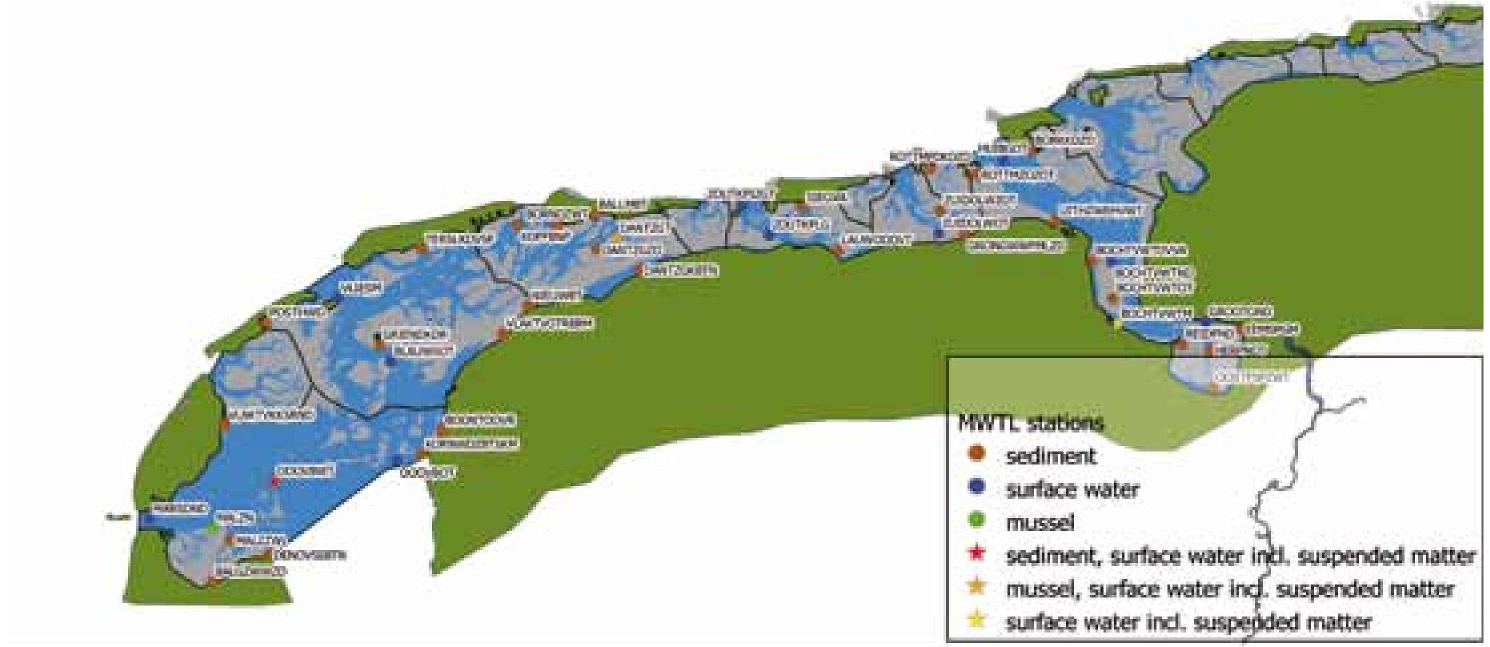


Figure 4: Sample locations in the MWTL program.

5.2.2 PHYSICAL AND CHEMICAL PARAMETERS

5.2.2.1 Water temperature, salinity, suspended matter, nutrients, turbidity and toxins

In the Dutch MWTL programme various physical and chemical (see following sections) parameters from the water column are measured. The most important parameters are: temperature, salinity, suspended matter concentration, nutrient concentrations, turbidity (with Secchi disc) and many different kinds of toxins. All of the parameters are collected at multiple stations in the Dutch Wadden Sea (*Figure 4*) for which long time series are available. It is not feasible to present for each parameter the period for which data are available. It is noted, however, that there are many stations that are currently not operational but for which historical data is available in the Donar database.

5.2.2.2 Waves and currents

The HMCN continuously measures wave heights and frequencies by means of buoys at some locations at the North Sea near tidal inlets of the Wadden Sea[8]. Data is made available to authorised institutions. Data are used to calibrate the SWAN wave model which is in development for the Wadden Sea to determine the safety levels of sea defences. No areal (fine-scale, contiguous grid) datasets were found for the Dutch Wadden Sea. The BSH operates five buoys in the German Bight, but none in the Wadden Sea Region. No assertions can be made about waves in the Danish Wadden Sea region.

Currents are calculated by means of model simulations for several locations. Currents, however, depend on local bathymetry and can not be reliably extrapolated.

5.2.3 BIOLOGICAL PARAMETERS

5.2.3.1 Primary production: pelagic and benthic microphytes

Pelagic primary production depends among other factors on the clarity of the water column and nutrient concentration. Locations where concentrations of nutrients are measured in the MWTL program are presented in Figure 5.3. Clarity of the water column depends on the amount of silt in the water and to a lesser extent on the density of phytoplankton (Essink 1999). Brinkman (2008) presents an overview of nutrient and chlorophyll concentrations for the Western and the Eastern Dutch Wadden Sea between 1980 and 2005. Salt marshes and fresh water represent sources of nutrients and organic material. There is a lack of consistent monitoring data of basic parameters such as nutrient and chlorophyll concentrations and estimates of primary production (Herman et al. 2009). The ZKO programme addresses some of these data gaps but the new measurements are currently not planned for inclusion in standard monitoring programmes.

Phytoplankton concentrations in the Dutch Wadden Sea are measured in the MWTL programme. Additional measurements are carried out by the NIOZ. The Marsdiep is well represented, while data collection at other tidal basins, including the tidal basins in the German and Danish parts of the Wadden Sea Region (except tidal Basins 1, 22 and 28), are scarce or absent. AWI-Sylt maintains a high quality phytoplankton time-series.

Microphytobenthos concentration and production is not part of any standard monitoring programme. However, in the ZKO programme IN PLACE, the NIOZ performs measurements at several locations in the Marsdiep tidal basin by means of automated sensors.

