Working with Nature in Wadden Sea Ports

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Abstract
Wadden Sea ports are situated at the border of the UNESCO World Heritage site Wadden Sea. Because of the protected status of this area, developing new economic activities is not straightforward. However, maintaining and developing port activities is needed to safeguard the economic viability of the Wadden Sea socio-economic region. In this paper we illustrate that sustainable port development is feasible when adopting a Working with Nature approach. This approach facilitates a design in which the proactive utilization and/or provision of ecosystem services serves as part of the engineering solution. We introduce four Working with Nature concepts that can be used in port designs, i.e. 1) optimising dredging strategies, 2) enhancing saltmarsh development, 3) creating estuarine gradients, and 4) optimising flow patterns. Based on these concepts, three case studies have been identified and pilot projects initiated. In the Port of Harlingen a pilot project has started in which an optimized dredging strategy is combined with saltmarsh development. Around the Port of Delfzijl an estuarine gradient is combined with the construction of a salt marsh and dredged sediment is used for dike strengthening. For the Port of Den Helder, a new design is proposed in which the concepts of enhancing salt marsh development, creating estuarine gradients and optimizing flow patterns are combined. Our conclusion is that even in a World Heritage site such as the Wadden Sea, port development is possible when ecosystem services are used and provided for, and when a Working with Nature concept is put at the heart of the design.

Keywords: Ecosystem services, Working with Nature, cohesive sediment, harbour development, wetland restoration

1. Introduction

The Wadden Sea, the largest coherent system of intertidal sand flats and mud flats in the world, is listed as UNESCO World Heritage since 2009 because of its Outstanding Universal Value on geological and ecological processes and biodiversity [1], [2]. Yet, the coastal morphology, hydrodynamic conditions and suspended sediment concentrations have been highly affected by human interventions such as the construction of dikes, dams, harbours and polders [3]–[6] and dredging works for navigation [7]–[9]. As a result, the ecological value of the system, especially in and around the economically active regions, such as ports, has decreased [10].

The Dutch Wadden Sea area has four medium sized and eleven small ports. Three ports have to deal with large siltation rates over 1 million m^3 per year; these are the ports of Den Helder, Harlingen and Delfzijl (Figure 1). Moreover, port development is hampered due to the protected status of nature in the World Heritage site. This headlock can only be solved when port development is combined with nature development.

In 2008, a Dutch consortium of private parties, government organisations, research institutes, universities and NGOs was formed under the name EcoShape. They carry out the “Building with Nature” innovation programme (BwN). The programme was the first to test and develop a new design philosophy in hydraulic engineering that utilizes the forces of nature, thereby strengthening nature, economy and society. The USACE’s Engineering with Nature and the PIANCS’ Working with Nature programmes were inspired by EcoShape’s Building with Nature. Within our BwN programme special attention is given to the Wadden Sea ports since 2013. Its focus is on decreasing siltation rates and increasing the potential for harbour development whilst at the same time enhancing the ecological state of the harbour and its direct surroundings. A ‘learning by doing’ approach is followed in which a variety of concepts is tested and studied in the most promising locations within the Wadden Sea area.

Figure 1. Dutch part of the World Heritage site Wadden Sea (green) and the locations of the three case studies.

2. Working with Nature Concepts

2.1 General Concepts

A key characteristic that distinguishes a Working with Nature design from other integral approaches is the proactive utilization and provision of ecosystem services as part of the engineering solution [11], [12]. Although situations differ, some basic steps appear to be part of every Working with Nature design. The following design steps were developed, tested and supported by scientific knowledge in the EcoShape BwN programme [11]–[13]:

Any Working with Nature concept demonstrates either that the engineering solution uses ecosystem services in providing the desired solution and/or that the engineering solution provides opportunities for development of extra ecosystem services.

Within the Wadden Sea Harbours programme, four Working with Nature key concepts have been identified that use and/or provide ecosystem services. Each of these is or will be tested in real-life case studies. The key concepts are: optimising dredging strategies, enhancing saltmarsh development, creating estuarine gradients, and optimizing flow patterns.

