Building with Nature - an integrated approach for coastal zone solutions using natural, socio-economic and institutional processes

T. Wilms[1], F. Van der Goot[2, 3] and A. O. Debrot[4]
[1] Witteveen+Bos, Jakarta, Indonesia; tom.wilms@witteveenbos.com
[2] EcoShape, Dordrecht, the Netherlands
[3] Royal Boskalis Westminster N.V. Papendrecht, The Netherlands
[4] Wageningen Marine Research, IJmuiden, the Netherlands

Abstract
This paper presents Building with Nature as a viable alternative to the traditional engineering approach, making the services that nature provides an integral part of the design of hydraulic infrastructure, thereby creating benefits for nature and society. In it we describe the necessary steps with which to implement a Building with Nature approach. Our case study in Demak, Central Java, Indonesia is used for examples to illustrate this approach and the lessons learnt on benefits and challenges.
The location in Demak concerns a tropical muddy mangrove coast. During the last decades, in several areas the coastline has retreated hundreds of meters up to several kilometres, while in other parts of the project area the threat of erosion and flooding by the sea and decline of aquaculture productivity continue to worsen. In 2015, a pilot project to restore the natural coastal mangrove forest was started. The first step was to establish a good understanding of the complex natural and local socio-economic environments. Based on this system understanding, we then chose for non-traditional solutions using temporary permeable structures made from local material to create wave-sheltered areas that stimulate the settlement of sediment and create a habitat favourable to mangrove recolonisation. Once the mangrove forest is fully-grown it will provide protection against waves. It will also provide other ecosystem services like food provisioning, tourism, nursery habitat for fishery production and CO2-storage. A long-term sustainable solution requires the integration of these technical measures into the local socio-economic and governmental context. To support a smooth transition towards sustainable practices, local communities are simultaneously trained in sustainable methods to improve the productivity of their aquaculture ponds. This is done using “coastal field schools” as modelled from the “farmer field school” methodology developed by the FAO in 1989 for rural development. The approach is embedded in the village regulations. Sustainability in this rural area is created by closely linking safety and livelihood.
The key lessons learnt from this project are that a combination of a thorough understanding of the bio-physical, socio-economic and governmental system and early stakeholder involvement results in higher vital benefits, reduces costs and provides the setting for sustainable design solutions. It requires a learning and adaptive planning cycle from all participants as this approach exemplifies a “learning by doing” approach.

Keywords: integrated coastal zone management, system understanding, non-traditional solutions mangrove restoration, socio-economics, muddy coast.

1. Introduction

This paper presents the Building with Nature (BwN) approach as a viable alternative for hydraulic engineering solutions in the tropics. The concept is implemented and illustrated through a pilot project executed in Demak, along the North coast of Java, Indonesia. The objective of this paper is to show how the BwN concept is successfully being implemented to restore the environmental and economic vitality of a degraded rural muddy coastal area and to discuss lessons learnt.

2. Building with Nature approach

In 2008, two very similar initiatives were launched: PIANC published its “Working with Nature” positioning paper [4] and the “Building with Nature” program was started in the Netherlands by the EcoShape foundation [6]. Both philosophies aim to combine natural, socio-economic and institutional aspects to develop sustainable design methods to address hydraulic engineering challenges. These approaches require a new way of thinking, acting and interacting compared to traditional approaches. They differ in that bio-physical, socio-economical and institutional aspects are fully incorporated from the very beginning and throughout all project phases. Building with Nature aims to meet society's needs for infrastructure and to stimulate nature development at the same time [6]. It is a new philosophy in hydraulic engineering that utilises the forces of nature and social cohesion and resolve to simultaneously strengthening nature, economy and society [11].

The Building with Nature approach entails developing a multi-way implementation plan to [12]:

- Understand how the bio-physical, the socio-economic and the institutional systems interact;

- Determine how the processes in all systems can be used and stimulated to achieve the project-related goals, how they can be embedded in local practice and governance and to plan the project accordingly;
- Monitor all systems during implementation, make risk-assessments and adapt both the monitoring and implementation as necessary during project execution (adaptive management);
- Monitor all systems after construction completion, so as to assess the project performance, if necessary adapt its management and harvest lessons learnt.