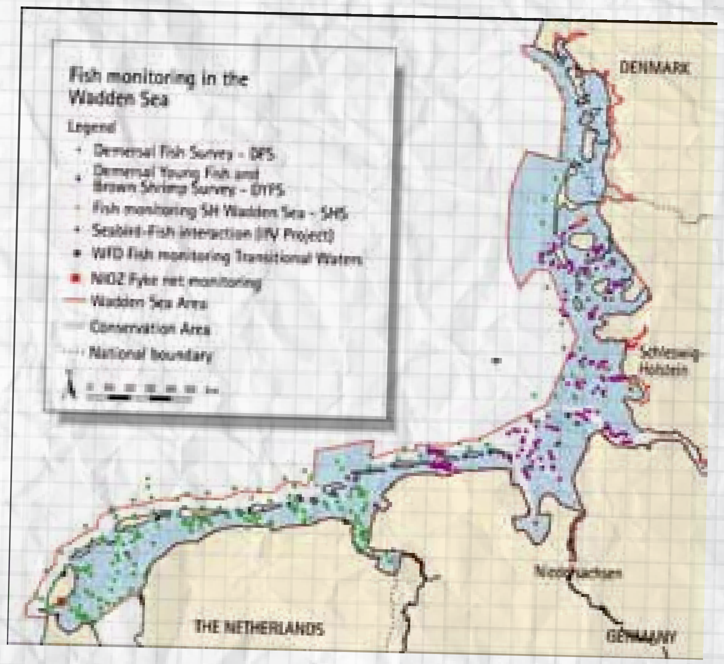


Figure 5: Sample locations of different fish monitoring programs (from Jager et al. 2009).

5.2.3.2 Macrozoobenthos and zooplankton

Secondary production in the Wadden Sea is mainly in the form of zooplankton and macrozoobenthos. There are several macrozoobenthos monitoring programmes in the Dutch Wadden Sea that vary in temporal and spatial scale.

Long term: There are several long-term datasets in the Dutch Wadden Sea: 1. Balgzand near Den Helder (since 1968); 2. Groninger wad near Noordpolderzijl (since 1969); 3. Heringsplaat in the Dollard (since 1977) and 4. Piet Scheveplaat, south of Ameland (since 1978). The series at Balgzand was initiated by the NIOZ and the other three series were initiated by RWS. In 1989 RWS initiated a similar series on three transects in the subtidal of the western Dutch Wadden Sea. Since 1991 all sampling is performed by the NIOZ except for the series on the Groninger wad which is performed by Koeman and Bijkerk BV. In the MWTL program, all macrozoobenthos data are freely available.

Large spatial scale: In 2008, the NIOZ (funding: NAM and NWO Sea and Coastal Research (ZKO)), initiated SIBES (Synoptic Intertidal Benthic Sampling) a benthic sampling program throughout the whole intertidal zone of the Dutch Wadden Sea (Aarts et al. 2010). NIOZ has performed similar sampling in several years before the SIBES program started (Kraan et al. 2007). The spatial scale was smaller during those previous years.

IMARES performs shellfish surveys in the Dutch Wadden Sea once a year. Samples are mainly collected along transects throughout the entire Dutch Wadden Sea. When high densities of cockles are expected, the local sampling intensity may be increased.

Zooplankton: AWI-Sylt maintains the only time series on zooplankton in the Wadden Sea. Zooplankton is not included in any monitoring program in The Netherlands. Recently, in the ZKO program some work has been initiated in two tidal basins in the western Dutch Wadden Sea.

5.2.3.3 Fish

There are separate programmes to monitor demersal and pelagic fish. The IMARES demersal fish survey covers most of the tidal basins in the Dutch Wadden Sea and the adjoining North Sea coastal zone, which enables comparison between areas (Jager et al. 2009). The main purpose of the Demersal Fish Survey (DFS) is to estimate population trends of both commercial and non-commercial species at various locations. The DFS is carried out by IMARES (before RIVO) since 1969. The survey also provides annual (September - October) estimates of shrimp and of non-commercial fish stocks. More detailed information may be obtained from the WUR website[9]. In addition the NIOZ has a juvenile demersal fish programme on the Balgzand.

The Demersal Young Fish and Brown Shrimp Survey (DYFS) (carried out by the von-Thünen-Institut) monitors populations in the German Wadden Sea. Recently there have been efforts in TMAP to coordinate data collection internationally. Jager et al. (2009) present trends in the density of different species of fish in different areas of The Netherlands and Germany based on DFS and DYFS. No information about surveys in Denmark could be obtained.

NIOZ and IMARES jointly run a pelagic fish monitoring programme which, by means of gill-netting, estimates the sizes of pelagic fish populations. Pelagic monitoring with stow nets started only recently (1991, 2001, 2006) and the spatial coverage of pelagic fish monitoring in the Wadden Sea is considered insufficient. The NIOZ maintains a long term (since the 1960s) data set on fish caught in fyke nets.

5.2.3.4 Birds

Numbers of birds are regularly counted at all main high tide roosts, mainly by volunteers. The data collection is organized by a variety of organizations which are represented in the Joint Monitoring Group of Migratory Birds in the Wadden Sea (JMMB). This group includes SOVON in The Netherlands, the Staatliche Vogelschutzwarte at the Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten und Naturschutz (NLWKN) and the Nationalparkverwaltung Niedersächsisches Wattenmeer in Niedersachsen, the Schutzstation Wattenmeer" and the Landesbetrieb für den Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein (LKN) in Schleswig-Holstein and the National Environmental Research Institute (NERI) in Denmark. The group operates within the framework of the Trilateral Monitoring and Assessment Program (TMAP) (Laursen et al. 2010).

The JMBB program has been very successful in organizing datasets and these have enabled comparison of numbers and trends of many species of birds throughout the Wadden Sea (Laursen et al. 2010). From the perspective of the birds, the Wadden Sea was divided into 29 'ecological units' of tidal flats and adjacent roosting sites (*Figure 6*).

