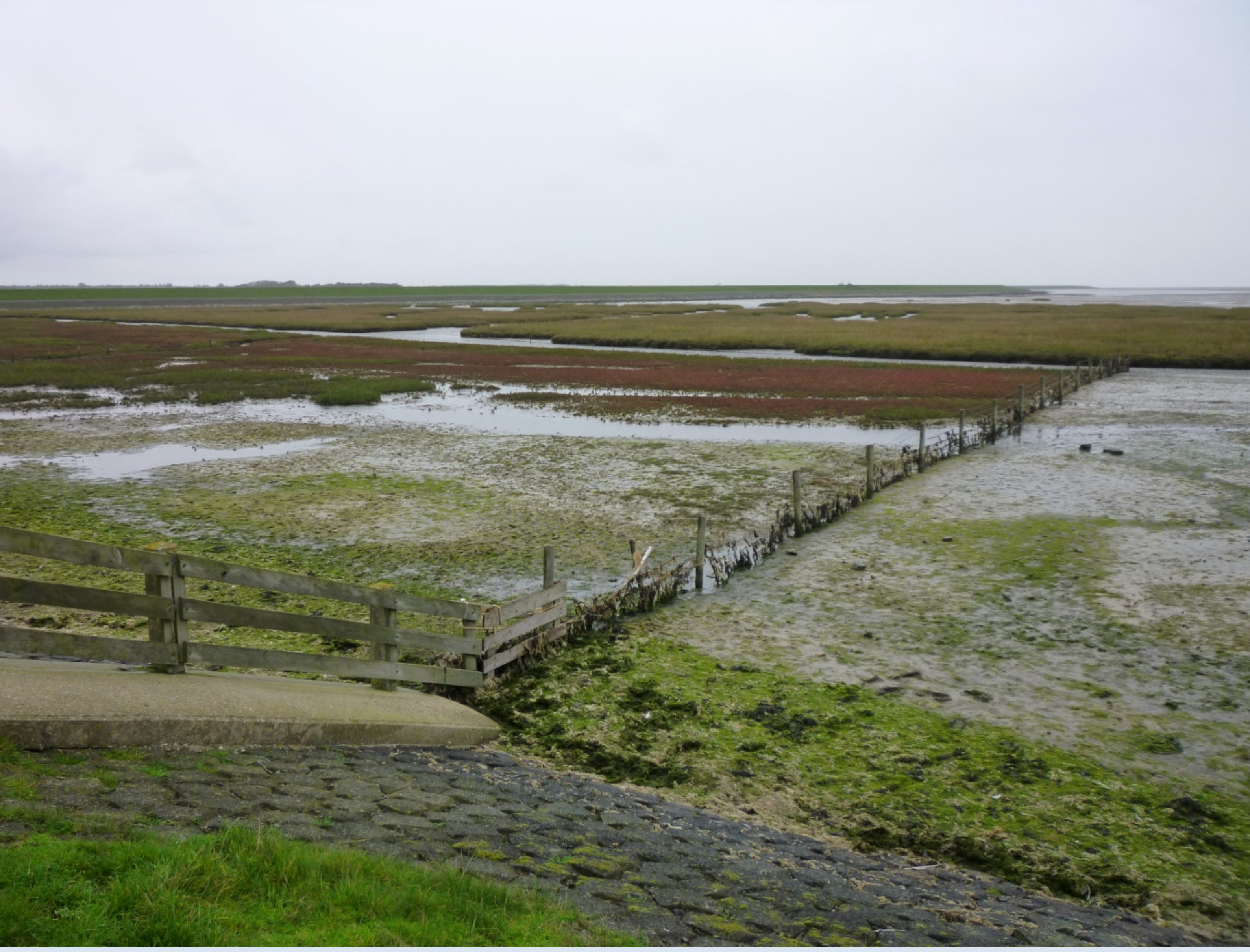
SUMMARY

Salt marshes for flood protection

Long-term adaptation by combining functions in flood defences



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This is a summary of the PhD thesis:
Salt marshes for flood protection; Long-term adaptation by combining functions in flood defences that will be defended on the 8th of October 2014 in the Aula of Wageningen University by Jantsje M. van Loon-Steensma.

Concerns about the effects of climate change have set in motion a quest for flexible and integrated flood protection concepts that could be applied to adapt our environment to the foreseen accelerated sea level rise. The current thesis, focusing on the Dutch Wadden region, explores a number of innovative concepts that combine functions such as nature and landscape conservation with flood defence systems. Special attention is given to the role of salt marshes. Salt marshes form vegetated transition zones from land to water. Their shallow waters break incoming waves, reducing wave length and velocity, ultimately dissipating wave energy via friction with vegetation and the marsh surface. Salt marshes thus function as a natural flood defence. Salt marshes outside dikes can, to some extent, protect these hard defences against wave action and wave run-up.