Since 2008, knowledge about Building with Nature is developed through pilot projects. By testing theories in practice, the Building with Nature knowledge base has been expanded [11] and as a result, many lessons have been learnt. The knowledge is disseminated though the network and beyond to make it applicable in other locations with comparable systems. Finally, the new knowledge and experience are translated to practical design guidelines [12]. The projects are developed and implemented by interdisciplinary teams and through collaboration between representatives from different industry sectors: contractors, engineering companies, research institutions, governments and NGOs [11].

Following the Building with Nature approach, five design steps have to be taken methodologically. These steps are [12]:

1. Understand the three interdependent subsystems: which are: (1) bio-physical, which includes both abiotic and biotic aspects, (2) socio-economic, which consists of the social aspects and the economic aspects and (3) institutional, which focuses on legal and governance aspects (Figure 1). Our subdivision differs from the standard triple bottom line approach that distinguishes social, financial and environmental subsystems. We here combine social and economic aspects as one subsystem and place governance in a special separate subsystem.
   This system understanding also includes a broader analysis of the problem, possible functions and services like ecosystem services, added values and interests of stakeholders;
2. Identify realistic alternatives: with understanding of the system, alternatives that are realistic in the system become evident more easily. Each alternative consists of a combination of building blocks. Also, additional ecosystem services are identified that provide even more incentive for implementation and embedding;

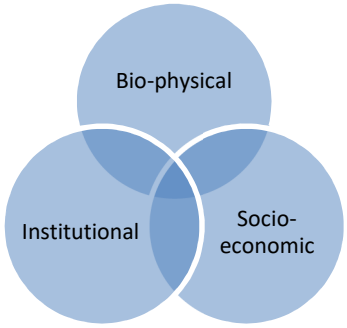

Figure 1 Three interdependent subsystems of sustainable development.

3. Evaluate each alternative: select the optimal alternative that fulfils a majority of all the requirements. Various alternatives have to be assessed to select the best integral solution;
4. Fine-tune the selected alternative: the selected alternative needs to be fine-tuned to fit in all the three subsystems. It has to simultaneously comply with practical restrictions, socio-economic requirements and governance context;
5. Prepare the selected alternative for implementation in the next project phase: the selected alternative needs to go through the following four project phases to be completed: initiation, planning and design, construction and operation and maintenance.

3. Introduction to tropical muddy coasts

In the tropics, alluvial coasts are often muddy and covered with mangrove forests. Resilient mangrove forests are highly bio-diverse and are found at many locations around the world along river deltas, lagoons, tidal inlets and open coasts. These mangrove forests provide many ecosystem services, of which several are presented in Figure 2.

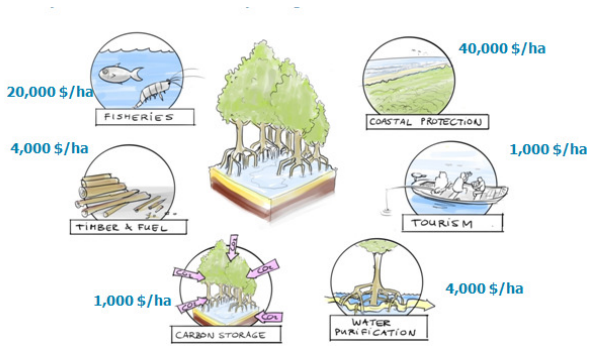

Figure 2 Ecosystem services of a mangrove forest [15]

Worldwide, these forests are under threat and huge mangrove coverage has already been lost [8] and [9]. Due to the global relevance of the mangrove forests, this pilot was initiated to learn more about the tropical muddy system, to test our methods in practice, to monitor performance, to develop knowledge and to share this for

application in other settings with comparable systems, such as in Vietnam, the Philippines and Surinam.

The present project is located in Demak district, along the north coast of Java, northeast of the port of Semarang, see Figure 3 and Figure 4.