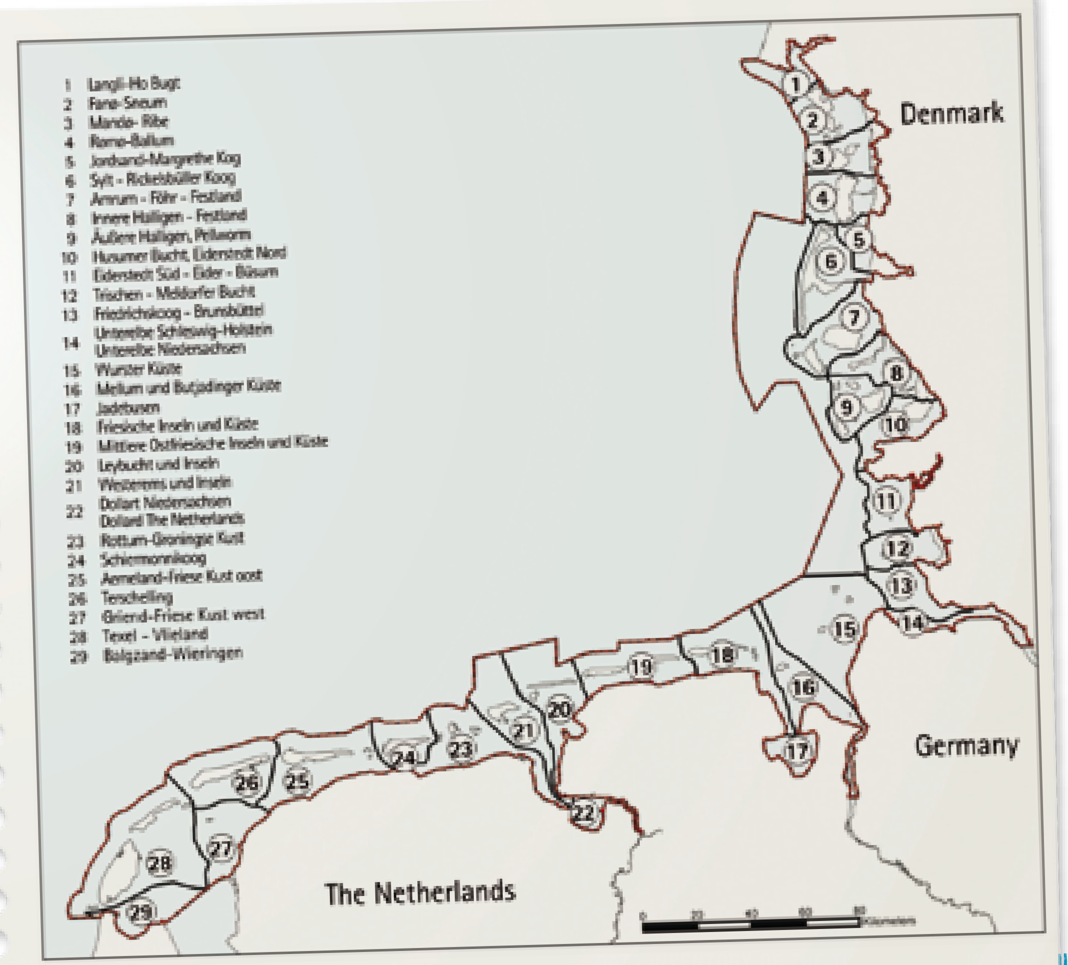


Figure 6: Sub-areas covering ecological units of tidal flats and roosting sites for migratory shorebirds (from Laursen et al. 2010).

[9] http://orca.wur.nl/surveys/survey_report_DFS_2009/


PHOTO: ROOS KENTIE

Sea ducks (Melanitta nigra, Melanitta fusca) do not roost at high tide refuges. Their numbers in the Dutch Wadden Sea and North Sea are estimated by means of airplane counts in January. Raw data are available from RWS. Additional winter counts have been performed by IMARES.

The size of a population and its dynamics depend on its demographic parameters. In general demographic parameters are poorly monitored in shorebirds that breed in the Wadden Sea or in the Arctic areas. Particularly, birth and death rates are not measured structurally (except for the species mentioned above). Demographic parameters, however, are estimated for Oystercatcher (Haematopus ostralegus), Red knot (Calidris canutus), Herring gull (Larus argentatus) and Spoonbills (Platalea leucorodia) by means of colour ringing programs. Aggregated data are and will become available via scientific publications.

5.2.4 HABITATS

TMAP and the European Union provide definitions to describe terrestrial and aquatic habitats. Reliable and precise data are available about the presence, sizes and vegetation properties of the salt marshes and intertidal habitats in the Wadden Sea region. Generally, both intertidal and subtidal standing stocks of mussel beds (Mytilus edulis) and oysters (Crassostrea gigas) are well monitored. Sea grasses (Zostera marina and Z. noltii) are closely monitored and mapped by RWS in the Dutch Wadden Sea. In Lower Saxony detailed surveys were conducted in 2000-2002 and in 2008. Seagrass stocks are described in detail in the Wadden Sea QSRs (CWSS 2005, 2009). TMAP provides GIS maps of the tidal area, salt marshes, dunes, mussel beds and seagrass beds for the whole Wadden Sea area. Furthermore, new technical and scientific approaches strive to deliver resilient habitat data in high spatial resolution, covering the whole area (e.g. OFEV, WIMO).

5.2.5 HUMAN USE

Generally, it is difficult to obtain site-specific information about human use. Data are collected by a variety of institutions and not compiled at the level of tidal basins. The Wadden Academy has started a project called WISWAD in which socio-economic information (often in the form of maps) relating to the Wadden Sea region will be collected and organised.

Since 1999 the Schleswig-Holstein Wadden Sea National Park Office has been carrying out a programme called Socio-Economic Monitoring which entails counts of guided walks in the Wadden Sea as well as surveys of inhabitants and guests. Apart from general maps of human uses within the German EEZ offered by the BSH and the Lower Saxony Ministry of the Environment and Climate Protection[10], shared data sources on human uses are limited.

5.2.5.1 Fisheries and shellfish culture

Mussel culture (incl. mussel seed fishery) and shrimp fishery are economically the most import types of fisheries in the Wadden Sea. Other types of fishery (eel, flatfish, mullet) are economically less important.

Total landings of shellfish, shrimp and fish are recorded, but generally not accompanied by spatial or temporal metadata. Total landed amounts (in time-series) are presented in the Wadden Sea QSR (2009) but do not include the fishing sites.

Locations and quantities of mussel (seed) fisheries in The Netherlands are recorded by (formerly) the Ministry of Agriculture and Fisheries (LNV). The locations in The Netherlands at which fishery for mussel seed is allowed are pre-determined; total stock estimates of mussels are carried out by IMARES. There are c. five licenses for mussel culture and seed fishing in Schleswig-Holstein and three or four in Lower Saxony. Maps of culture lots are available as well as seed fishing locations. Seed fishery takes place in the subtidal in Schleswig-Holstein and in the intertidal in Lower Saxony. There are also artificial seed collecting nets in operation. In the Danish part of the conservation area, commercially sized mussels are fished from wild natural beds because mussel culture is not allowed. Mussels and cockles are landed according to quotas set annually for the fishery (Kristensen et al. 2007).

Pacific oysters are monitored on a less accurate level. In The Netherlands there is limited (experimental) fishery of oysters (hand gathering), the impact of which is followed by IMARES. The exact fishing area is not yet known, but the fishermen are equipped with GPS-trackers. In Germany one commercial oyster cultivation farm is operating offshore by List/Sylt, covering 30 hectares.

