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ENGINEERING THE ECOSYSTEM SERVICES OF THE SAND MOTOR

To actually design for sandy solutions, designers need to know the key factors that drive ecosystem services. This section will look at the key factors that drive the three main ecosystem services of coastal defense, recreation and nature development, followed by a description of how to evaluate these. Finally, an example of arguable the most important design factor is discussed.

Drivers of the main ecosystem services
Coastal defense
The dunes landward of the Sand Motor need to grow to increase coastal safety from flooding. Sediment composition will determine how effective this process is; this involves the mean sediment diameter, the sediment grading, and the presence of shells (Figure 1). Simulations suggest that if shells had not been present in the nourished sand, much more sand would have been transported from the crest of the Sand Motor. In addition, the Sand Motor developed an armor layer which resulted in relatively limited wind-blown transport activity. This was largely due to its height. If the Motor had been lower and the dry beach had experienced more frequent flooding, the development of the armor layer might have been limited, thus stimulating aeolian activity. Similarly, the dune lake and lagoon intercepted much of the sand transported from the low-lying beaches, limiting the possibilities for embryonic dunes to form. If these water bodies had been smaller or in different locations, local dune growth might have been stimulated. The long-term effects of the trapping remain to be seen, because at some point these reservoirs of fine, wind-blown sand will become available, as the waves and currents continue to erode the Sand Motor.

Figure 1. (left) Photo of the variation in grain size diameter of the nourished sand taken at the cliff (Photo by Iris Pit)

Recreation
The Sand Motor has become a hot spot for kite surfers, due to relatively flat waters in the lagoon combined with an undisturbed sea wind; in addition, the neighboring open waters provide more challenging conditions. A design without a lagoon would not have attracted kite surfers, although other beachgoers seemed complained about the smells generated by the lagoon.

Swimmer safety can be increased by minimizing tidal eddies and rip-currents. This can typically be achieved by reducing bathymetry gradients as well as preventing alongshore variability in sandbar dynamics. To some extent, this can be engineered by changing the size and shape of the nourishment, the bathymetry and grain diameter of the nourished sand. Of course, catering for such various recreational activities requires many physical and social factors to be considered, and this leads to tradeoffs. The sheer size and uniqueness of the Sand Motor seem to be the main factors driving recreation; however, in future nature development and suitability for recreation need to be explicitly considered when designing sandy solutions.

Nature Development
The Sand Motor has created habitats that do not normally occur along the linear sandy beaches of the Dutch coast. At first, the lagoon promised to be a biodiversity hotspot, as it accumulated mud and organic material and became a productive habitat for benthos and young fish. However, after some years, high oxygen loss and low seawater exchange soon resulted in anoxia and loss of life in parts of the lagoon deeper than two meters. A shallower lagoon could have evolved faster into a green beach, which would have created a much rarer habitat type than the one that has now developed. Furthermore, the lagoon side of the Sand Motor has created a location where fine materials, like clay particles and organic material, can be deposited. This material attracts soil organisms related to a tidal flat, but it can also bring contamination. Even though the contamination is relatively low and harmless to humans, it might hinder soil organisms from creating large populations.

Research into benthic species has shown that they can recover rapidly from such a large disturbance (within a few years) as long as the grain size composition of the sediment has not changed. However, since the nourished sand in the Sand Motor is coarser, long-lasting changes will occur if the coarse fraction remains in place. As the Sand Motor is expected to continue to act as a "sediment sorter", this could have long-lasting effects on the composition of foreshore fauna. Selecting an appropriate sediment size and composition for a beach nourishment are key factors for the development of the marine ecology.

Study of the intertidal zone after the creation of the Sand Motor indicated that macro-invertebrates started to colonize the new beach within a year and continued throughout the study period. Another striking discovery was that different

Figure 2. Predicted bathymetric evolution between 2011 and 2040 of the present Sand Motor.

