Project plan:
Trilateral desktop study on the hydromorphology and ecology of ebb-tidal deltas of the Wadden Sea
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Trilaterial desktop study on the hydromorphology and ecology of ebb-tidal deltas of the Wadden Sea

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Summary
This report is the concept Project Plan for a trilateral hydromorphological and ecological inventory desk study on ebb-tidal deltas in the light of climate change.

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Project plan: Trilateral desktop study on the hydromorphology and ecology of ebb-tidal deltas of the Wadden Sea
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1 Introduction

The hydro- and morphodynamic development of the Wadden Sea forms the foundation for the ecological, cultural and economic development of the area. A central notion is that the trilateral Wadden Sea consists of a number of joined sediment sharing inlet systems. Ebb-tidal deltas constitute an integral element of Wadden Sea tidal inlet systems. Situated remotely along the seaward margin of the Wadden Sea ecosystem, they haven’t received much attention yet in the trilateral cooperation. Furthermore little is known about their possible development to climate change, as ebb-tidal deltas develop over a long stretch if time. Over the last years it has become apparent that the deltas are of high importance, especially with respect to the natural resilience of the Wadden Sea (eco)system to climate change and with regard to the connectivity between the North Sea and the Wadden Sea backbarrier basins. Huge amounts of sand are available in the ebb-tidal deltas. This sediment may function as a natural source of sand for the barrier islands and tidal basins, which is needed to keep pace with sea-level rise. Furthermore, the ebb-tidal deltas provide shelter to the islands and backbarrier area, thus providing the low-energetic conditions for sediment to deposit. Also, due to a wide variety in depths and energy distribution (waves, currents) over the various elements of ebb-tidal deltas, a wide range of habitats is formed, hosting a diversity of biota. Erosion of several ebb-tidal deltas and relatively rapid changes in orientation and height of ebb-tidal deltas have been observed in the trilateral Wadden Sea. These changes are reason for concern, as they might lead to changes in shelter for, or sediment supply to, the downdrift barrier island coasts and the backbarrier area of the inlet system in question. Thus it was decided to run a project to make a trilateral inventory study on data and on the available hydro-morphological and ecological knowledge of the Wadden Sea tidal deltas.

The Trilateral Wadden Sea Cooperation has identified a Wadden Sea Cooperation Area as the geographical basis of their Cooperation. The Wadden Sea Area includes an offshore zone 3 nautical miles from the baseline as fixed nationally or where the Nature Conservation Area exceeds the 3 nautical mile, the offshore boundaries of the Nature Conservation Area (Figure 1). As from 14 March 2011, the Netherlands has redefined the delineation of the Natura 2000-area North Sea Coastal Zone to be based on the NAP -20 m depth contour, which is slightly deviating from the 3 NM boundary shown in Figure 1.

Ebb-tidal deltas are addressed in the Wadden Sea Plan (2010) in Chapter 7 “Offshore Area”. Trilateral targets have been set for the Offshore Area of which targets 7.1 and 7.2 are most relevant to the objectives of this study:

7.1 Triangular policies will be based on an integrated approach to coastal flood defence and protection and nature protection on the mainland coast, the islands and the offshore zone.
7.2 In view of accelerating sea level rise, increased attention will be given to the role of the offshore zone in the total Wadden Sea sand balance.

In this respect sand will only be extracted from outside the Wadden Sea Area. Exemptions for local coastal flood defence and protection measures may be granted, provided it is the Best Environmental Practice for coastal protection (e.g. taking the sand from below the wave base).

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1 An ebb-tidal delta is the bulge of sand formed at the seaward mouth of tidal inlets as a result of interaction between tidal currents and waves (USACE 2003).
Scattered Information

Information about geomorphology and ecology of a number of Wadden Sea ebb-tidal deltas lies scattered in publications and data archives. A trilateral assessment is not yet available. Relevant data need to be gathered in one comprehensive overview. Furthermore literature has to be gathered on the functioning of the various ebb-tidal deltas of the Wadden Sea both from scientific and (optional; see chapter 5) grey literature (i.e. management reports and studies etc.).

Project goal/aim

The aims of the project are:

- to provide an overview of the current hydromorphological and ecological knowledge and information on the Wadden Sea ebb-tidal deltas.
- to demonstrate the significance and, from available data, the functioning of the trilateral Wadden Sea ebb-tidal deltas, amongst others for the long-term stability of the trilateral Wadden Sea in times of climate change.
This project proposal describes how to produce the overview itself, which will come in the form of a **brochure**, and two separate underlying **overviews (preparatory compilations; not reports)**: one on hydromorphological significance and one on the ecological significance. The aims of the brochure and overviews are:

- to provide information on the Wadden Sea ebb-tidal deltas and
- to provide an overview of the current knowledge on hydromorphology and ecology of ebb-tidal deltas.