5.2.5.2 Natural gas extraction

In the Dutch Wadden Sea, gas is extracted at several locations[11]: 1. Zuidwal (between Harlingen and Terschelling); 2. Blija (Frl.); 3. Ameland (Frl.); 3. Moddergat (Frl.); 4. Lauwersoog (Gr.); 5. Vierhuizen (Gr.). In Lower Saxony there is gas extraction in the Leybucht and at the Ems estuary. In the protected areas of Denmark and in Schleswig-Holstein gas extraction is prohibited.

[10] Environmental Report Lower Saxony, 2010
[11] The production has not been found but may most likely be obtained from the NAM.

5.2.5.3 Shell and sand mining

A short overview about policies and practice regarding dredging and extraction of shells and sand is given in the Wadden Sea QSR 2009. Total amounts of shells (max. 90.000 m3 per year) and sand extracted in The Netherlands are published by INTERWAD (data collection by RWS). However, shell extraction is not allowed in tidal basins 1-4, 5-29 and 32, 34, 36, 37 and 39. Sand extraction in the Wadden Sea region is only permitted in relation to the regular maintenance of shipping lanes, except in the national park area of Schleswig-Holstein, where sand extraction for coastal protection purposes is allowed.

5.2.5.4 Dredging and dumping

Dredging and dumping of sediment is generally poorly documented. Ports do record the amounts that are dredged but not where the sediments are dumped. In The Netherlands, RWS may possibly become a source of the needed data. In Germany, the Federal Institute of Hydrology (BfG) is the body responsible for maintaining the waterways. The Koodinationsstelle Baggergut, together with the WSA should hold the amounts dredged and the dumping sites. In general this data is not, so far, accessible. An overview is presented in the Wadden Sea QSR (2009) and the OSPAR QSR 2010. The amounts of dredged and dumped material in the Wadden Sea region are included, as well as the dumping sites.

5.2.5.5 Recreation

The Wadden Sea QSR (CWSS 2009) contains an overview of tourism and recreation, covering overnight stays, touristic demands and mudflat hiking. The number of passengers on ferries is well known but not easy to obtain (ferry companies generally don't share their information, except TESO (transport to Den Helder, published yearly). Municipalities have information on the capacity and use of ports.

[10] Environmental Report Lower Saxony, 2010

[11] The production has not been found but may most likely be obtained from the NAM.

5.3 DATA GAPS AND SOLUTIONS

Table 1 (page 16) shows gaps between demand and availability of data. This section briefly discusses some of the most important gaps.

5.3.1 GENERAL PARAMETERS

Existing bathymetries provide cross-sections (snapshots) of a highly dynamic system. Whether the data are useful to compare tidal basins depends strongly on the underlying question. To find out whether mudflats grow with a rising sea level, regular high quality measurements of depths in the gullies and of mudflats (LIDAR) are required. Research projects like WIMO work on this issue intensively.

Hydrodynamic parameters are important for most purposes. Areal (fine-scale, contiguous grid) estimates of waves and currents are generally lacking because measurements are taken at point locations. There are, however, various programmes that will fill these gaps in the future (e.g. COSYNA).

5.3.2 PHYSICAL PARAMETERS

Most of the physical parameters are measured at various locations throughout the Wadden Sea but areal data are rare. Point measurements are not commonly interpolated to cover the whole region. Atmospheric data is an exception to this rule.

Combinations of statistical, mechanistic modelling and remote sensing provide a way to extend the point measurements to obtain areal estimates. For various cases it has to be realized that central tendencies (means, medians) may not be relevant to describe the dynamics in the Wadden Sea. Comparison of multiple long-term series from different types of tidal basins may provide insight in how long term dynamics depend on properties of the tidal basins.

5.3.3 CHEMICAL PARAMETERS

Oxygen, chlorophyll and nutrient concentrations of the water column are important indicators of various biological processes. They are currently measured at distinct point locations in many of the tidal basins. The temporal frequency in the MWTL program is once a month which is too low for many important ecological questions. Salt marshes, rivers and creeks are some of the important sources of nutrients and organic material and estimates of fluxes cannot be made due to a lack of areal data.

The demand for areal data of these parameters is high. Despite the shortcomings in current data, a 'simple' trophic categorisation of the tidal basins based on these data would be welcomed by all concerned.

High quality data on silt-content and turbidity of the water are lacking. Measured values are strongly dependent on local hydrodynamics. Currently, these variables are measured at several (few) fixed stations at different moments during the tidal cycle. Therefore these data are not suitable to detect long-term trends in turbidity and silt-content.

5.3.4 BIOLOGICAL PARAMETERS

When it comes to biotic presence and abundance data, 'more is better'. However, some gaps are considered more severe than others.

1. Zooplankton are important secondary consumers. However, at present no data on zooplankton (species composition and densities) are collected such that they can be used for comparative research of tidal basins.
2. Phytoplankton and microphytobenthos are difficult to measure on large spatio-temporal scales which makes it difficult to compare tidal basins. Remote sensing in combination with in situ measurements are available and in development to estimate chlorophyll content or biomass (and species composition) to obtain estimates at larger scales (e.g. INPLACE).
3. Dolphins (particularly Harbour purpoise, Phocoena phocoena) are too rarely observed so that systematic monitoring and reliable analyses are currently not possible.

5.3.5 HUMAN USE

The most obvious data gaps concerned various aspects of human use.

- Total catches of shrimp are recorded but not how much was caught where. Furthermore, data are hard to obtain. In general the data situation is better for mussels.
- Dredging of channels and related changes in erosion/sedimentation processes are not recorded well, so that their effects on the system are impossible to investigate.