Figure 3 Map of Indonesia showing the project location at the north coast of Java, in the Demak district

The coast is a tropical muddy mangrove coast. Until the 1980s, the area mainly supported rice production. As the price of rice dropped, land-use was gradually transformed to aquaculture, producing principally shrimp and milkfish. When the aquaculture productivity declined, the remaining natural mangrove forests were cut and dredged for conversion to aquaculture ponds. With removal of the protective coastal mangroves the shores and the hinterlands became more exposed to erosion, flooding and salinisation. This resulted in degradation of productive land and loss of ponds, infrastructure and even whole villages. In the last decades the coastline retreated hundreds of meters or even several kilometres. Several villages had to be abandoned; all the while other sections of in the project area came under threat by the sea and aquaculture productivity continued to decline.

Figure 4 Map of the project area. The coastline retreated several hundreds of metres in 10 years [Wetlands International Indonesia].

Other contributors to coastline erosion were land subsidence caused by groundwater extraction, disturbance of the sediment influx through canalisation, which rerouted sediment, as well as construction of coastal structures, which acted to block and interfere with longshore sediment transport [3], [7], [8] and [9].

In the past this complex process was addressed by taking various measures such as construction of hard sea defences and mangrove replanting. However, these measures failed, as neither measure addressed the root causes of the problem. The hard sea defences blocked sediment transport and collapsed over years as hard structures tend to undermine themselves when built in soft sediments [8] and [9]. When mangroves were actively planted aiming to restore the green belt, only a small percentage of mangroves typically survived after several years [2], [5], [1]. Massive mangrove planting operations often failed because planting took place in areas unsuitable for mangrove growth.

A related problem was that the productivity of the aquaculture ponds decreased due to reduced fresh water availability caused by sea water intrusion, in turn resulting from land subsidence. The latter also caused an increase in the frequency of flooding.

4. Restoration of coastal mangroves and revitalisation of aquaculture in Indonesia

In Demak a 2-year pilot was begun in 2013 to test the effectiveness of permeable structures in trapping sediment and creating habitat suitable for mangrove recolonisation. This pilot was the basis for our present larger pilot study of 5 years, which started in 2015. The current 5-year pilot study has as one additional main goal to increase the productivity of the local livelihoods, including aquaculture and other livelihoods.

The ultimate goal of the project is to simultaneously create community understanding, governance support and livelihood alternatives that will provide a sustainable basis for maintenance of the mangrove greenbelt. At the same time the mangrove greenbelt provides coastal safety which enables the economy to prosper.

4.1 Coastal safety

A key component of muddy mangrove coastal systems consists of fine sediment that is easily brought in suspension. Such systems are characterised by mild seabed slopes that allow very gradual dissipation of wave energy. This allows sediment deposition in the shallow intertidal zone where mangroves are able to establish and grow. The mangroves in this system further trap the sediment with their roots. Wide mangrove forests, naturally developed in this way, provide protection from the waves and give many other ecosystem services.

In this dynamic muddy system, the sediment is brought in by the tide and removed by wave erosion. Net erosion or accretion is the result of the balance of opposing directions of sediment transport. Most sediment transport occurs in the stormy and wet monsoon season, when the water contains most sediment as it is most turbulent due to the waves. The effect of a measure becomes most visible after the wet monsoon. Hard structures, like revetments, typically block the tide and sediment transport. In addition, due to reflection on the solid structure, scour occurs at the base causing more sediment to be taken by the waves and leading to eventual collapse of the structure. Figure 5 shows the contrasting effect on the sediment balance by mangrove and hard structures.