The brochure is intended for decision makers and non-scientists. The overviews compile the investigations and studies toward a more (popular-)science format and provide the knowledge basis for the brochure. For details: see Appendices A,B,C.
2 General: Ebb-tidal deltas as part of tidal inlet systems

The tidal inlet systems of the Wadden Sea each consist of a back-barrier tidal basin (with tidal channels and flats), an ebb-tidal delta and barrier islands at either side of the inlet. All elements of the system are coupled and are assumed to be in, or evolving towards, a dynamic quasi-equilibrium with the hydrodynamic conditions (Dean, 1988; Eysink, 1991; Eysink & Biegel, 1992; CPSL, 2001, 2005, 2010). Hydromorphological changes in any part of a tidal-inlet system will primarily be compensated by sediment transport (mainly sand) to, or from, the other parts of the same system (Oost et al., 2012; Elias et al., 2012; Wang et al., 2012). Net sediment import into the inlet system from the outside (e.g. North Sea) is possible.

Figure 2.1 Ebb tidal delta of Marsdiep (Texel Inlet).

When changes in boundary conditions/drivers are temporary (e.g. perturbations by storm surges) or limited (e.g. subsidence by local mining activities or dredging), the morphodynamic quasi-equilibrium may be restored. If changes are more permanent (e.g. higher rates of sea-level rise or decrease in tidal volumes), a new dynamic quasi-equilibrium may develop. How fast a dynamic quasi-equilibrium can (re-)establish depends on the magnitude of the perturbation, the sediment availability and transport capacity. The limits to the extent to which a basin can keep pace with relative sea-level rise are one of the major focal points in trilateral sea-level rise research (CPSL, 2001, 2005, 2010; Oost et al., 2014).

It is assumed that an increase in sediment transport is primarily mainly possible by an increase in the volumes of tidal- or storm-surge water transport (Hofstede, 2015) and
secondarily if sediment availability increases in some way. Possible sources are ebb-tidal deltas.

Ebb-tidal deltas (Figure 2) play an essential role in the sedimentary development of inlet systems. They are the intermediary in the sediment exchange between the open sea, the barrier islands and the tidal basins. Also, they dissipate the wave energy and provide shelter to parts of the islands and to the adjacent back-barrier area. Driving forces (tide, wind and waves) exert a strong influence on the morphology of the ebb-tidal deltas and change during the year, as well as over decades (Sha & Van den Bergh, 1993; NLWKN, 2010; Herrling & Winter, 2014). Changes in the driving forces will lead to morphological changes (Ridderinkhof, 2016), which may influence development of other parts of the system. For instance the landing point of the ebb-tidal delta shoals on the barrier island may shift. Thus, knowledge about ebb-delta development under different drivers (Herrling & Winter, 2014) is essential to our understanding of the functioning of the sediment sharing inlet system. The interaction between tide, wind and waves is a complex process. This interaction needs to be unravelled for potential manipulation of the various factors for reduction of flood risks and erosion.

The ecosystems of the Wadden Sea and the North Sea are intimately linked via the ebb-tidal deltas. The organic matter turnover in the Wadden Sea is driven by import from the North Sea (Van Beusekom et al. 2012). Shellfish may restock the Wadden Sea from populations from deep water refuges in the North Sea. Mobile animals like fish, shrimps and crabs largely leave the Wadden Sea in autumn to survive the winter in the relatively warm waters of the North Sea, after which they return to the Wadden Sea. And last but no least birds and sea mammals demonstrate both a daily and a seasonal shift in their use of the Wadden Sea and the North Sea (Garthe et al., 2009). Ebb-tidal deltas themselves are specifically rich in fish-eaters such as terns, gulls, cormorants and seals. Smelt or other sand eel species probably are key-stone species for the ecological functioning of ebb-tidal deltas. Besides these, shellfish eating birds such as the common scoter and eider find important food stocks on the edges of the deltas (Leopold & Baptist, 2016).
3 Possible implications of changing ebb-tidal delta configurations

Introduction
Erosion of several ebb-tidal deltas and changes in the orientation and the height of ebb-tidal deltas have been observed in the trilateral Wadden Sea. These changes are reason for concern, as they might lead to changes in shelter or sediment supply to the downdrift barrier island coasts or to the backbarrier area. Additional questions have been raised about the influence on shelter and sediment transport due to increases in height of the shoals in some ebb-tidal deltas and about long-term changes in orientation of ebb-tidal deltas. After a short description of changes in sediment supply and shelter effects, the implications of the morphological changes are discussed below.

Sediment supply
A reduction of the ebb-tidal delta volume might result in a reduction in sediment transport from the ebb-tidal delta to the down-drift island. Also, the back-barrier area might receive less sediment. A situation of a total disappearance of the ebb-tidal delta is not likely: some volume will always be there. Whether the remaining volume can provide sufficient amounts of sediment to the down-drift coast and back-barrier area is not known.

Sheltering effects
Ebb tidal shoals provide a sheltering effect by their wave breaking function offshore of the barrier islands. In general a lowering of the ebb-tidal delta shoals will likely result in less shelter and waves might penetrate deeper into the back-barrier area or larger waves might reach the barrier coasts. A reduction in shelter for waves implies a shift in wave spectrum. Whether such a shift leads to higher net sediment transports will differ per location.