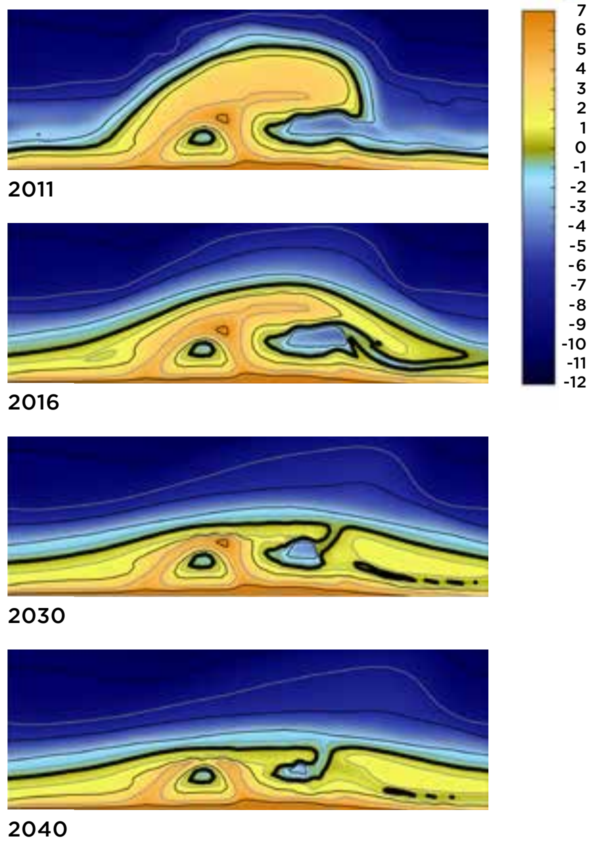


Figure 3. Time series of the predicted development of the surface area of the sheltered subtidal ecotope (lagoon area).

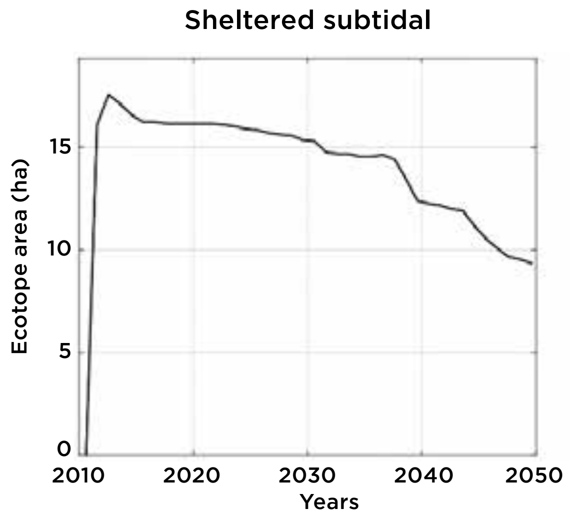
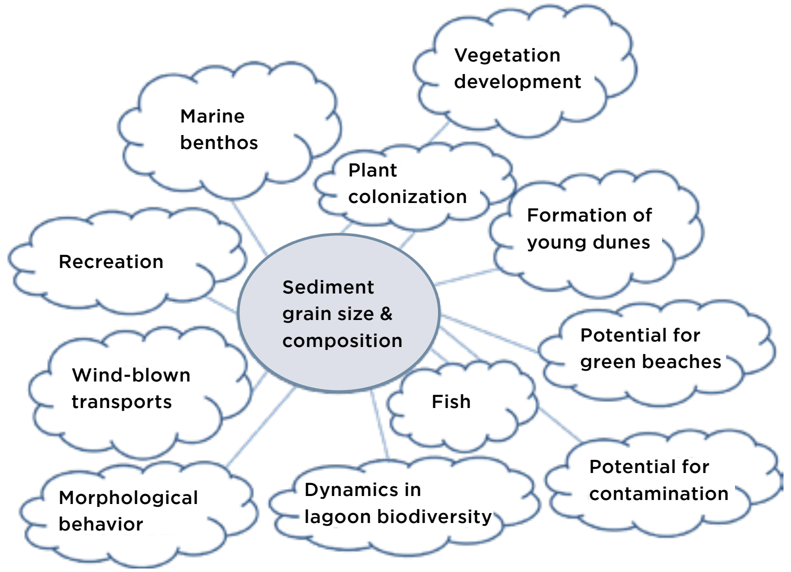


