RESEARCH PERSPECTIVES ON ECOLOGICALLY-WISE MEANS OF COASTAL PROTECTION – CURRENT DEFICITS AND FUTURE DEMANDS

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Throughout history and continuing into the modern age, coastal and estuarine zones have been a place of preferred settlement, for its abundant food sources, yield-rich soils, trade opportunities, and favorite climatic conditions. Population in these areas has grown significantly, hence exacerbating the negative effects that dense settlements have on the surrounding environment and coastal communities.

New elevation data, employing artificial neural networks to improve upon coastal digital elevation models (SRTM products[1]), yield a population of up to 630 million people at risk from extreme coastal water levels under a high emission scenario[2]. Numerous problems related to higher rates of population growth and stronger trends of urbanization along coastlines have been addressed revolving around waste management, sustainable transportation solutions, air/water quality, soil degradation, and so forth, applying to mid-size and mega-cities alike. The benefits coastal locations offer are balanced by the challenges driven by population growth and rapid urbanization. The onset of emission-induced climate change and related sea level rise tendencies have though aggravated the situation along the world's coastlines, since efforts to maintain and develop existing coastal defense infrastructure turn more and more costly. Coupled with sea level rise and increased storminess is the observation that up to 24% of our globe's coastlines are eroding at a rate of 0.5 m/yr or higher[3], thus increasing the pressure exerted on coastal defenses.

Ever-growing evidence suggests that sea level rise will continue for the decades to come. Depending on the effectiveness of human intervention through cuts in greenhouse gas emissions, the world's coastlines will see mean SLR relative to the mean sea level of 1986-2005 ranging between +43 cm in 2100 (RCP 2.6, "Paris scenario") to +84 cm (RCP 8.5, "business as usual scenario"). Global mean sea levels have been recently reassessed, confirming trends of 3.1±1.4 mm/yr consistent with satellite altimetry (1993-2012)[4]. The debate about the definition of "Coastal Squeeze"[5],[6] has brought attention to the detrimental effects that anthropogenically-enforced coastal landward defense and SLR plus increased storminess on the ocean side have on ecosystems and their associated services. In recent years, research has hence started to investigate the status and services of coastal and estuarine ecosystems, as well as

Figure 1. Dynamic development of natural mudflats and salt marshes in the re-opened summer polder Langwarder Groden, Lower Saxonian coast. Access is provided by log paved paths (credit Jan Visscher).

their functioning mechanisms. These questions are increasingly relevant, as communities and academia have started to debate choices of robust adaptation measures varying from "hold-the-line" to "managed retreat" approaches. Adaptation to SLR along coastlines requires a more fundamental understanding of system-wide, holistic functionalities and feed-back mechanisms, without which sustainable coastal engineering design and integrated coastal zone management cannot be done.

In this context it remains unclear how much coastal defense infrastructure benefits from regulating ecosystem services, how the inter-connections between engineered structures such as dikes and natural dune systems with adjacent salt marshes and tidal flats actually depend on each other, and how co-benefits could be efficiently resourced with respect to future coastal defense developments. This article hence attempts to provide insight into a current research approach in Germany, along its North Sea coastline, aiming at *ecologically-wise means of coastal protection* that is conducted in close contact with research partners in governmental agencies, local stake-holders, and nature conservation groups in order to derive a *co-design* to implement adequate nature-based solutions in coastal protection. It covers the interrelation between existing ecosystems located in close vicinity of the coastal defense infrastructure, and also encompasses an emerging, but invasive ecosystem – a Pacific Oyster reef - in the German Wadden Sea, that has started to thrive extensively to the extent that it starts altering incoming waves and currents.

Examples of German Coastal Research

In this context, two recent examples of German coastal research showcase the increased necessity to strive collaborating across science fields. Addressing research questions that extend the scope of traditional engineering interest and contexts, such as wave run-up or subsequent overtopping on coastal dikes, demands the inclusion of relevant disciplines that provide fundamental knowledge of ecosystem functioning and species-related response to typical wave and current-induced loads and impacts. Coastal Engineering research has gradually undergone a transfor-mation, as the following two examples of research projects testify to the change taking place.

- ***Real-world laboratories along the Lower Saxony coastline – "Gute Küste Niedersachsen"***

Scientists and decision makers in the federal State of Lower Saxony mutually agree that the named challenges can only be faced by combining coastal defence with habitat conser-vation and strengthening of ecosystem services and thus addressing all aspects of the socio-ecological system. "*Gute Küste Niedersachsen*" (in English: Good Coast Lower Saxony) addresses the question how such a state of well-being, i.e. a good coast, could look like and provides baseline data and process under-standing to transform traditional technical coastal defence and its strategies towards a sustainable integrated management solution. Figure 1 provides an aerial impression of a typical northern German coastline with salt marsh-lined foreshores adjacent to a traditional grass-covered dike[7]; in many instances, secondary lines of coastal defence have been retained, now adding to the complexity that such protection systems exhibit.