Changing Dimensions
In general, a larger tidal volume results in a larger sediment volume of the ebb-tidal delta (Eysink & Biegel, 1992). However, man-made changes in tidal basin volume can significantly reduce the sediment volumes and orientation of the deltas as is shown for several Dutch inlet systems (Sha, 1990a&b; Oost, 1995; Elias, 2006; Elias et al., 2012; Ridderinkhof et al., 2016). Closure works of the embayments of the Zuiderzee and Lauwerszee enhanced sediment demand in the back-barrier area which led to reductions of the sediment volume of several of the Dutch ebb-tidal deltas during the past century. Such reductions may also have consequences for the barrier islands. Indeed, a 1 km landward retreat of the island coast of West-Vlieland was observed in the 16-17th century after landward retreat of the ebb-delta (Abogado Rios, 2009).
In contrast to the Dutch ebb-tidal deltas, Denmark at the moment has a positive sediment budget, resulting from onshore transport from the North Sea and substantial long-shore transport from the Jutland peninsula (Nielsen & Nielsen, 2006; Madsen et al., 2010). Ebb-tidal deltas are currently stable in volume or even growing. The only exception is the ebb-tidal delta off the Grådyb Inlet which is dredged. The question is what the long-term effects will be of the dredging at this location.
It is thought that loss of sand of the ebb-tidal deltas will also occur in comparable situations when sediment demand of the backbarrier area increases, for example resulting from accelerated sea-level rise. Therefore, it has to be anticipated that in future more ebb-tidal deltas may be eroding faster than at present.

On the longer run it may influence the provision of shelter and sediment supply to the backbarrier area and the adjacent island tips. Currently, there are Dutch plans to study the feasibility of nourishing ebb-tidal deltas, which in turn has raised concern about the possible influence on the ecology of the ebb-tidal deltas and on their role on the ecology of the Wadden Sea.

**Reorientation**

A coastal retreat of 1.5 km was observed at SW Texel in the 19-20th century after reorientation of Marsdiep ebb-tidal delta to the SW: 1.5 km (Oost et al., 2014). In Niedersachsen the landing point of the ebb-shoals shifted due to shifts in orientation in several inlets. An eastward shift led to erosion at the west side of Baltrum and Norderney, whereas a strong westward shift led to erosion at the west side of Juist. During the past century massive protection works were needed at the western sides (with the exception of Juist & Langeoog; NLWKN, 2011). The protection works also lead to a stop in the eastward shift of the islands updrift of the inlets and hinder their envisaged natural development. Van der Berg & Sha (1998) suggest that the orientation of the inlet and the ebbtidal delta is determined by 1) the tidal volume and 2) the differences between the tidal phases through the inlet and the open North Sea.

If such shifts and erosional developments would occur in future in combination with increased sediment demand of the backbarrier area and flooding of the coast due to sea-level rise, keeping the position of the coasts might become even more difficult.

**Changing heights**

A change in height of ebb-tidal deltas may result in a change in wave spectra along the barrier islands coasts and within the backbarrier area. It is still unclear what the exact consequences are. Along the North-South trending Wadden coasts of Schleswig Holstein, lowering of the ebb-delta shoals has been observed in the Hörnum inlet. The exact reason is not known. The lowering of the ebb-delta shoals reduces the shelter provided to Amrum. It is a matter of concern, especially in combination with the increasing high water levels (Hofstede, 1999b). In contrast, vertical growth of shoals has been observed on most of the Dutch ebbtidal deltas, thus providing extra shelter. If ebb-delta shoals lower and storm surge water levels at the same time increase due to climate change, changes in wave spectra affecting the island coasts near the inlet and the backbarrier area might become more common.

**Ecosystem**

Any change in the morphodynamics of ebb-tidal deltas may lead to changes in the availability and quality of habitats for biota and may affect the connectivity between the North Sea and the Wadden Sea. A change or disappearance of the shallow tidal flat habitats may for instance lead to effects on the nursery function of fish, the foraging habitat of birds, or the resting habitat for seals.
4 Organisation model

The project is ordered by the Task Group Climate (for overview see table I), consisting of two representatives with relevant knowledge per region (the Netherlands, Niedersachsen, Schleswig Holstein, Denmark). Responsibilities of the Task Group Climate members are:

Start of project:
- To discuss the draft project plan;
- Give overview on morphology and ecology of the various ebb-tidal deltas in their region;
- Defining parameters relevant to management.

Before the summer 2017:
- Bring in regional data from the various governments;
- Choose which inlets/areas to select based on data availability, scientific information and representativeness;
- Discuss the selected deltas based on scientific literature on the functioning of the ebb-tidal deltas.

Around the summer 2017:
- Intermediate workshop with expert team;
- Discuss results so far and to help identify special further ebb-tidal deltas of interest;
- Discuss how to further improve the quality of the brochure;
- (Optional) Discuss the selected deltas based on grey literature and institute data.

After the summer:
- Comment on brochure.