Figure 4. (far below) The many relations of the sediment grain size and composition to other processes and aspects at the Sand Motor.



invertebrate communities occur at different locations within the Sand Motor. This is due to the currents, but also to the design of the Sand Motor, with the lagoon playing a very important role. To increase the diversity of the beach communities, future designs should try to create more diverse “beachscapes”.

Research on new dune development away from the existing dunes showed that the high, barren plain of dredged sea bed material hampered perennial plants from colonizing, because root stalks transported by storms could not reach the higher elevations. Wind-blown seeds that could reach these elevations found conditions that were too dry to germinate, and the steadily lowering bed level due to wind erosion did not help either. Without perennial vegetation, it was hard for permanent dunes to form on the dry beach. Thus, the sediment composition and crest height are two important factors that affected the development of vegetation at the Sand Motor. Another surprising factor is the effect of human behavior. The seaward expansion of vegetation was affected by activities such as raking the beaches, driving on them for supervision and research, and construction of beach huts; this slowed the development of vegetation and new dunes.

All in all, “nature development” covers many different facets of the vast and complex Sand Motor ecosystem, and there are many factors behind these developments. Although using a broad term like “nature” will get many stakeholders on board, designs for sandy solutions should have specific ecological aims that can be readily monitored. All these factors need to be incorporated when designing and evaluating Building with Nature solutions with specific emphasis on nature development.

Evaluating ecosystem services over time
To truly achieve solutions that offer ecosystem services along our coasts, we would need to integrate coastal defense, recreation and nature development more comprehensively. Only then can an optimal sandy solution be designed and implemented - the one that provides the best combination of desired ecosystem services.

We found that most ecosystem services are driven by factors that can be captured in hydro- and morphodynamic models. Hence, to quantify and evaluate the ecosystem services we applied numerical models to predict the morphological changes over time. Field-verified predictions still show clear remainders of the Sand Motor along the coast in 2050 (Figure 2). As sandy solutions will change over time, it is important to realize that the different ecosystem services will also change. For example, the predicted ecotope (a landscape feature), representing the sheltered subtidal lagoon area, shows that the surface area of the lagoon will diminish over time reducing the kite surfing opportunities (Figure 3). In addition, the beaches towards Scheveningen harbor will become significantly wider. This will be disadvantageous for beachgoers as the walking distance to the water line will become much longer.

When comparing alternatives for sandy solutions, the focus should not only be on the initial impact on the most important ecosystem services, but also consider how these are affected at various time points in the project’s lifetime. Adding the time dimension into the design phase provides even more opportunities to truly integrate and (potentially) optimize the ecosystem services. This, however, demands a sound understanding of how these services behave over time and what drives them.

The influence of sediment size and composition
The NatureCoast research has clearly illustrated the complexity of the Sand Motor’s behavior in space and time. Many interrelations were found that could only have been identified by combining knowledge across various disciplines. The most telling example is how sediment size and composition has influenced the Sand Motor’s morphology and ecology and thus the ecosystem services. The driving mechanisms of the tides, waves and wind cause sediment sorting processes to act upon the nourished sand. The sediment size and composition were found to influence everything from the communities of marine benthos, fish, plant colonization, wind-blown transports, the formation of embryo dunes, development of vegetation, the dynamics in biodiversity in the lagoon, the potential for green beaches in the lagoon, the potential for contamination, morphological behavior, and even recreation.

Figure 1.
Predicted bathymetries for the reference case (the Sand Motor as constructed in 2011) and three alternative designs;
Alternative A - the lowered Sand Motor,
Alternative B - the mirror-image version of the Sand Motor, and
Alternative C - the wing-shaped island.