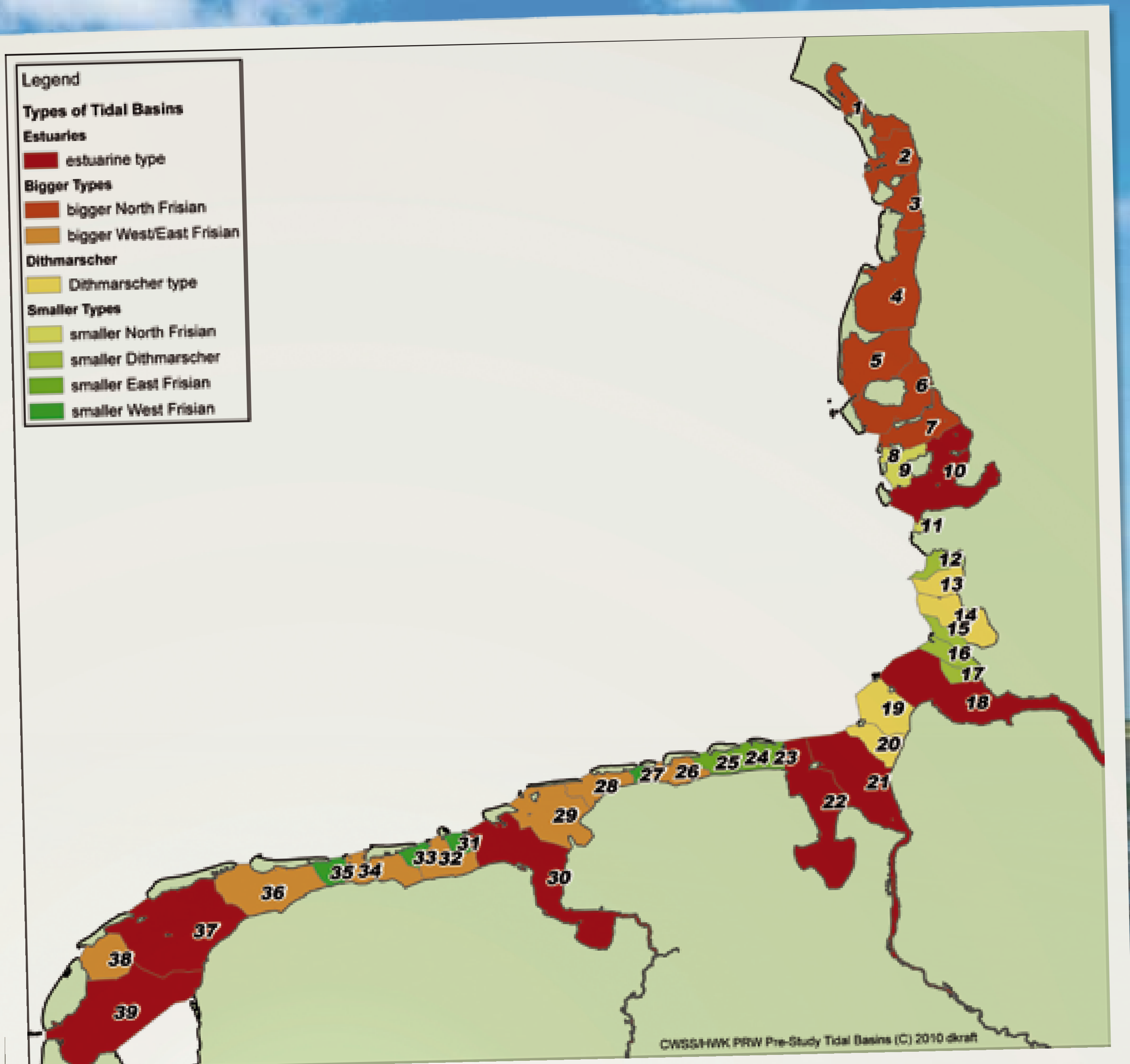


Figure 7: Typification of the tidal basins of the Wadden Sea, according to size, width of inlet and general character.

6 TYPOLOGY OF TIDAL BASINS

The previous chapter illustrates that some of the tidal basins are intensively studied and monitored while other basins receive considerably less attention. Some interviewees stressed that it would be useful to classify tidal basins according to their basic characteristics. Knowing the basic characteristics of the tidal basins might enable identification of a number of typical tidal basins which may be exemplars for other, less monitored, tidal basins.

6.1 MORPHOLOGY, BARRIER ISLANDS AND INLET WIDTH

Some basic morphological characteristics are size (volume or area (see Ridderinkhof 1988), presence of barrier islands, amount of intertidal mudflat, width of inlets, presence of rivers and tidal amplitude. Tidal basin 10 – 22 (*Figure 7*) for example lack barrier islands and may be expected to function differently than more sheltered basins.

Figure 7 presents an example of how tidal basins may be classified on the basis of their location, size and width of inlet. Four main groups are distinguished in *Figure 7:* 1. estuaries (large and riverine input, relatively small proportion of intertidal mudflats), 2. large tidal basins (no riverine input), 3. medium tidal basins (high tidal range and open inlets), 4. small tidal basins.

Various other kinds of typification are possible. The next section provides examples of other characteristics which may be useful to describe and classify tidal basins.

6.2 MUDFLAT AREA

There is a general geological relationship between the percentage of intertidal area and the tidal range of a tidal basin (Hayes 1975). Particularly, the larger the tidal amplitude the larger is the relative surface area of intertidal mudflats. Wolff (1982) presents this relationship for the Wadden Sea.

As a simple but clear example, a map that presents the surface of intertidal mudflat in relation to its total size was constructed. The map shows that the small tidal basins contain large proportions of mudflat (in relation to total size). This type of information is important when considering primary production which may have benthic and pelagic origin. The relative contribution of benthic primary production would be relatively high in small basins, ceteris paribus.