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The project will be executed by a team of Dutch experts, who are familiar with the trilateral knowledge concerning hydromorphology and ecology of ebb-tidal delta's. They are led by their general coordinator, who is in close contact with the delegated coordinator on behalf of Task group Climate (R. Zijlstra). Members of the expert team are expected to work closely together with each other and with the Task Force Members. Responsibilities of the expert team are:

- Overall project management.

Start of project:
- To discuss concept project plan;
- To discuss the results of the Task Group;
- To help define of parameters relevant to management;

Before the summer:
- Compile data brought in via Task Group;
- Draft tables and maps based on data available from the governmental databases;
- Gather Peer-reviewed scientific literature all inlets;
- Help choose which inlets/areas to select based on data availability, scientific information and representativeness;
- Discuss selected deltas based on scientific literature;
- Compile and combine hydromorphological and ecological data and literature compilation;
- (Optional) gather data from research institutions and grey literature.

Around the summer:
- Intermediate workshop with Task Group;
- Discuss results so far and to help identify special further ebb-tidal deltas of interest;
- Discuss how to further improve the quality of the brochure;
- (Optional) Discussion of the selected deltas based on grey literature.

Autumn 2017:
- Further improvement of the information;
- Compilation of information into brochure;
- Writing brochure.

The general overview of the organisation can be seen in Figure 4.1.
Available data on ecology (governmental and where needed, research institute data)

Available data on hydromorphology (governmental)

Peer reviewed scientific literature

Peer reviewed scientific literature

Trilateral Task Group:
Regional contact persons for ecology and hydromorphology
Task: define project, collect knowledge, approve products

Project expert team:
Task:
Compile data and scientific information, generate overview, reporting

Figure 4.1 Organisational diagram of the project
5 Action plan

The aim is to carry out the project in 2017 and present the results in 2018 on the trilateral Wadden Sea minister conference. In the project the following actions are defined (for details: see description of hydromorphological and ecological studies in Appendix):

Phase I: Overview with focus on governmental and peer-reviewed scientific information
1. Inception workshop with:
   - Discussion of concept project plan by Task Group Climate members and expert team.
   - Task Group members (see table I) to discuss their results with expert team and give overview on morphology and ecology of the various ebb-tidal deltas in their area, which should encompass: overview of the available governmental data, insights per delta of main developments from a management perspective and identification of the main problems related to the various deltas in their area of interest.
   - To define parameters relevant to management, which can be considered indicators for (change in) flood-safety, sedimentary and ecological build-up (for details see appendices I & II) by Task Group Climate members and expert team.

2. Gathering and compilation of national governmental hydromorphological data and scientific literature of ebb-tidal deltas. This part of the study is the preparation for the trilateral brochure (see appendix III).
   - Data to be brought in via Tass Group members from the various governments, i.e. national government of The Netherlands, Bundesländer in Germany and national government of Denmark. Digital data will be kept in the form as delivered and not be made into a uniform format.
   - Drafting of tables and maps based on data available from the governmental databases. The most recent data set of sufficient quality should be the “show-case” in GIS-pictures and descriptions. All other data sets should be used to describe developments through time and, if deemed important (see below), should be used to illustrate these developments in pictures. Where possible the spatial and temporal availability of the data should be given. Wherever data quality allows a quantitative discussion should be given; otherwise a qualitative discussion will be given. Where possible the uncertainty of the quantitative interpretation should also be quantified. If based on expert judgement this should be stated in text.
   - Peer-reviewed scientific literature to be gathered on all inlets.
   - Choice to be made by Task Group and expert team which inlets/areas to select based on data availability, scientific information and representativeness. As the number of ebb-tidal deltas is too large to discuss them all, a representative subset will be chosen to discuss in more detail. Essential criteria for the choice are: 1) should be representative (end)member of the variability of deltas, also representative of (missing) strong human influences; 2) sufficient information should be available; 3) should be spread in a representative way over the trilateral Wadden Sea. It will be indicated what might be the most important gaps in knowledge which cannot be filled by a desk study.
   - Discussion of the selected deltas based on scientific literature on the functioning of the ebb-tidal deltas.
• Hydromorphological data and literature compilation

3. Gathering and compilation of national governmental ecological data and scientific literature of ebb-tidal deltas. This part of the study is a preparation for the trilateral brochure (see appendix III).
  • Data gathering and compiling, ecological description of ebb-tidal deltas (methodology as in 2). It will be inventoried what are the species most dependent on the ebb-tidal deltas. Also, the role of ebb-tidal deltas in connecting the North Sea with the Wadden Sea (connectivity) will be addressed. When needed and if time allows grey literature and research institute data might be inventoried to some extent. It will be indicated what might be the most important gaps in knowledge which cannot be filled by a desk study. The study should be contributing to, and form the basis for, the trilateral brochure.
  • Ecological data and literature compilation.

4. Intermediate workshop with Task Group:
  • To discuss the results so far and to help identify special further ebb-tidal deltas of interest.
  • To discuss how to further improve the quality of the brochure (point 8). For instance, workshops and interviews might be conducted with academic scientists, policy makers and consultants to identify the most important current and future policy concerns, related research topics and associated parameters. This has to be (in part) organized by the Task Group.

