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1. Introduction

The Netherlands is a low-lying country with a sediment-rich coastal system, comprising a closed beach-dune coast (Holland Coast) and an interrupted barrier coast with tidal basins (Wadden Sea and Southwest Delta). At present, the Dutch coast is managed using a dynamic conservation strategy, developed using the results from the first Coastal Genesis (Kustgenese) research programme in the 1980's and 1990's. The coastline and the coastal foundation (the area between the landward boundary of the dunes and the 20 m iso-depth line) are maintained with sand nourishments. Anticipating a future acceleration in sea level rise, this management strategy may require a significant increase in the annual nourishment volume, raising questions on the sustainability of the strategy. Therefore, Rijkswaterstaat initiated, funded, and coordinated (together with research institutes and universities) the Coastal Genesis 2 (Kustgenese 2) research programme from 2015 to 2021, aiming at the development of a future-proof long-term coastal management strategy.

This research programme, carried out in cooperation with Deltares, various universities (via the NWO project SEAWAD) and private parties, has resulted in recommendations adopted by the Dutch Ministry of Infrastructure and Water Management and Parliament, and scientific insights on the Dutch coastal system, which are interesting for coastal scientists and managers worldwide. The papers in this special issue describe selected scientific results and the policy impacts from this research programme.

In the early 1980's, interest arose in the natural evolution of the Dutch coast on long time scales and at large spatial scales to complement the then predominant physical-mathematical investigation of coastal processes. The resulting ten-year Coastal Genesis 1 programme was initiated in 1985 and brought together academics, practitioners, and policy makers from diverse disciplinary backgrounds, including geology, historical and physical geography, engineering, oceanography, and ecology. It aimed to deepen understanding of (natural) coastal evolution and its drivers to inform coastal management. The need to shift from an *ad hoc* response to a management approach based on a scientific understanding of the natural coastal evolution was captured in the document entitled 'A new coastal defence policy for the Netherlands' (Ministry of Transport and Public Works, 1990). Following two major storms in January and February 1990, which caused substantial erosion

Abbreviations: NWO, Nederlandse Organisatie voor Wetenschappelijk Onderzoek (Dutch Research Council).

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along all of the Dutch coast, the policy of 'holding the (coast-) line' with sand nourishments was adopted in practice and persists to this day. This flexible approach has been quite successful as the nourishments not only have maintained the coastline, but they also have created a net gain of sand for the Dutch coast, against relatively low costs. The knowledge and understanding acquired in the first Coastal Genesis programme therefore formed the basis upon which Coastal Genesis 2 programme rests, namely knowledge of the long-term and large-scale (viz. Holocene) evolution of the Dutch coast and the drivers of the development of the beach-dune coast of Holland and the barrier/back-barrier basin coast of the Dutch Wadden Sea at meso-scales.

2. Outline of this special issue

This special issue consists of three types of papers, representing three core aspects of the Coastal Genesis 2 programme, namely the interface between science and policy, the long-term dynamics of the lower shoreface, and the Wadden Sea tidal inlet systems:

- *Part 1: Research agenda, operational experience and policy development*
- *Part 2: Lower shoreface of the Dutch coast*
- *Part 3: Wadden Sea tidal inlet systems*

2.1. Part 1: research agenda, operational experience and policy development

Undertaking research that informs policy is a challenging task from the perspective of both the researchers and policy makers. The Coastal Genesis 2 programme is a scientific programme, focussed primarily on the biophysical environment of the Dutch coast, that yet succeeds in influencing coastal policy. The papers in Part 1 of this VSI seek to clarify how this came about by first addressing how the research agenda was determined (Lodder and Slinger, 2022), then explaining how experiential knowledge from nourishment practice informs policy (Brand et al., 2022), and finally by highlighting the pivotal role played by a shared conceptual model of the long-term sediment budget of the Dutch coast in achieving lasting impact on coastal policy (Lodder et al., 2022/3).