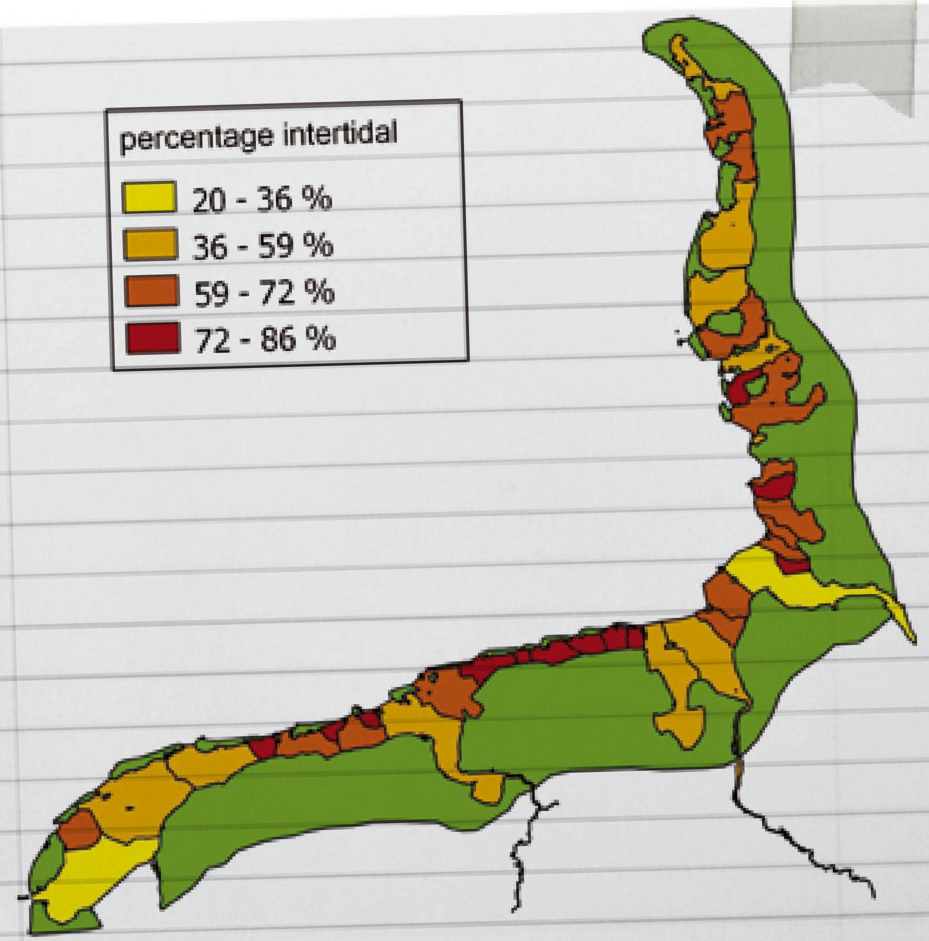


Figure 8: Tidal basins in the Wadden Sea. The colour represents the percentage area that is intertidal mudflat. Vector files (shapefiles) describing the locations and extents of mudflats were obtained from CWSS.

6.3 AVERAGE DEPTH

Based on the bathymetry of the Wadden Sea, which was obtained from EMODnet, the average depths of tidal basins were calculated (*Figure 9*). The depths are measured in relation to the lowest astronomical tide (LAT). Depths are relevant from geomorphological and ecological perspectives.
Figure 9 shows that the Danish tidal basins are relatively shallow. The deepest tidal basins are those with substantial riverine input.

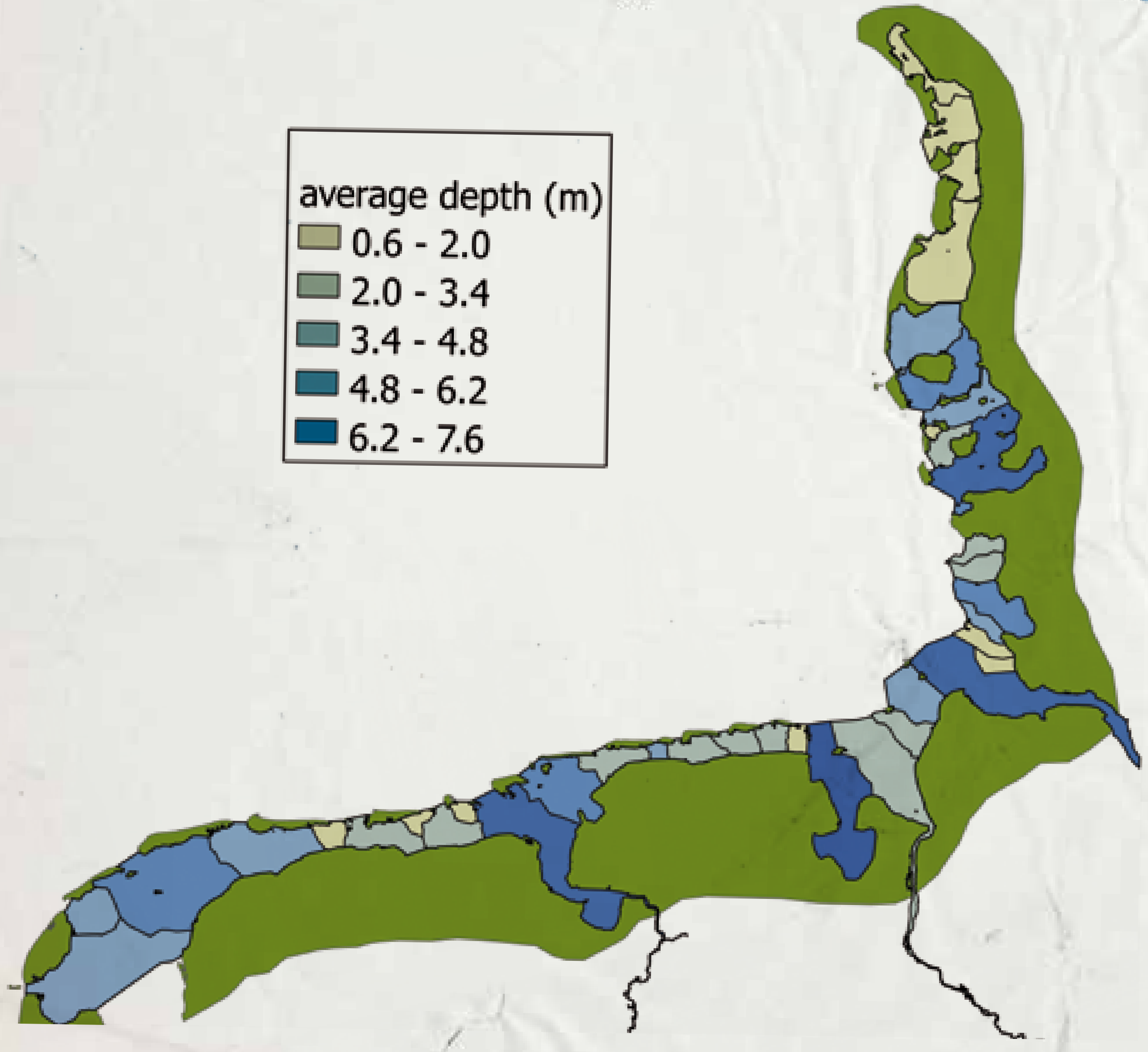


Figure 9: Average depths of the tidal basins in the Wadden Sea; data obtained from EMODnet (see text).

7 CONCLUSION AND RECOMMENDATIONS

The 'tidal basin approach' was generally considered promising and feasible and the inventory was considered a useful undertaking. There is large demand for GIS maps that describe basic characteristics of the Wadden Sea with data summaries (e.g. population sizes and trends). A lot of information is (digitally) available and is suitable for a comparative approach .