Optional Phase II: Adding Research Institute Information and grey literature

5. Research institution-based data & grey literature gathering and compiling hydromorphologic overview of ebb-tidal deltas (extension of phase I.2). The study should be contributing to the trilateral brochure (see point 7).
  • Data to be gathered from the various research institutions;
  • Grey literature to be gathered of identified inlets.
  • Presentation of the gathered data. The most recent data set of sufficient quality should be the “show-case” in GIS-pictures and descriptions. All other data sets should be used to describe developments through time and, if deemed important, should be used to illustrate these developments in pictures. Where possible the spatial and temporal availability of the data should be given. Wherever data quality allows a quantitative discussion should be given; otherwise a qualitative discussion will be given. Where possible the uncertainty of the quantitative interpretation should also be quantified. If based on expert judgement this should be stated in text.
  • Discussion of the selected deltas based on grey and scientific literature on the hydromorphological functioning of the ebb-tidal deltas in the hydromorphological overview.

6. Research institution-based data & grey literature gathering and compiling ecological overview of ebb-tidal deltas (extension of phase I.3). The study should be contributing to the trilateral brochure (see point 7).
  • Research institution-based data gathering and compiling & finalizing ecological overview of ebb-tidal deltas (methodology as in 5). It will be inventoried what are the species most dependent on the ebb-tidal deltas. Also, the role of ebb-tidal deltas in connecting the North Sea with the Wadden Sea (connectivity) will be addressed.
It will be indicated what might be the most important gaps in knowledge which cannot be filled by a desk study. It will also be indicated what might be the most important gaps in knowledge which cannot be filled by a desk study. Special attention will be given to the role of climate change. The study should be contributing and form the basis for the trilateral brochure (see point 7).

Phase III: Production of an English trilateral information brochure summarizing the underlying hydromorphological and ecological studies.

The information collected in Phase II is summarized in the Brochure which gives an overview of available knowledge and data on all ebb-tidal deltas. The Brochure describes the hydromorphology and ecology of ebb-tidal deltas with indication of possible consequences of climate change. To that end the selected ebb-tidal deltas will function as illustrations of possible developments and behavior.

Activities

The following activities are defined for the preparation of the brochure:

- First draft of brochure following the content (see appendix) around summer;
- Discussion with project team;
- Final draft of brochure;
- Acceptance by project team;
- Final version of brochure November 2017;
- Presentation on Ministers conference in 2018
6 Finances

Finances consist primarily on hours spent on the project and to a minor extent project management (10%). A small amount of money is reserved for travelling costs and such. No reservation has been made for catering or renting project rooms for meetings: these will be held at the offices of the experts or in offices of the trilateral Task Group members, when possible. Also, no money is reserved for hiring other experts or the trilateral Task Group members: information will be gathered on a voluntary basis and the expert group in combination with the Task Group members are thought to have sufficient knowledge available.

It can be noted that the costs of ecology are nearly identical to the costs of hydromorphology, although that is probably a bigger data set. That is partly due to the various meetings which are to be held and partly because ecological data on ebb-tidal deltas will probably be more difficult to obtain. At this point it is considered likely that data sets on ecology have to be gathered from research institutions. To that end a greater effort has to be made by the experts.

Phase II is optional. This is also true for the extra’s. For illustrations costs have to be made if photo material has to be searched from different sources or when new illustrations have to be made (copyrights not included). Archiving are actions needed to store the project and data. Evaluation is after the project has finished.

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Table 6.1 Estimated costs for the various phases (no rights can be derived from this estimate: for a more detailed overview the reader is referred to the appendix costs in the xls-file).
For the various phases (I to III) and steps (1 to 7) the estimation of the costs have been calculated based on all actions needed for each step (table 6.1). Phase II is identified as optional. Occasionally grey literature and research institute data might be needed to finish point 3 (ecology), which in that case have to be collected. At the moment it is not clear if this is needed.
7 Timeline

As stated: all work has to be carried out during 2017 to meet the timely delivery of the brochure at the start of 2018. The timeline with the various actions is given in table 7.1 (for details see appendix xls file with products). This timeline is the critical timeline giving the last possible period that actions should be carried out in order to deliver the brochure timely. The timely deliverance of governmental data by Task Group Members is a critical to the preparation of the data-maps. It is proposed that data which are not delivered timely shall be left out, in order to meet the goal of timely delivery of the proposal. It should be noticed that, because it is a critical timeline, there is room to speed up processes. If for instance the intermediate workshop can take place in July it is possible to finish the brochure earlier.
Table 7.1  Overview of critical timeline for the project in 2017 in order to produce brochure before 2018
8 References


A Hydromorphological overview ebb-tidal deltas trilateral Wadden Sea

Goal
Generate and improve information on morphology and sediment budgets and other hydromorphological data for ebb-tidal deltas in the trilateral Wadden Sea. Gather information from governmental data and peer-reviewed scientific literature on possible pathways of sediment transport related to long-term (decadal) development. Identify possible implications of climate change. Optional: augment with grey literature and research institution data-sets.