Previous work has shown, that consideration of regulating ecosystems services such as wave attenuation and soil stabilization in coastal defence strategies is generally feasible as coastal vegetation has been proven to provide such a service under a wide range of condi-tions[8],[9],[10]. The required next step undertaken in the project "*Gute Küste Niedersachsen*" is to parameterise these processes for their integration in forecast models and design equations. For an *exemplary coast*, however, other habitats and ecosystem services need to be considered that may not directly be associated with coastal defence. Given the competition for space along the coast, multi-functionality needs to be considered for all parts of the coastal defence belt including dike revet-ments[11]. Dikes in Lower Saxony are dominated by monoculture grass revetments and solutions will be sought to improve their ecological value by adapting seeding-mixtures and maintenance routines towards a higher supply of food for insects and higher aesthetics due to increased diversity in flowering colours. The challenge is to maintain the high resistance against mechanical stress from wave run-up and breaking as requirement for a dike revetment.

Finally, coastlines requires reliable planning and approval procedures which allow efficient imple-mentation of necessary management and construction solutions. Next to short communi-cation pathways between and among science and decision making in this context is the communication with the civil society which needs to support the decision-making process and its results. To integrate solutions to the above challenges on the way towards an

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exemplary coast, "*Gute Küste Niedersachsen*" operates a set of real-world laboratories. Designated field sites serve as joint and sustained research work spaces in which scientists from all relevant disciplines work together with local stakeholders and decision makers to assess the efficacy and effect of novel coastal defence and management concepts in order to establish transformatory knowledge based on enhanced system understanding[12].

- ***Introduced species and their impact on the German Wadden Sea – BIVA-WATT***

The Pacific oyster *(Crassostrea gigas)* has populated most of the former existing blue mussel beds *(Mytilus edulis)* in the German Wadden Sea[13]. As ecosystem engineer, oysters build reef structures which provide food and habitat for other species (Figure 2) and ecosystem services for coastal engineering[14]. There is a strong link between energy reduction through rough seabed, shallow water conditions provided through the reef systems and local dampening of sea states, eventually impacting mainland dike infrastructure, thus ecosystem services co-regulating coastal defense functioning. Oyster reefs are extremely resistant to mechanical stress exerted through waves, currents and ice drift; their impressive growth rates hence are not slowed by mechanical disturbances. The effects of reef formations on hydro- and morphodynamics in the Wadden Sea have been so far largely ignored in research. Oyster reefs are hypothesized to have an influence on the ecological composition of the Wadden Sea, on the bathymetry of shipping lanes, as well as on the long-term terrain elevation or vertical diversity in the light of climate change. Field and laboratory investigations on the Pacific oyster and the blue mussel under hydrodynamic load are the focal point of a current research project including experimental investigations, focussing on the effects of oyster reefs on waves and currents. Methodologically, the research questions are addressed using field studies to determine relevant distribution patterns and geometric parameters, laboratory investigations on wave and current effects, as well as conceptual work on the future numerical modelling of relevant processes. Considerations are made on the parameterisation of rough reefs and blue mussel beds for the experimental investigations. To this end, ecological parameters, such as abundance distributions, coverage rates as well the location of selected oyster reefs and mussel beds are determined and digitalised by 3D scanners. Based on this data and a parameterised characterisation, appropriate production methods for manufacturing laboratory specimen involving a digital building fabrication laboratory (i.e. a CNC-controlled milling and printing of concrete) for the models are investigated in terms of their suitability. Roughness and wave dissipation parameters are obtained for use by coastal engineers and authorities in numerical modelling including the growth state variation and spatial distribution of oyster reefs, which are necessary to answer hydrodynamic and morphodynamic issues.

Figure 2. Pacific oyster patches and close-up of individual oysters functioning as ecosystem engineer (credit: Nils Goseberg)

Conclusions and Outlook

Ecologically-wise means of coastal protection are required along densely populated and urbanized coastlines and demand answers and insights that are not yet available. Through two current research examples it has been shown that a deeper understanding of processes and effects is needed to provide timely and accurate knowledge-based policy recommendations, which requires multi-facetted research. In that regard, it is paramount to overcome currently existing disconnections between the general public, responsible stakeholders and the science community, which offers well-researched future scenarios in delivering a co-design of either effective coastal protection or managed re-allignment of (over) exposed coastlines. Effective communication between the involved and responsible parties is more important than ever before in history. Ecologically-wise means of coastal protection has a potential that has yet to be lifted, with joint efforts between traditional engineering measures in combination with strong insight into ecosystems provided by natural science disciplines. Social sciences are equally important as stakeholder processes and science-based research dissemination is nowadays critical to the overall success of implementation measures. Harmonizing design guidelines and standards with spatio-temporal effects of ecosystem contributions to coastal defence will require continued trans-disciplinary research and openness of all stakeholders and the public, ideally combined with real-world laboratory approaches combining co-design and co-living aspects of local communities at risk.

Future research in the coastal realm will continue to deepen our understanding of the abiotic nature of the coastal dynamics, however it will have to capitalize on a more holistic understanding of the biotic aspects of coastal systems. Examples of future research scope – and that list is by no means exhaustive – could be the stabilizing/destabilizing effects of biogenic activity on coastal sediment dynamics, holistic-functional modelling of food web-ecosystem-physical feedback, and ecologically-wise combinations of innovative coastal defence infrastructure effectively complemented by regulating services of ecosystems. ■

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