2.2 Optimising Dredging Strategies

Dredging of sediments from ports and access channels provides an economic loss to port authorities. Disposal of sediments is often considered to have negative environmental consequences resulting in turbid waters and burial of benthic organisms. At the same time, sediment is becoming an increasingly valuable resource especially in view of accelerating sea level rise. One of the Working with Nature concepts to be tested in a pilot study is using fine-grained dredged sediments as a resource for nature development. Mud, dredged from the port of Harlingen, is disposed at a location where tidal flows transport the material to a nearby intertidal area and salt marsh: a Mud Motor. The sediment is dredged and transported in a small trailing hopper suction dredger (approximate capacity of 600 m^3). Dredging and dumping will take place in the storm season over an 8 month period from September to March in two consecutive years. Differing from the Sand Motor or Sand Engine, in which a large volume of sand was deposited once [14], [15], the Mud Motor will serve as a semi-continuous source of sediment. Besides a high biodiversity, salt marshes supply important ecosystem services such as flood protection. Another ecosystem service of a salt marsh is that it acts as a sediment sink. Because less sediment flows back towards the port, it is expected that the dredging costs will reduce. The concept of Optimising Dredging Strategies is therefore using and providing ecosystem services.

2.3 Enhancing Salt Marsh Development

Coastal habitats such as tidal areas and salt marshes are ranked among the most important habitats in the Netherlands regarding ecosystem services [16]. One of these services (next to water infiltration and regulation, nurturing fisheries and providing livelihoods to communities, from shellfisheries to tourist industries) is coastal protection through wave attenuation [16]–[18]. Therefore, tidal flat and salt marshes form a very important part of coastal safety worldwide.

The initiation and development of new salt marshes in areas where they do not yet exist is one of the concepts being used in the Wadden Sea Harbour programme. In The Netherlands there is ample experience in enhancing salt marsh development in areas where boundary conditions need relatively small adjustments to stimulate salt marsh extension. These conditions involve (1) providing more shelter against waves and (2) enhancing drainage of soils. In a pilot study executed near the port of Delfzijl however we need to raise the bed topography first and prescribe the correct slope of the intertidal area. This slope subsequently needs a mixture with silt before development of pioneering species can start. Testing different initial conditions will provide valuable new information concerning salt marsh development.

2.4 Creating Estuarine Gradients

In most of the Wadden Sea ports, the release of freshwater runoff from the hinterland within the ports is contributing significantly to the maintenance dredging requirements by strengthening sediment import from the sea. The concept of creating estuarine gradients was developed to resolve this issue. It consists of creating bypasses around a port, creating more gradual salinity transitions and accompanying natural variations, whilst at the same time improving fish passage possibilities. These solutions form a win-win situation reducing maintenance dredging and improving the natural quality.

2.5 Optimizing Flow Patterns

The configuration of breakwaters strongly influences the hydrodynamics and morphodynamics around a port. Traditionally, the design of breakwaters primarily aims at optimizing the hydrodynamic conditions for ship traffic (safety) and minimizing harbour siltation. However, breakwater design may be additionally optimized to improve the hydromorphological conditions of the surrounding coastal area, thus improving local habitats. The result is enhanced development of salt marshes, tidal flats or brackish environments. This concept may be used at locations where the possibilities for harbour expansion are limited due to regulation on nature protection. In general an extensive hydromorphological study is necessary to determine which port layout will optimally improve the ecological quality of a surrounding area.

3. Overview of Case Studies in Wadden Sea Ports

Based on the concepts illustrated above, a number of case studies have been identified. Three of these will be elaborated below in more detail.

3.1 Port of Harlingen

To safeguard navigation, about 1.3 million m^3 of mainly fine sediments per year are dredged in the harbour basins of the Port of Harlingen. The dredged sediment is currently disposed in the Wadden Sea, in front of the port. A considerable amount of sediment flows back into the port, leading to a cyclic series of dredging and disposal. This is not only economically inefficient, it may also lead to increased local turbidity, negatively impacting primary production and the ecological food chain [3]–[6], [19]. Beneficial use of these dredged sediments by disposing the sediment at a new location (Figure 2), closer to a salt marsh system, is expected to:

1. Reduce recirculation towards the harbour, hence less maintenance dredging;
2. Promote the growth and stability of salt marshes, improving the Wadden Sea ecosystem;
3. Stabilize the foreshore of the dykes, and therefore less maintenance of the dyke.

Within the Building with Nature program, a pilot was set up in order to determine the effectiveness of using offshore deposited excess dredge material for salt marsh development (Figure 2). Firstly, the necessary licenses to work within the protected nature area had to be requested [20]. Next, the new disposal location for the Mud Motor was determined based on numerical model predictions, tidal predictions and technical feasibility [21]. The effectiveness of the Mud Motor in accreting the foreshore was determined through the use of tracers.

