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Damming deltas: A practice of the past? Towards nature-based flood defenses

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ABSTRACT

There is extensive experience in adaptive management of exposed sandy coastlines through sand nourishment for coastal protection. However, in complex estuarine systems, coastlines are often shortened through damming estuaries to achieve desired safety levels. The Dutch Deltaworks illustrate that this approach disrupts natural sediment fluxes and harms ecosystem health, which negatively affects derived ecosystem services, such as freshwater availability and mussel and oyster farming. This heavily impacts local communities and thus requires additional maintenance and management efforts. Nevertheless, the discussion on coastline shortening keeps surfacing when dealing with complex coastal management issues throughout the world. Although adaptive delta management accompanied by innovative approaches that integrate coastal safety with ecosystem services is gaining popularity, it is not yet common practice to include adaptive pathways, a system-based view and ecosystem knowledge into coastal management projects. Here, we provide a first attempt to integrate ecosystem-based flood risk reduction measures in the standard suite of flood risk management solutions, ranging from structural to non-structural. Additionally, for dealing with the dynamic and more unpredictable nature of ecosystems, we suggest the adaptive delta management approach that consists of flexible measures, measurable targets, monitoring and intervention, as a framework for embedding ecosystem-based alternatives for flood risk mitigation in the daily practice of engineers and coastal planners.

1. Flood risk management along estuarine coastlines

Many coastal areas and river basins worldwide are flood prone. Keeping the risk of flooding at an acceptable level is an ongoing challenge. Nowadays the range of options to mitigate flood risk is becoming more diverse, varying from non-structural measures, such as early warning systems and zoning, to traditional structural measures, such as levees, dams, flood detention areas and pumping stations (U.S. Army Corps of Engineers, 2013). The impact of structural measures on natural processes is large and often results in undesirable side effects, such as land subsidence or disturbance of ecosystem functioning and a loss of ecosystem services, with large consequences for local communities. Therefore, the potential of more nature-based flood defense solutions, such as oyster reefs, salt marshes and mangroves, that are thought not to have such negative effects on the natural environment, is actively being explored (Day et al., 2007; Barbier et al., 2008; Borsje et al., 2011; van Slobbe et al., 2013; Cheong et al., 2013). Although these studies make a strong case for application of nature-based defenses and provide valuable information underbuilding the efficiency of nature-based defenses, they do not offer ready to use tools for decision makers and coastal managers.

There is extensive experience in adaptive management of exposed sandy coastlines through nourishment (Nordstrom, 2005). However, in complex estuarine systems, coastline shortening by damming estuaries is often chosen as a means to achieve desired safety levels (Saeijs and Stortelder, 1982; Pilarczyk, 2012). The Dutch Deltaworks illustrate that this approach disrupts natural sediment fluxes and may severely harm ecosystem health, which negatively affects ecosystem services such as freshwater availability due to algal growth and mussel and oyster farming due to reduced carrying capacity (Smaal and Nienhuis, 1992). Additional

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maintenance and management efforts are needed in order to reduce impact on local communities. This requires continuous investment (Smits et al., 2006; Verspagen et al., 2006). Nature-based coastal defenses, most likely including a combination of engineered defenses with restored coastal ecosystems that play an important role in attenuating waves and stabilizing shorelines, can provide an adaptive and robust alternative (Borsje et al., 2011; Temmerman et al., 2013). Here, we review effects of the Dutch Deltaworks on the natural estuarine system and on derived services. We discuss whether damming of bays, estuaries and entire delta systems is still desirable and to what extent nature-based solutions might provide a suitable alternative. For including nature-based alternatives into planning and decision making we integrate these measures into a framework that shows possible structural and non-structural measures for flood risk mitigation.

2. Coastal management in the Netherlands

In the Netherlands, coastal zone management is rooted in the geological background of the area (Fig. 1). The current coast mainly originates from marine sediments, deposited after the last ice age and reworked by wave action. Nowadays, after millennia of continuous sea level rise, sediment supply from the inner shelf is limited and shoreline erosion is the norm (van der Meulen et al., 2007). Ongoing sea-level rise will result in continued erosion of beaches and dunes, which represent the first line of defense against flooding for the most densely populated part of the Netherlands (Fig. 1). In order to prevent the coast from receding, the sand volume in the critical part of the coastal profile is regularly assessed and strategically maintained by nourishments with sandy sediment dredged from offshore (van Koningsveld and Mulder, 2004; Mulder et al., 2011).