"The 'Research for Policy' cycle in Dutch coastal flood risk management: The Coastal Genesis 2 research programme" by Lodder and Slinger (2022) describes the development of the Coastal Genesis 2 research programme and its role in contributing to Dutch coastal policy. By detailing the conceptual model of the long-term sediment budget, the paper demonstrates how key uncertainties related to this model guided the determination of the research agenda for Coastal Genesis 2.

"Dutch experience with sand nourishments for dynamic coastline conservation – An operational overview" by Brand et al. (2022) provides an overview of the operational aspects of the more than 300 nourishments along the Dutch Coast since the 1990s and discusses the evolution of the nourishment approach and lessons learned. It draws on measurement data to demonstrate how the combination of beach, dune and shoreface nourishments has succeeded in preserving the coastline at its desired position and enabling the coastal zone to stay in equilibrium with sea level rise over the past 30 years.

"The Coastal Genesis 2 research programme: Outputs, Outcomes and Impact" by Lodder et al. (2023) analyses the substantive scientific contributions of the Coastal Genesis 2 research programme by applying an output-outcome-impact framework. The analysis highlights that synthesizing new scientific insights into shared conceptual models is critical to achieving impact in policy and practice. It demonstrates how in the Dutch situation a new shared conceptual model of the long-term sediment demand enabled advice on the sustainability of nourishment strategies, and a recommended strategy. The adoption of the recommended strategy until 2032 represents a lasting impact of the Coastal Genesis 2 research programme in policy and practice.

2.2. Part 2: the lower shoreface of the Dutch coast

Besides the question how much sediment is required for the coastal foundation to remain in equilibrium with sea level rise, the offshore boundary of the coastal foundation was also under discussion. To decide on alternative boundaries, more information on the net supply of sand from the inner shelf of the North Sea to the shoreface of the Dutch coast, and the distribution of sand over the shoreface is needed. Since sand transport in the surf zone is comparatively well known, the focus of this part of the Coastal Genesis 2 programme was on the lower shoreface (LSF), approximately between 8 m and 20 m water depth. After a survey of published reports and journal papers on the LSF of the Dutch coast, the requirements for a field campaign to collect data were determined. Two study areas were selected to establish similarities and differences in composition and processes between the Holland and Wadden coasts, and one area at the outer slope of the ebb-tidal delta of Ameland Inlet, to determine the contrast between barrier island and ebb-tidal delta. Moreover, the study area at Ameland Inlet links to the tidal inlet research in the programme. For all the study areas a field campaign including coring, echo sounding, and process measurements was designed. Decadal-scale developments were studied using the yearly surveyed coastal profiles (Jarkus data set). In addition, a numerical model was developed using D Flow Flexible Mesh software to calculate sand transport over the lower shoreface.

The paper "The lower shoreface of the Dutch coast – An overview" by Van der Spek et al. (2022b) presents an overview of the results from both the literature survey and the collected field measurement data. It describes the interpretations and conclusions based on the collected vibrocores, box cores, multibeam sonar bathymetry, and in-situ measurements of flows, sediment concentrations and micro morphology. Moreover, the results of the numerical modelling are discussed briefly. The multibeam surveys in 2017 and 2018 revealed several types of shore-oblique and -normal gullies between −12 m and −18 m, especially after high-wave events. Some of the gullies are excavated into Holocene clay deposits, others were formed by cross-shore flow under high waves. All suggest seaward sand transport. The paper concludes that the variation in shoreface composition and morphology is larger than previously anticipated and that the modelled net landward sediment transfer needs to be further verified.