Type of project
Overview based on desk study combining with scientific literature and governmental monitoring data collection, for a synthesis of existing knowledge.

Description
Currently there is concern with coastal managers about the development of the ebb-tidal deltas in the trilateral Wadden Sea. Sitting at the “doorstep” of the tidal backbarrier basins and forming the intermediary between the North Sea (island) coasts and the trilateral Wadden Sea itself, they provide sediment and shelter to the backbarrier area and the barrier islands. The major reason for concern is that the deltas may change in volume and orientation upon nature-induced or human-induced (including climate change) changes in the conditions. Such changes may bring about changes in shelter and sediment availability.

Sediment balances (or sediment budget analysis) show the net erosion and sedimentation of a given area in the trilateral Wadden Sea. These budgets can help to provide insight in the possible pathways of sediment movements. In the Netherlands the whole Wadden Sea (including the coastal zones of the islands) is covered (Elias et al. 2012). It is proposed as a first step to provide an overview of the geographical coverage of depth soundings of the ebb-tidal deltas based on national data which would allow making additional analyses in Germany or Denmark. Furthermore, relevant additional data on hydromorphological information stored at governmental water management institutes will be compiled (optionally augmented with research-based data) for all inlets. All data will be represented in tables and GIS-maps.

Also, the morphodynamic development of several of the ebb-tidal deltas in DK, GE and NL has been described in considerable detail on various spatial and temporal scales. It covers centuries and the horizontal shift of whole inlets, to decades and the three-dimensional development of sediment volumes, to years and the shift of channels and bars in the ebb-tidal deltas. Several developments can be observed such as cyclic behavior, and shifts and decay or growth of deltas (Relevant for questions such as: “How to distinguish between potential effects of sea level rise mistaken for natural behavior or vice versa?”).

An inventory of scientific literature (optional grey literature) will be made for all ebb-tidal deltas. Based on the outcome and the GIS-information a choice will be made for 5-6 deltas of special interest which will be discussed in detail. It has to shed more light upon both natural (e.g. the strongly cyclic development of the Pinkegat ebb-delta) and human induced developments (e.g. the fast retreat and reorientation of the Marsdiep ebb-tidal delta) of ebb-tidal deltas.
As far as possible these will be related to various steering parameters. Furthermore, the effects of climate change upon morphological developments and implications for management should be assessed.

These actions will enable inter-comparison of developments of these parts of the tidal inlet systems between the trilateral Wadden Sea countries and can increase knowledge on how sediment dispersal is taking place. Sediment budgets (where available) can also be used to validate (semi-empirical) morphological models. For the 2018 conference a trilateral common dataset of ebb-tidal deltas with the current knowledge on the sedimentary development of Wadden Sea ebb-tidal deltas should be developed.

Activities
The following activities are defined with an eye on the preparation of the overview:

- Inventory of existing scientific literature (journal papers; optional grey literature, such as management reports) on the hydro-moropology of ebb-tidal deltas of the Wadden Sea;
- Inventory of historical and existing hydro-morphological state monitoring programmes in and around ebb-tidal deltas;
- Inventory of the availability of digitized hydro-morphological data of ebb-tidal delta’s;
- Definition of hydro-morphological parameters is left to the contractor who will make a listing which will be discussed between the Task Group and the contractor after which a choice is made. It should at least, but not exclusively, encompass:
  - A short listing of the abiotic parameters of all ebb-tidal deltas following the table 1 of Kraft et al. (2011).
  - Of each ebb-tidal delta for which digitalized depth sounding data are available in the form of a base map with the depth contours in m below MSL from -20m up to minimum depth and also indicating MLW, MHW line\(^2\). If budget allows, sediment volume and hypsometry have to be calculated with a fixed grid (which is comparable for all available soundings) and, if appropriate a moving grid.
  - Of each ebb-tidal delta (estimated/measured) sand and mud transports through the inlet; mud concentration in the water; long shore transport, wave climate and direction and tidal volume\(^3\) have to be calculated.

- Drafting of tables, maps and fact sheets:
  - Tables for the hydro-morphological data will be drafted following table 1 of Kraft et al. (2011). Uncertainties will be addressed in fact sheets.
  - An over-arching (series of) fact sheet(s) should show the similarities and differences between ebb-tidal deltas and the (possible) relation to driving abiotics, climate change effects and the human interferences.

\(^2\) In the German-Dutch research project PACE (NWO/BMBF call “GeoRisk”), a homogenous digital terrain model has been produced for the whole Wadden Sea, based on official national datasets. The bathymetry is available at IOW and should be used as overview and to establish the 3D basemaps of all deltas as well as sediment volumes and hypsometries (the latter both for the whole delta and the delta divided in 3 zones: zone 2 of 45 degrees of which the centre is perpendicular to the main wave direction; (sheltered) zone 1 updrift of it and (sheltered) zone 3 downdrift of it. All information should give quality of the data (in table).