Natural processes are harnessed for coastal defense purposes and for maintaining the beach and dune system and continuous optimization of nourishment strategies is also part of the adaptive management approach. Initially, sand nourishment was executed on the beach. However, nourishment under water in the active zone where waves transport sediment towards the beach, turned out to be more effective in distributing sediment equally over the beach, while sediment losses are relatively small (Hamm et al., 2002). Currently, large-scale offshore nourishments in a single downstream location, are being explored. The first trial project is called the sand engine and it is large enough to be visible on Google earth as a small peninsula south of The Hague. The sand that constitutes the peninsula is expected to distribute along the upstream coast over several decades, thereby creating an extremely wide beach area over several kilometers (Stive et al., 2013; van Slobbe et al., 2013). This beach area should enhance natural dune formation and additionally, this method should limit frequency of nourishment, thereby reducing disturbance of benthic fauna.

Besides the availability of sand resources for nourishment purposes, several factors are essential for successful adaptive management of sandy coastlines (Van Koningsveld, 2003; Mulder et al., 2011):

1. a monitoring strategy should be in place,
2. clear targets and goals should be defined such as a benchmark coastal volume or coastline position beyond which coastal erosion is not allowed,
3. monitoring is assessed to determine whether defined goals are met,
4. a clear management plan defines what action should be undertaken in relation to monitoring results,
5. and costs for measures should be budgeted for the long-term.

In the end the main challenge for managing sandy coastlines will be to optimize biodiversity by allowing natural dynamic processes while maintaining reasonable safety levels and keeping costs flexible. A similarly effective, robust and adaptive form of

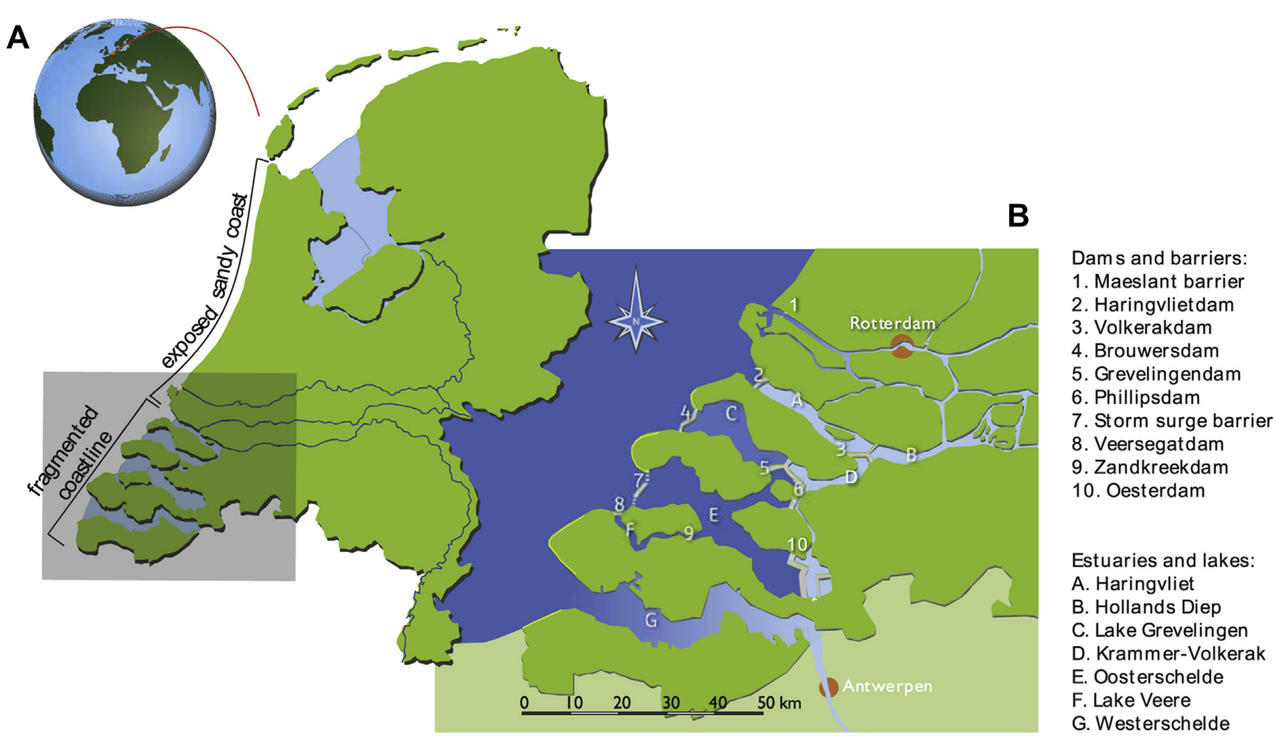

Fig. 1. Coastal management strategies in the Netherlands (51° 32′ 39.84″ N, 3° 53′ 11.23″ E) differ along enclosed coastlines (A) and along more complex estuarine coastlines (A and B). The Dutch Deltaworks close off the major part of the Rhine-Meuse delta, resulting in fragmented water bodies with different management problems (B). Numbers indicate dams and letters indicate water bodies. Different shades of blue indicate different salinities (light blue/light grey water is fresh and dark blue/dark grey water is salt).