Chapter 1 of this thesis introduces the Wadden region and the concepts and definitions that underlie this study. The Wadden Sea is one of the world's largest tidal areas. In recognition of its unique tidal ecosystem, it has been designated a World Heritage site. Its nature values are therefore the focus of national and international conservation efforts. The Wadden Sea also performs a key role in protecting the coast of the Netherlands' mainland by its wave-damping capacity, via its barrier islands, tidal flats, banks and salt marshes. The Dutch have a tradition of erecting dikes to defend the barrier islands and mainland against flooding by the Wadden Sea. Inhabitants of the Wadden region have a long history of adapting their environment to their needs, by building dikes and reclamation of salt marshes for agricultural uses. This interaction of human activity and nature has produced a unique flat, open landscape of broad horizons and flood defences. However, the construction of fixed dikes (now measuring some 227 km in length, excluding the '*Afsluitdijk*'), together with the closing of parts of the Wadden Sea and a rising sea level, has also resulted in coastal squeezing and diminishment of natural salt-marsh area along the fringes of the Wadden Sea.

Chapter 2 of this thesis describes the development and application of an approach to adapt the existing flood defences along the Wadden Sea coast to the expected sea level rise in the context of other uncertainties and developments. It starts by developing a dike 'portfolio' introducing both traditional and innovative flood protection concepts. Next, these concepts are evaluated with the input of local experts and using multi-criteria analysis. For application in rural areas, eco-engineering techniques received the highest scores. The construction or conservation of salt marshes for flood protection emerged as a particularly attractive option for the Wadden region, because such marshes could also increase the natural quality of the Wadden Sea landscape. In built areas, multifunctional dikes were perceived as attractive. However, their performance in an integral assessment is strongly dependent on the functions considered and the weights assigned to the different evaluation criteria.

Chapter 3 provides background information on the Wadden Sea's salt marshes and their potential contribution in terms of wave damping. The chapter furthermore screens opportunities to integrate salt marshes into flood defences. The current salt marshes along the coast of the Dutch mainland are the result of constructed accretion works. These works were originally designed for reclamation of agricultural lands, but the goal progressively shifted towards nature conservation from the 1970s onward. Along some dike sections, the salt-marsh zone is rather narrow (a few metres), while at other locations it is more than a kilometre in width. Promising locations for integrating salt marshes into flood defences (based on the current abiotic and biotic conditions) are presented in a '*salt marsh potential map*'. Besides elongated stretches where semi-natural salt marshes are already present (some 73 km), several stretches along the Wadden Sea coast have favourable abiotic conditions for salt-marsh development (some 15 km). However, such development may come at the cost of valuable littoral and sublittoral habitats. At some stretches salt-marsh development would require minimal effort (some 42 km) or considerable effort (some 56 km), in the form of raising the elevation via nourishment and possibly additional measures to prevent erosion and to cushion the unfavourable conditions that led to increased local water depth. Along some 75 km of dike, abiotic conditions are considered to be entirely unsuitable for salt-marsh development.

Chapter 4 sketches the trade-offs between the intentional use – or deliberate creation and management – of salt marshes for flood protection, and other services provided by the salt marshes in the Wadden Sea. Under favourable conditions, salt marshes form self-maintaining 'horizontal levees' that attenuate wave energy, thus contributing to coastal protection. In addition, they host valuable ecosystem services, like biodiversity. Restoration and conservation of salt-marsh zones thus constitutes an attractive flood protection strategy. Climate change influences salt-marsh formation processes through its effect on sea level, wave conditions and vegetation. These factors must therefore be taken into account in developing policy concerning the suitability of salt marshes for use as a climate-change adaptation measure. Protecting and restoring salt marshes using soft engineering techniques represents an interesting 'no regret' adaptation strategy. Moreover, due to the time scale of climate change (long term) and salt-marsh dynamics (short term) there still is some time to experiment with techniques to protect, develop and effectively manage salt marshes.