The investigations of the vibrocores, sand transport modelling and process measurements are presented and discussed in separate papers. The paper "Holocene deposits at the lower shoreface and inner shelf of the Dutch coast" by Van der Spek et al. (2022a) presents detailed insights into the composition and distribution of Holocene deposits at the surface and in the shallow subsurface of the LSF. The deposits in the collected vibrocores indicate remarkable differences in evolution: the Terschelling LSF does not consist of the deposits of a transgressive barrier island but was formed as part of an ebb-tidal delta. Resuspension of seabed sediments by storm waves followed by post-storm settling, produces typical 1-m-thick fining-upwards sequences at Noordwijk. At Terschelling these sequences are missing; here the active sediment layer is only 0.2 m thick which suggests removal of the resuspended sediment during storms and structural erosion of the lower shoreface.

The paper by Grasmeijer et al. (2022) presents a modelling study on the annual sand transport rates at the Dutch LSF. The results show that the total cross-shore transports, determined by asymmetrical peak tidal velocities, density-driven residual flows, wind-driven residual flows and waves, are directed onshore over the continuous 20 m, 18 m and 16 m depth contours and increase with decreasing water depth.

The paper "Observations of near-bed orbital velocities and small-scale bedforms on the Dutch lower shoreface" by Van der Werf et al. (2022) presents the measurements of orbital velocities and bedforms at various depths and locations on the Dutch LSF. The new data indicate significant sediment mobility at the LSF under higher wave events. The data are used for supporting detailed simulation modelling to determine LSF net transport rates, and to unravel the controlling sand transport mechanisms.

2.3. Part 3: Wadden Sea tidal inlet studies

The sediment exchange between the North Sea coast and the Wadden Sea is influenced by sea level rise and human interferences such as the closure of the Zuiderzee in 1932 and the closure of the Lauwerszee in 1969 (Elias et al., 2012). This remains a focus in the Coastal Genesis 2 programme as it is key to the sediment budget of the Dutch coast and it is necessary for the intertidal flats to keep pace with sea level rise, and so maintain the ecological value of the Wadden Sea. The sediment exchange through the tidal inlets of the Dutch Wadden Sea and their consequences for the intertidal flats are predicted up to 2100 under diverse future sea level rise scenarios using the aggregated model ASMITA (Lodder et al., 2022; Huismans et al., 2022). Process-based modelling and extensive field measurement campaigns were also carried out to study the processes and mechanisms involved in the sediment exchange across tidal watersheds (Van Weerdenburg et al., 2021). The smaller scale morphodynamic and ecological processes on the ebb-tidal delta of Ameland Inlet are analysed using field data to investigate if the ebb-tidal deltas of the tidal inlets are suitable locations for large-scale nourishment, anticipating that the required amount of sand nourishment for maintaining the coast will substantially increase with accelerating sea level rise (Elias et al., 2022; Pearson et al., 2021; Holzhauer et al., 2022). Nourishments on an ebb-tidal delta can serve multi-purposes: maintaining the size of the ebb-tidal delta, feeding the downdrift coast and stimulating sediment import to the Wadden Sea. The pilot nourishment on the ebb-tidal delta of the Ameland Inlet demonstrated that this type nourishment forms a useful tool for the coastal nourishment strategy (Elias et al., 2022).

"Understanding meso-scale processes at a mixed-energy tidal inlet: Ameland Inlet, the Netherlands – Implications for coastal maintenance" by Elias et al. (2022) presents the intra-delta dynamics of Ameland Inlet using extensive field data from bathymetric surveys and hydrodynamic observations. It is shown that Ameland Inlet can be classified as a typical mixed-energy, wave-dominated system. However, the ebb-tidal delta contains distinct areas that are either wave or tide dominated, and it is the updrift island rather than the delta sand body that forms the sediment source for the back-barrier basin.

"Tracking fluorescent and ferrimagnetic sediment tracers on an energetic ebb-tidal delta to monitor grain size-selective dispersal" by Pearson et al. (2021) studies the dispersal of dredged sediment placed as a sand nourishment on the ebb-tidal delta of Ameland Inlet using dual signature (fluorescent and ferrimagnetic) sediment tracers. The observations show that preferential transport as a function of grain size is a key process in shaping the morphology of ebb-tidal deltas, governing the dispersal of sand nourishments on the ebb-tidal delta.