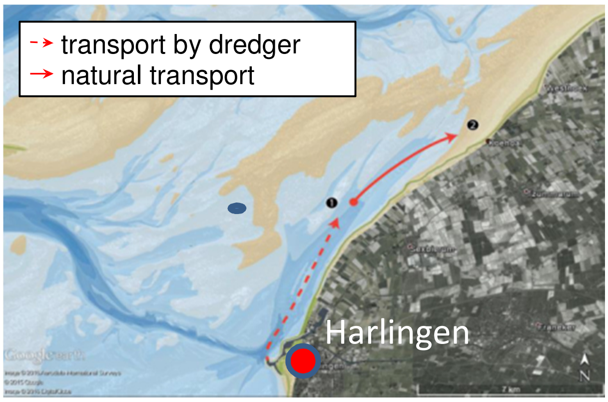

Figure 2. Overview of case study Port of Harlingen with (1) Mud Motor location and (2) saltmarsh development location.

Two types of tracers were released at the existing disposal location in front of Harlingen, and at the new disposal location. The retrieval of the tracers in the study area determines the effectiveness of dredged sediments reaching the salt marsh area. The results indicate that 80% of the mud disposed at the Mud Motor location reaches the intertidal area where salt marsh enhancement is desired, compared to only 20% from the existing location [22].

Vertical salt marsh accretion is the result of the balance between sediment deposition, sediment erosion and soil compaction. It is hypothesized that by increasing the sediment load of tidal flows towards the salt marshes, the net accretion rate will increase. Monitoring the salt marsh growth rate will focus on two indicators: the sediment balance in the mudflat and salt marsh, and the morphological profile from the salt marsh to the channel. These are measured with Sedimentation-Erosion Bars (Figure 3) and DGPS measurements.

A natural stabilizing factor for accreted sediment is the development of perennial vegetation on the salt marsh. Perennial vegetation lowers the hydrodynamic energy from currents and waves, thereby increasing the sedimentation rates on the marsh. The root systems stabilize the soil which reduces the potential for erosion. As a result a vegetated saltmarsh is likely to continue to accumulate sediment. Perennial vegetation on a salt marsh can develop at a height of at least mean high water (MHW). The mudflat and saltmarsh accretion, therefore, needs to be large enough to develop to this morphological height. Once perennial vegetation establishes, it will stimulate accretion by positive feedback processes. The development and cover of perennial vegetation is verified with photography from an Unmanned Aerial Vehicle and with in situ measurements of vegetation density (Figure 3).

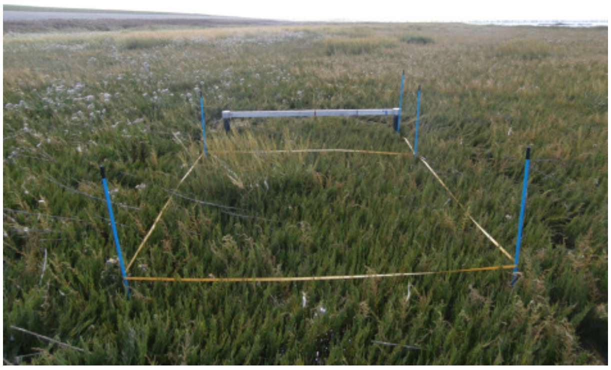

Figure 3. Sampling location in the salt marsh, with a permanent quadrate (in front) and Sedimentation-Erosion Bar (in the back).

The applied research project is coupled to a fundamental research programme financed by the Netherlands Organisation for Scientific Research (NWO) and involving two PhDs and a post-doc. The aim of the fundamental research programme is to understand in detail the underlying physical and ecological processes evolving around the Mud Motor. Within the project detailed measurements of suspended sediment transport processes, and numerical modelling of the mud transport from the subtidal zone, through the intertidal area and towards the salt marshes, are conducted. Furthermore, studies on the influence of biota on salt marsh extension are carried out. Such in-depth knowledge is essential for upscaling the concept to different and / or larger environments.

3.2 Port of Delfzijl

The city of Delfzijl is located along the Ems-Dollard estuary, close to the border between The Netherlands and Germany. It is a small town (around 25,000 inhabitants) with many challenges such as a strong declining population, a shortage of recreational space, and an increasing risk of flooding due to a rising sea level. In 2011 the project Marconi Offshore started. The goal of this project was to enhance the environment and economy in the Delfzijl region. The Marconi Offshore project focusses on improving flood safety of the city and at the same time connecting the city to the estuary by improving the spatial quality (recreation and nature). This involves not only improving the connection with and view to the sea, but also improving and creating recreational areas and valuable habitats for estuarine flora and fauna.