\(^3\) An example of the phase difference between the North Sea tide and the tide through the inlet and the implications for sediment transport should be given (see a.o.: Sha & van den Berg, 1993; Ridderinkhof, 2016) as a possible pathway for future research.
For some representative ebb-tidal deltas give a short recapitulation of the hydromorphological studies available, in combination with the above data.

- Fact sheets will be written that give a recapitulation of the morphological studies available, where possible related to selected ebb-tidal delta’s, in combination with the above data, with special emphasis on the relation with the hydromorphological information.
- Maps of each ebb-tidal delta of which several digitalized depth soundings are available:
  - maps of the various depth soundings (in identical manner as the abovementioned base-map)
  - development of sediment volume and net erosion and net sedimentation data (where available). If budget allows, the calculations should take into account, where available and if possible, dredging, dumping and nourishment data (following the method of Elias et al., 2012 and discussing quality of the data).
  - changes in hypsometry (according to the zonation discussed above) in terms of erosion from the original depth and the sedimentation on the original depth.
  - Also, migration velocities of shoals on the ebb tidal delta should be given (see Ridderinkhof, 2016).
  - Where available give sediment distribution map and correlation with depth at time of sediment survey.

- The most important data should be visualized in maps or given in comprehensive tables, including dredging and dumping data.
  - Discussion of results and intercomparison of the data and scientific knowledge. It will be indicated what might be the most important gaps in knowledge which cannot be filled by a desk study. It will also be indicated what might be the most important gaps in knowledge which cannot be filled by a desk study. Special attention will be given to the role of climate change.

**Product 2017**
- Overview of available literature, governmental monitoring program data;
- Tri-lateral description of the ebb-tidal delta morphodynamics based on literature;
- Overview of hypotheses of hydrodynamic functioning in the perspective of the whole Wadden Sea and possible consequences of climate change;
- Overview of parameters for brochure (see below);
- Hydromorphological overview of ebb-tidal deltas in the trilateral Wadden Sea.

**Tri-lateral relevance**
Improving reliability of knowledge by adding data of multiple ebb-tidal delta systems.
This project can enhance the results of the Interreg Building with Nature project.

**Links to other projects**
- Kustgenese 2: large-scale investigation in NL to determine future sand nourishment strategy
  - Interreg Building with Nature
- KPP Kust: ongoing research program Dutch coast, including sediment budget studies
- SEAWAD: research programme, focusing on the morphology of ebb-tidal delta (acronym: SEDiment supply at the trilateral WAdden Sea ebb-tidal Delta)
- TMAP
- WaLTER

Project plan: Trilateral desktop study on the hydromorphology and ecology of ebb-tidal deltas of the Wadden Sea
B  The ecosystem of ebb-tidal delta’s

**Goal**
To investigate the ecological connection between the ebb-tidal deltas and adjacent systems (North Sea, Wadden Sea) and to investigate the ecosystem of these deltas based on the morphological, hydrodynamical and geological characteristics by gathering information from governmental data and peer-reviewed scientific literature on ecology. Identify possible implications of climate change. Optional: augment with grey literature and research institution data-sets.

**Type of project**
Overview based on desk study combined with scientific literature and governmental monitoring data collection, for a synthesis of existing knowledge.

**Description**
The trilateral Wadden Sea (eco)system consist of different (large scale) geomorphological elements, such as backbarriers (with sub- and intertidal flats, salt marshes and channels), barrier islands (with dunes, salt marshes, washovers and beach plains) and ebb-tidal deltas (with subtidal shoals, intertidal shoals and supratidal shoals and channels). All these elements will be influenced by climate change. Additionally interventions by humans take place, for instance sand nourishment on the coastline and along gullies and sand abstraction from ebb-tidal deltas and channels (dredging). Large-scale sand nourishments on the ebb-tidal deltas of the Dutch Wadden Sea system are seriously considered. According to the Wadden Sea Plan (2010) trilateral policies will be based on an integrated approach to coastal flood defence and protection, and nature protection on the mainland coast, the islands and the offshore zone. However, much is unknown about the ecosystem of the ebb-tidal delta’s making it hard to give policy recommendations on large scale sand nourishments in relation to nature protection.

It is, therefore, proposed to investigate and describe the biology and ecological functioning of the ebb-tidal deltas in relation to the (connectivity with) other elements of the North Sea and the trilateral Wadden Sea ecosystem. Available governmental monitoring data and peer-reviewed scientific data on geomorphological (see previous task) as well as biological aspects will be considered with respect to climate change, i.e. the influence of ebb-delta volume, ebb-tidal delta shoals, shape, dynamics and grain size in relation to the marine and terrestrial biology and ecosystem functioning.

**Activities**
The following activities are defined with an eye to the preparation of the brochure (see below):
- Inventory of existing peer-reviewed scientific literature (journal papers; optional augment with grey literature) on the ecosystem of ebb-tidal deltas;
- Inventory of historical and existing governmental biological monitoring programmes in and around ebb-tidal deltas’s (optional augment with Research Institute data), such as the Dutch “Monitoring Waterstaatskundige Toestand des Lands” (MWTL) and the German Bund-Länder Messprogram (BLMP);
- Inventory of the availability of digitized biological data on ebb-tidal deltas;
- Definition of biological parameters. Dependent on the detail of the available data a choice for parameters will be made.
This can be for instance species, species communities, functional groups, food-web elements, habitat-functionality, spatio-temporal migration patterns, etc. Kraft et al. (2011) use: dolphins, seals, birds, fish, macrophytes, macrozoobenthos, phytoplankton, microphytobenthos, zooplankton & neobiot.