The forms of data and information encountered originated from a large variety of monitoring programs and projects. Many of the datasets were collected using a variety of spatial and temporal scales. The investment needed to harmonize data from various sources to enable meaningful comparisons is large. This might explain why comparisons at the level of tidal basins are rare. In recent years, however, a trend towards more integrated monitoring and trilateral collaboration is developing. Another difficulty relates to the availability of data. Collecting data from online sources can be a frustrating task. In particular, data will often have to be collected bit by bit, data-platforms may be off-line, metadata is often lacking and restrictive legal rights have been encountered. The workload related to obtaining and harmonizing data should not be underestimated.

Some harmonization efforts and data provide information that is particularly useful. For instance, the JMBB program for migratory birds has been extremely successful in comparing trends of many species of birds throughout the Wadden Sea (Laursen et al. 2010). It has turned out to be difficult to underpin the causes of change in populations in relation to natural variation and management. Better investigation into the causes of change would be possible if more information at the level of tidal basins was available.

Another good example of data harmonization concerns mussel bed data. To enable comparisons of mussel bed trends tri-laterally, a common definition of a mussel bed was developed (CWSS 2002). This definition enables comparison between various aspects of population dynamics in the three countries. The organizations that are responsible for the collection and management of mussel bed distributions are highly cooperative and willing to share data for the purpose of comparative research. Since nearly all tidal basins are monitored yearly, a comparison at the level of tidal basins is expected to be promising.

A striking gap on the other hand is the availability of data on human use. Because data are generally collected by a wide variety of institutions (e.g. governmental departments, fishery organizations, research institutes) they are difficult both to obtain to harmonize for comparative analysis.

One of the main outcomes of the expert interviews was that existing data, integrated modelling approaches, and remote-sensing results should be merged in an intelligent way. The aim of better understanding cause and effect relationships between various elements is not simply a data-related challenge: in highly dynamic systems like tidal basins, abiotic features like weather conditions (including extreme events), currents, and tides affect ecological developments. In addition to these physical parameters, chemical variables like salinity, suspended matter and nutrients have to be taken into account.

TOWARDS A TIDAL BASIN ATLAS

The largest investment to construct a tidal basin is related to the collection and quality control of data for the purpose of tidal-basin-level comparisons. The most efficient and safest way is by involving experts in the process. It turned out that many of the experts in particular fields have much knowledge about many of the programs and data-availability and the possibilities and limitations for comparative research.

MORPHOLOGICAL TYPOLOGY AND HABITATS

Development of basic maps which provide a description of the main morphological characteristics of the 39 tidal basins would be sensible. In this report, as a first step, a base-map describing the borders of tidal-basins was constructed. The map was used to illustrate the simple relationship between size and mudflat area and the average depth of tidal basins. In a similar way, other (summaries of) variables may be related to the tidal basins.

PRIORITIZATION OF PARAMETERS

Table 1 provides insight into the feasibility (effort, quality of data) of constructing data products (means, trends, maps) to be included in the atlas. From the perspective of availability of data some of the most promising parameters are related to geomorphology and water levels, biota (e.g. mussel beds and birds).

It was noted that areal data of chemical (chlorophyll and oxygen) and physical (temperature) variables are hardly available and that they are limited to point measurements. In this respect an inventory of remotely sensed data would be important because this type of data may be suitable for inclusion in the atlas.

METHODOLOGICAL DEVELOPMENTS

Geographical Information Systems and computer models can project and extrapolate point measurements into wider spatial and temporal scales, including hind casting and forecasts. Experts have frequently emphasised the importance of integrating data, models (including GIS) and remote sensing. These types of systems (e.g. COSYNA) will provide (real-time) data that are highly relevant for tidal-basin level comparisons. These developments are best developed for hydrological parameters such as currents and waves, which are the main drivers of the morphodynamic development.

Various chemical parameters can be estimated by means of remote-sensing at the surface and gauges may be used to obtain measurements at larger depths. Investigating the value of oxygen as a proxy for nutrients – or, rather, for eutrophication – in combination with sensors and models is an overarching theme in WIMO.

Most projects, especially the recent ones, work on large scales using remote sensing and modelling approaches (e.g. MARCOAST, COASTCOLOUR). Because these types of projects are relatively new, data are typically not available to the public.

PLATFORM TO DISTRIBUTE INFORMATION AND MAPS

To share the maps and information among users, a sophisticated interactive platform is needed. It would include an inventory of existing data, facts and statistics for further reference and analysis as well as information on management issues (plans) and expected developments (scenarios). The platform should provide links to metadata about the owner or provider of the data or any information offering a direct link to the sources (O'Dea et al. 2007). The platform could provide a way to discuss the existence and quality of data by users.

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9 APPENDICES

9.1 DEMARCATION OF TIDAL BASINS (D. KRAFT)

Tidal basins are claimed to be an important natural landscape unit. A (very) simplified approach to distinguish the basins is presented in this short report. The aim of this approach is to get a basis for a simple, primarily topological comparison of the tidal basins of the Dutch, German and Danish Wadden Sea.

The data basis consists of two GIS-shapes provided by the CWSS (Common Wadden Sea Secretariat) as a result of the TMAP (Trilateral Monitoring and Assessment Program), containing the intertidal area and the coastline. These shapes are the result of a remote sensing approach, deducing the lines of high tide and low tide from air photos and laser scans respectively.

Following a general definition, a tidal basin is the catchment area of a sea inlet – a small passage between the barrier islands – in the Wadden Sea, bordered by the islands and the mainland. Additionally tidal basins consist of an associated system of branched tidal creeks and of the tidal flats that are loaded and drained by these creeks. The individual tidal basins are separated from adjacent basins by tidal divides.

Thus the high tide line (the shortest line between islands) and the tidal divides roughly demarcate the extent of the tidal basins. The first two are included and can easily be constructed from the offered shape-files.

However, instantaneously available maps on the tidal divides are limited to the Dutch and North Frisian Wadden Sea (Spiegel, 1997; Spiegel 1998; Herman et al., 2009). The analogous maps from these references have been digitized and verified with the details afterwards, and agreement between the estimated data and the data in the literature is quite high (cf. Table A1).

Suitable maps on tidal basins of the East Frisian Islands and the Danish Wadden Sea could not be made available, except for data on the total area of some tidal basins (Bartholdy and Peirup, 1994; Ferk, 1995; Louters and Gerritsen, 1994; Jacobsen, 1975, Renger, 1976; Walter, 1972). Subsequently, the basins of the East Frisian and Dutch Wadden Sea were sketched in a GIS, following the silhouette of the intertidal areas. Comparing the results of these sketches with data from literature offers quite sophisticated consistency (cf. Table A1).