In 2013 the Building with Nature programme redesigned the Delfzijl region [23] comprising a new beach (recreation), a salt marsh leisure park (recreation, nature and flood safety) and a pioneer salt marsh (nature and flood safety) that is expected to grow in due time towards a naturally functioning salt marsh.

Figure 4. Overview of case study Port of Delfzijl with (1) location of pioneer salt marsh and (2) location of fresh water outflow

Dredged sediment from the port of Delfzijl will be used for creating the new salt marshes. To further reduce the siltation in the port, a plan was made for redirecting the fresh water outflow from the hinterland into the estuary. In this paper we elaborate on the specific Working with Nature concepts that will be used in the case study Port of Delfzijl (Figure 4).

3.2.1 Constructing Salt Marshes

First, an extensive literature study showed best practises for creating new salt marshes [24]. Subsequently a design for a pilot study was made. Since this is the first time that new salt marshes are to be constructed in a location that is too deep and too exposed, an experimental set-up is proposed. The pilot study will determine whether and how it is possible to build-up a pioneer salt marsh from scratch and let it grow towards a natural full grown salt marsh, mainly using the force of nature. The pilot focusses on the following key questions:

- What sediment silt content should best be used to create a pioneer salt marsh;
- Does salt marsh vegetation start to grow or are specific measures needed to kick-start the growth by planting or creating sheltered areas;

In order to answer these questions several test fields will be incorporated in the pioneer salt marsh layout (Figure 5). Within these test fields, conditions will be varied with respect to the sediment silt content, wave reducing structures such as brushwood groynes or Geohooks and sowing in specific salt marsh species. The pilot is expected to start early 2018.

Besides answers to the research questions on salt marsh development, the pilot project will provide three bonuses. First of all, the ability of salt marshes to capture sediment has a positive feedback on the sediment concentrations in the near surroundings. This is an important aspect as sediment concentrations in many estuaries around the world are becoming (too) high as a result of anthropogenic influences. Secondly, due to the presence of a salt marsh in front of the coast, the wave attack on that coast will decrease. This can lead to lower maintenance costs of the defence and an improved flood safety. Thirdly, excess dredge material from the harbour will be used to build the salt marsh, possibly reducing dredging costs.

Figure 5. Prospected elements at the Port of Delfzijl; a pioneer salt marsh, a salt marsh leisure park and a recreational beach. Drawing by Anoula Voerman.

3.2.2 Creating Estuarine Gradients

Another Working with Nature concept that is incorporated in the Port of Delfzijl case study is creating estuarine gradients. The port of Delfzijl suffers from high sedimentation rates. This is enhanced, as it is in many harbours in the world, by the fresh water outflow that is situated in the port basin. Relocating the fresh water outflow from the harbour towards a more southern location will reduce these siltation rates [25]. Moreover, this creates possibilities to form estuarine gradients. Estuarine gradients are important to support a healthy and sustainable estuarine ecosystem.

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Figure 6. Prospected estuarine gradient at the Port of Delfzijl. Drawing by Anoula Voerman.

A reconnaissance study [25] showed that, despite the difficult spatial situation in the area with large petrochemical industry sites, a design can be made that is favourable for the port (reduced sedimentation) and for the ecosystem in and around the estuary, while at the same time not hampering industrial development. The design incorporates a large wetland area that guides the fresh water flow towards the estuary and a fish passage with a brackish basin for migratory fish to find shelter and rest. The proposed design is shown in Figure 6.

3.3 Port of Den Helder

The Port of Den Helder is known as the main naval base of the Netherlands, an important hub for offshore services and for its high-frequency ferry connection to Texel. The port would like to extend its quay area to host the anticipated growth of services for offshore renewables (e.g. wind farms). Also, it would like to reduce maintenance dredging costs. At the same time, its environmental impact on the Wadden Sea should decrease, or still better, change from negative to positive for instance enhancing the quality of surrounding habitats. This shows that the Port of Den Helder struggles with the same kind of problems as in many other ports in the world. Den Helder serves as a showcase for a port in which a Working with Nature design will be studied.