- Drafting of tables, maps and fact sheets:
  - Tables for the biological data (non-living nature to be addressed in the hydro-morphological study) will be drafted following table 1 of Kraft et al. (2011). Uncertainties will be addressed in fact sheets.
  - Fact sheets will be written that give a recapitulation of the ecological studies available, where possible related to single ebb-tidal deltas, in combination with the above data, with special emphasis on the relation with the hydromorphological information (derived from the previous project). An over-arching (series of) fact sheet(s) should show the similarities and differences between various ebb-tidal deltas and the (possible) relation to driving abiotics and to climate change.

**Possible products 2018**
- Overview of available literature, governmental monitoring programmes and biological data.
- Tri-lateral description of the ebb-tidal delta ecosystem based on literature,
- Overview of hypotheses of ecological functioning in the perspective of the whole Wadden Sea and possible consequences of climate change.
- Overview of parameters for brochure (see below).
- Ecological overview.

**Tri-lateral relevance**
Ebb-tidal deltas are present in the whole Wadden Sea. Insight in the ecological functioning of ebb-tidal deltas is relevant to gain insight in the response of the whole Wadden Sea ecosystem to climate change and human interventions, such as sand nourishments. Moreover, ebb-tidal deltas are hardly monitored, so they can be considered terra incognita, but still are an integral part of the protected Natura 2000 habitat.

**Link to other projects**
- Kustgenese 2: large investigation in NL to determine future sand nourishment strategy
- SEAWAD: research programme, containing ecology of ebb-tidal delta (acronym: SEdiment supply At the trilateral WAdden Sea ebb-tidal Delta)
- Ecologisch Gericht Suppleren: ongoing investigation and monitoring in NL to determine ecological impact of sand nourishment on coastal ecosystem.
- Zandmotor: large scale pilot along the Dutch coast
- TMAP
- BLMP
- MWTL
- WaLTER
Trilateral brochure encompassing the hydromorphodynamic and ecological overviews – draft content

Introduction
A brochure comprehensible to decision makers and non-scientists has to be established for the next Trilateral Governmental Conference in 2018, highlighting the role of the ebb-tidal deltas as an integral and coherent part of the trilateral Wadden Sea ecosystem on basis of the hydromorphodynamic and ecological overviews.

For the contents, the brochure will be shaped after the brochure “Data inventory of the tidal basins in the trilateral Wadden Sea (Kraft et al., 2011)”, so that these two brochures will be complementary. See: http://www.rijkewaddenzee.nl/assets/pdf/dossiers/natuur-en-landschap/NHP0047%20Rapport%20Kombergingsatlas%20binnen-voor%20web.pdf

Goal
Brochure highlighting the role of the ebb-tidal deltas as integral and coherent part of the trilateral Wadden Sea ecosystem.

Type of project
Desk top study based on the hydromorphodynamic and ecological inventories described above.

Description
General
The brochure follows the work of Kraft et al., (2011) to make these works complementary. Also, the brochure is to be written in items of maximum 500 words each to facilitate eventual web-pages concerning ebb-tidal deltas. The brochure should be rich in content with pictures, figures and tables. Special insets might be given to illustrate specific details of a subject. All data should be made available in mutually identical text lay-out: maps, tables and data-sets.

Proposed Contents

1 Summary
2 Introduction
  2.1 Background
  2.2 What is an ebb tidal-delta?
  2.3 Objectives of the brochure
  2.4 Structure of the brochure
3 Methods
  3.1 Organisations involved
  3.2 Information sources
4 Policy concerns, scientific questions and required parameters
  4.1 Sea level rise and sea floor subsidence
  4.2 Human use
  4.3 Morphology and climate change
4.3 Ecology and climate change
4.4 Ecosystem services

5 Data
5.1 Data demand, quality and availability
5.2 Data sources and measurement methodology
5.3 Studies on ebb-tidal deltas: a compilation
5.4 Data gaps and solutions

6. Significance and functioning of ebb-tidal deltas
6.1 Morphology ebb-tidal deltas
6.2 Ecology of ebb-tidal deltas
6.3 General discussion with special emphasis on climate change

7 Conclusions and recommendations

8 Literature

**Tri-lateral relevance**
Ebb-tidal delta's are present in the whole Wadden Sea. Insight in the hydromorphological and ecological functioning of ebb-tidal delta's is relevant to gain insight in response of the whole Wadden Sea ecosystem to climate change and human interventions, such as sand nourishments. Moreover, ebb-tidal delta's are not frequently monitored, so they can be considered terra incognita, but are an integral part of the protected Natura 2000 habitat.

**Link to other projects**
See above
Brochure on back barrier basins.