Chapter 5 presents three case studies to illustrate the potential of salt-marsh development and preservation for coastal defence. The first case study explores and quantifies the effects of low stone dams on salt-marsh development on the barrier islands of Terschelling and Ameland. The dams were constructed to prevent erosion of the marsh edge. Within decades, sedimentation had raised the mudflats between the dam and the former cliff, creating a broader foreshore and a new marsh area with characteristic salt-marsh vegetation. The second case study examines the impact of erosion and restoration measures on habitat development and on the flood protection value of a small salt marsh along the Wadden Sea dike of Terschelling. The third case study focuses on a location where salt marshes are combined with a ‘wide green dike’ along the Dollard Estuary. The case studies reveal that under favourable abiotic conditions, erosion protection by low stone dams greatly reduces retreat of the salt-marsh edge, while also helping to restore an ecologically attractive foreshore zone. Both the areal extent and vegetation of the restored salt marsh affect wave height. Findings from the Dollard case study indicate that implementation of a wide green dike comes at the expense of salt marsh area, yet it offers a more natural transition from the marsh area to the grass-covered dike, especially in comparison with a traditional reinforced dike (which is covered by asphalt or a stone revetment).

In chapter 6, the ecological value of stabilized and restored salt marshes is further quantified by comparing vegetation relevés made at two study sites with a reference set consisting of some 6,000 relevés of salt marshes throughout the Dutch Wadden region. Both simple species-by-species analysis and ordination analysis reveal that salt-marsh succession alongside low dams is no different from normal succession starting on unprotected mudflats. Therefore, measures targeting salt-marsh development for flood protection objectives do not necessarily frustrate nature conservation ambitions.

Chapter 7 explores the effect of salt-marsh vegetation on wave damping by modelling wave height for different salt-marsh scenarios. Data on species composition, vegetation height, number of stems and diameter of the plant species observed at study site Grië were used to parameterize and apply the Simulating WAves Nearshore (SWAN) model to investigate a – schematized but realistic – restored salt-marsh zone in front of the dike. The modelling results confirm that in addition to the width and height of the foreland, vegetation characteristics like stem density, stem diameter and height of plants also affect the wave-damping capacity of forelands.

Chapter 8 brings together the most important findings. On the whole, this thesis shows that integration of salt marshes into long-term adaptation strategies is very promising for the Wadden region, especially for dike sections where salt marshes are already present or developing. The salt marshes of the Wadden Sea form a shallow foreland that dampens incoming waves. Explorative modelling indicates that integration of salt-marsh forelands into Wadden Sea flood defences could reduce, or postpone, the need for reinforcement works along several Wadden Sea dike stretches. In a changing climate, however, integration of salt marshes into flood defence systems cannot entirely replace future reinforcement works whereby the crest of the dikes is raised. Salt marshes affect wave action and wave run-up, but they do not prevent overflow under conditions of a rising sea level.

This thesis confirms that vegetation is a major factor in the wave damping capacity of salt-marsh forelands. The analyses also reveal the considerable potential impact of vegetation in the different salt-marsh zones, and thus the importance of the spatial distribution of the various vegetation types typically found in natural salt marshes. Hence, over-simplified experiments or simulations that do not take into account the zonation of different plant morphologies may lead to biased (or at least imprecise) conclusions. Furthermore, when considering adaptation strategies that include vegetated foreshores, it is advisable to pay attention to salt-marsh vegetation management. For more optimal flood protection, management should favour salt-marsh plant communities with the greatest wave-damping characteristics and include spatial and temporal aspects.

Finally, this thesis reveals that in salt-marsh restoration, the goals of flood protection and nature and habitat conservation and enhancement can be mutually reinforcing.

Some chapters are published as an article:

Van Loon-Steensma, J.M., Schelfhout, H.A. & Vellinga, P., 2014. Green adaptation by innovative dike concepts along the Dutch Wadden Sea coast. Environmental Science & Policy 44:108-125.

Van Loon-Steensma, J.M. & Vellinga, P., 2014. Robust, multifunctional flood defenses in the Dutch rural riverine area. Natural Hazards and Earth System Science 14(5): 1085-1098.

Van Loon-Steensma, J.M., Slim, P.A.. Decuyper, M. & Hu, Z., 2014. Salt-marsh erosion and restoration in relation to flood protection on the Wadden Sea barrier island Terschelling. Journal of Coastal Conservation 18:415-430.

Van Loon-Steensma, J.M. & Vellinga, P. 2013. Trade-offs between biodiversity and flood protection services of coastal salt marshes. Current Opinion in Environmental Sustainability 5(3-4): 320-326.

Van Loon-Steensma, J.M. & Slim, P.A., 2013. The Impact of Erosion Protection by Stone Dams on Salt-Marsh Vegetation on Two Wadden Sea Barrier Islands. Journal of Coastal Research 29(4): 783-796.