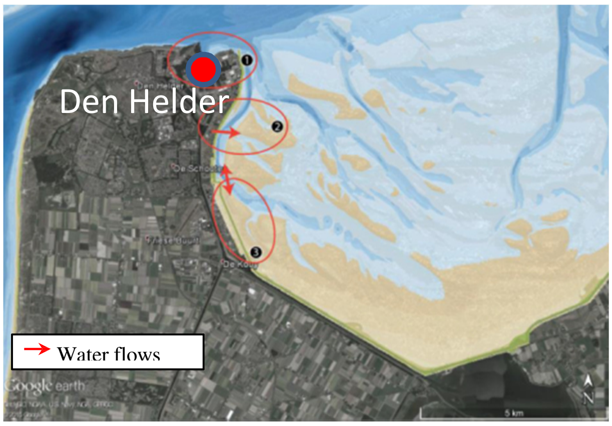

Figure 7. Overview of case study Port of Den Helder with (1) modification of port entrance lay-out, (2) relocation of freshwater discharge and (3) estuarine gradient in Balgzand canal.

To achieve a Working with Nature design, it is aimed to investigate three concepts by three design parts (see Figure 7):

1. Optimising flow patterns: a change of the lay-out of the port entrance breakwaters;
2. Creating estuarine gradients and enhancing salt marsh development: a relocation of the freshwater discharge from the port towards the Wadden Sea;
3. Creating estuarine gradients in the Balgzand canal.

A new design of the port entrance enables the strengthening of economic activities by creating more space inside the port. At the same time, a new design can reduce the trapping efficiency of sediments and consequently maintenance dredging. One of the options for reducing trapping efficiency is to create a double-entry harbour.

A relocation of the freshwater discharge will also reduce maintenance dredging, as density-driven exchange between the sea and the freshwater in the port will be reduced. At the new freshwater discharge location a brackish habitat can be developed offering optimal habitat suitability for target species such as seagrass.

The positive effect on habitat suitability could be extended landwards by introducing a gradual transition (comparable to the estuarine gradient in Delfzijl) between the discharged freshwater within the Balgzand canal bordering the Wadden Sea.
As both a modification of the harbour entrance and a relocation of the freshwater discharge are too costly for a field pilot, these aspects will be studied with 3D numerical models for hydrodynamics and sediment transport. The results from these models should then be analysed in multiple iterative design workshops, resulting in optimised designs to reach both economic as well as ecological goals.

To make the final design viable, criteria on costs, (traditional) port functions and ecosystem services should be well balanced. Both port functionality and ecosystem services should be enhanced requiring acceptable financial investments. Last but not least, creating local support by the public, governmental and non-governmental organisations is essential for a successful project.

4. Conclusions

Ports all over the world are hampered in their economic development induced by nature legislation. At the same time, a viable economy is essential for generating financial means for nature protection and development. This is certainly true for several harbours along the Wadden Sea, a UNESCO World Heritage listed site. The need for port developments has led to the idea of using Working with Nature concepts that proactively use and provide for ecosystem services as part of the engineering solution. Four Working with Nature concepts have been introduced in this paper: Optimizing dredging strategies, Enhancing salt marsh development, Creating estuarine gradients and Optimizing flow patterns.

The introduced concepts are often connected with each other. The concept of optimizing flow patterns through changes in port layout can result in an enhancement of salt marsh development. The same is valid for the concept of creating estuarine gradients. The concepts can therefore be used as single concepts or they can be joined together.

The concepts have been introduced via three case study projects within the EcoShape BwN programme. In the Port of Harlingen a pilot project has started in in which excess dredge material is deposited further away from the harbour in order to stimulate salt marsh development and decrease maintenance dredging costs. Around the Port of Delfzijl an extensive new design has been made for the coastal zone. The design comprises, amongst others, a pioneer salt marsh and an estuarine area. The development of the salt marsh is enhanced by using dredge material from the harbour whilst the estuarine area is created by redirecting the outflow of fresh water from the harbour basin towards a location south of the harbour. The first phase of the salt marsh construction starts early 2017. For the port of Den Helder a new design approach has been proposed based on the following key elements: a change of the harbour entrance layout, a relocation of the freshwater discharge and a coupling with a salinity gradient in the canal south of the harbour. All three case studies encompass one or more Working with Nature concepts.

Although detailed project results are not available yet and some projects have not even started, the fact that the pilot projects have been initiated and that they are supported by local and regional authorities and stakeholders, already contributes to the success of these Working with Nature concepts. It shows that the future in port development lies in Working with Nature.

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