"Future sediment exchange between the Dutch Wadden Sea and North Sea Coast - Insights based on ASMITA modelling" by Lodder et al. (2022) presents projections of the future sediment import to the Dutch Wadden Sea from the North Sea using the aggregated morphodynamic model ASMITA for five sea level rise scenarios. It is shown that the import rate increases with accelerating sea level rise, but the differences in the projected import rates between the five sea level rise scenarios until 2100 are not as large as the differences in sea level rise rates may suggest.

"Development of intertidal flats in the Dutch Wadden Sea in response to a rising sea level: Spatial differentiation and sensitivity to the rate of sea level rise" by Huismans et al. (2022) explores the effects of sea level rise on the intertidal flats in the Dutch Wadden Sea using the ASMITA simulations by Lodder et al. (2022). It is shown that the intertidal flats are sensitive to the sea level rise rate and the larger basins are most vulnerable to drowning. The intertidal flats in the smaller basins mainly reduce in average height, while those in the larger basins mainly reduce in surface area. Within the basins, the largest losses are expected to occur just adjacent to the land reclamation works and along the western part of each tidal watershed.

"The geomorphology of an ebb-tidal-delta linked to benthic species distribution and functionality" by Holzhauer et al. (2022) describes an investigation of the macrobenthic fauna distribution at the ebb-tidal delta of Ameland, using a unique dataset of 166 benthic and sediment samples. It is shown that small, short-lived, surface deposit-feeding, highly mobile, burrowing organisms dominate in the most exposed sites, whereas long-lived, filter-feeding and sessile organisms become more dominant in more sheltered sites. This suggests that the fauna of the most exposed sites will likely show a faster recovery from disturbance by sand nourishments than those on sheltered parts of the ebb-tidal delta.

"Field measurements and numerical modelling of wind-driven exchange flows in a tidal inlet system in the Dutch Wadden Sea" by Van Weerdenburg et al. (2021) studies the wind-driven fluxes over two tidal watersheds separating the back-barrier basin of Ameland Inlet from the neighbouring basins and the residual flow of water through the Ameland Inlet, based on flow measurements and numerical modelling. Due to the difference in flow carrying capacity the total volume exchanges at the two tidal watersheds are different, leading to an outward residual compensation flow through the inlet during winds from the prevailing southwestern wind direction.

3. In conclusion

The papers in this special issue describe major results from the Coastal Genesis 2 research programme in the Netherlands and demonstrate how the scientific insights are implemented in Dutch coastal policy and practice. It is our hope that the contents of the special issue are of deep interest and relevance to coastal researchers and managers worldwide. Additional results from the Coastal Genesis 2 programme can be found within the complementary SEAWAD project (4 PhD theses in total of which 3 are published: Brakenhoff, 2021; Pearson, 2022; De Wit, 2022), which is co-financed by the Dutch Research Council NWO and by Rijkswaterstaat as part of Coastal Genesis 2.

It is now more than two years since we initiated the virtual special issue Future Dutch Coast, and we are proud and pleased to successfully conclude this initiative. We extend particular thanks to the authors who contributed the papers in this special issue, and to the reviewers who constructively criticized their submissions. Without the efforts of the authors and reviewers there would be no special issue. Similarly, the successful completion of this VSI would not have been possible without the cooperation of the editorial board and the editorial office of the Journal of Ocean and Coastal Management. We are indebted to the late Editor-in-Chief Prof. Victor de Jonge, who helped with the initiation of this VSI but could unfortunately not see the results. We would like to thank Prof. Xiuzhen Li, the managing editor for this VSI, for her valuable support throughout the process and especially for arranging independent review of the final paper of which all guest editors are (co-)authors. This special issue was supported by a contribution from the Wadden Academy within the framework of development and sharing of knowledge on the morphological development of the Wadden Sea area.

Finally, to our readers, we extend the invitation to explore the Future Dutch Coast.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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