The consistency between the values from literature and our own estimates in the GIS are frequently high; two thirds of the tidal basins have been sketched quite well (more than 90% consistency). Drafting the open basins and estuaries of Elbe and Jade is challenging due to the missing islands, as well as outlining small basin. However, it should be obvious that much better alternative methods of demarcating tidal basins exist. High-resolution bathymetries and hydrological models should be used, if high accuracy is necessary. Nevertheless, the approach we used should be sufficient as the basis of a general overview on the morphology of the tidal basins.

Tidal Basin, total area (km²)	According referenc	Own estimate	Consistency (* >90%)	References
1. Graadyb	125,00	133,58	*94%	Bartholdy & Pejrup (1994)
2. Knude Dyb	165,00	181,73	*91%	Jacobsen (1975)
3. Jyvre Dyb	130,00	116,92	*90%	Jacobsen (1975)
4. Lister Tief	402,30	389,73	*97%	Spiegel (1997)
5. Hörnum Tief	290,20	283,63	*98%	Spiegel (1997)
6. Norderaue	245,20	236,03	*96%	Spiegel (1997)
7. Süderaue	169,30	166,00	*98%	Spiegel (1997)
8. Hoogeloch	17,80	20,87	85%	Spiegel (1997)
9. Rummeloch West	83,70	80,01	*96%	Spiegel (1997)
10. Norderhever-Heverstrom	441,80	407,85	*92%	Spiegel (1997)
11. Tümlauer Bucht	6,30	13,58	46%	Spiegel (1997)
12. Eidermündung	49,90	70,38	71%	Spiegel (1997)
13. Wesselburener Loch	66,10	92,84	71%	Spiegel (1997)
14. Piep/Meldorfer Bucht	203,00	193,86	*95%	Spiegel (1997)
15. Flackstrom	45,40	59,16	77%	Spiegel (1997)
16. Neufahrwasser	37,30	73,96	50%	Spiegel (1997)
17. Schatzkammer	17,10	50,52	34%	Spiegel (1997)
18. Elbe		567,40		
19. Westertill/Nordertill	136,60	185,99	73%	Ferk (1995)
20. Robinbalje	99,90	114,95	87%	Ferk (1995)
21. Weser		491,28		
22. Jade/Jadebusen	167,16	462,68	36%	Walter (1972)
23. Blaue Balje	39,90	42,80	*93%	Ferk (1995)
24. Harle	64,90	66,35	*98%	Ferk (1995)
25. Otzumer Balje	74,30	74,31	*100%	Ferk (1995)
26. Accumer Ee	92,00	96,34	*95%	Ferk (1995)
27. Wichter Ee	22,90	25,07	*91%	Ferk (1995)
28. Norderneyer Seegat	101,60	112,48	*90%	Ferk (1995)
29. Osterems		300,11		
30. Eems-Dollard	520,00	570,34	*91%	Louters & Gerritsen (1994)
31. Schild	31,00	35,86	86%	Herman et al. (2009)
32. Lauwers	143,00	141,97	*99%	Herman et al. (2009)
33. Eilander Balg	40,00	36,83	*92%	Herman et al. (2009)
34. Zoutkamperlaag	143,00	160,11	89%	Herman et al. (2009)
35. Pinkegat	58,00	61,56	*94%	Herman et al. (2009)
36. Amelander Zeegat	295,00	332,92	89%	Herman et al. (2009)
37. Vlie	674,00	690,00	*98%	Herman et al. (2009)
38. Eierlandse Gat	164,00	158,27	*97%	Herman et al. (2009)
39. Marsdiep	675,00	678,22	*100%	Herman et al. (2009)

Table A1: Comparison of the estimated area sizes with values from the literature.

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9.2 LIST OF ABBREVIATIONS

AWI	The Alfred Wegener Institute for Polar and Marine Research
BfG	Federal Hydrology Institute
BLMP	German Marine Monitoring Programme
BSH	Bundesamt für Seeschifffahrt und Hydrographie
Cesar	Cabauw experimental site for atmospheric research
CLC	Corine Land Cover
COASTCOLOUR	Developing, demonstrating, validating and intercomparing different algorithms over a global range of coastal water types
COASTDAT	Compilation of coastal analyses (i.e. hindcasts and reconstructions) and scenarios for the future obtained from numerical models
COSYNA	Coastal Observing System for Northern and Arctic Seas
DFS	Demersal Fish Survey
DMI	Danmarks Meteorologiske Institut
DMSA	Danish Maritime Safety Administration
DWD	Deutscher Wetterdienst
DYFS	Demersal Young Fish Survey
DYFS	Brown Shrimp Survey by vTI
EEZ	Exclusive Economic Zone
EMODNET	European Marine Observation and Data Network
EU	European Union
EUCC	The Coastal and Marine Union
HMCN	Hydro Meteo Centrum Nordzee
HWK	Hanse-Wissenschafts-Kolleg – Institute for Advanced Study
ICBM	Institute of Chemistry and Biology of the Marine Environment
ICES	International Council for the Exploration of the Sea
IMARES	Dutch Marine Research/Consultancy Institute
INPLACE	Integrated Network for Production and Loss Assessment in the Coastal Environment
INTERWAD	Dutch Web Map Service of the Wadden Sea
KMNI	The Royal Netherlands Meteorological Institute (Koninklijk Nederlands Meteorologisch Instituut)
LMW	Het Landelijk Meetnet Water
LNV	Former Dutch Ministry of agriculture and fisheries
MARCOAST	Marine and Coastal Environmental Information Services
MDI-DE	Marine Data Infrastructure Germany
MSFD	Marine Strategy Framework Directive
MWTL	Monitoring Programme of the Dutch Water Systems
NIOZ	Royal Netherlands Institute for Sea Research
NLWKN	Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency
OSPAR	Oslo-Paris Convention
PRW	Towards a rich Wadden Sea
QSR	Quality Status Report
RIVO	Netherlands Institute for Fisheries Research
RWS	Dutch National Institute for Coastal and Marine Management (Rijkswaterstaat)
SIBES	Synoptic Intertidal Benthic Survey (Dutch benthos monitoring program)
TMAP	Trilateral Monitoring and Assessment Program
vTI	von Thünen Institut
Web GIS	Web Geographical Information System
WIMO	Scientific Monitoring Concepts for the German Bight
WISWAD	Waddeninformatiesysteem (Project hosted by the Waddenacademie)
WSF	Wadden Sea Forum
ZKO	Dutch National Programme Sea and Coastal Research

PROGRAMMA NAAR EEN RIJKE WADDENZEE

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