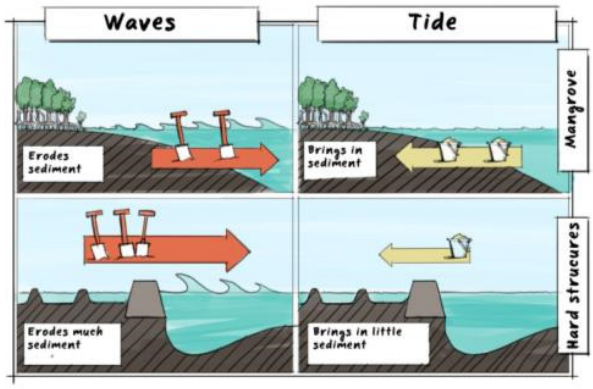

Figure 5 The contrasting effect on the sediment balance caused by waves and tide in situations with mangroves and hard structures. With mangroves, sediments will tend to remain in balance but with hard structures there is net erosion [15].

This means that a positive, accretionary sediment balance will result when the tide brings in the sediment, but waves are prevented from removing it. Our answer to create such a system has been to construct small temporary permeable structure with regular spatial openings at a limited distance from the existing coastline. This kind of intervention was used in the Wadden Sea, Northwest Europe, over the past centuries as a method to reclaim land. These structure are permeable so the reflection is limited, which reduces scour. Due to the regular openings the tide can bring in the sediment. In the sheltered areas behind the structures the sediment transport capacity is lower, the sediments settle, gradually raising the level of the seabed. When the level is around mean sea level, the conditions are favourable for mangrove seedlings to recolonise. In our project area propagules of several species are available in the system thanks to surviving adult trees. The currents distribute these propagules widely, including to sheltered conditions where the mangroves can recolonise and grow naturally.

When a sheltered area has filled with sediment and mangroves are sufficiently regrown, a new permeable structure is built seawards of the previous one to extend the shore zone gradually seawards from the coast. In this way, over a number of years a full greenbelt can restored largely relying on natural processes, see Figure 6. In this way the temporary permeable structures eventually outlive their function and can either degrade, remain or be removed.

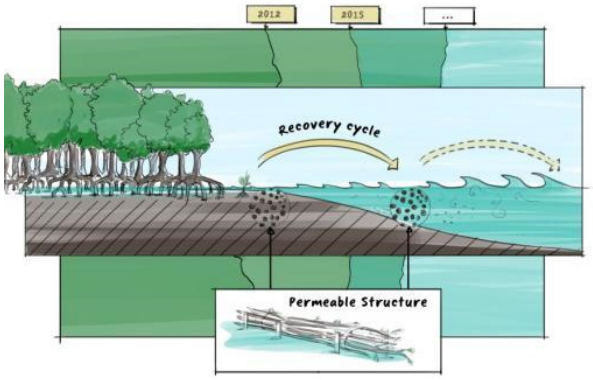

Figure 6 Recovery cycle where permeable structures create shelter, sediment settles, seabed rises and mangroves recolonise and grow [14].

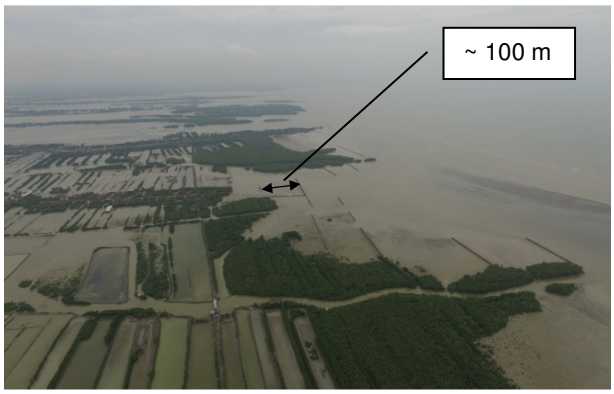

Figure 7 Drone photo of the project area taken February 2016. At the left are the aquaculture ponds. In the middle are the remaining mangroves. The straight lines are the permeable structures. Landward of the structures (at their left side) sedimentation is visible.

In our pilot the sedimentation rate has already been measured for 2 years with sedimentation poles at various locations in the system, both in front and behind the structures as well as in undisturbed locations for reference. Initial results show that in this coastal system the sedimentation rates are at some locations more than 30 centimetres within a few months after construction, see Figure 8. Permeable dams are constructed about 100 m from shore and with openings between the structures of 10 m, see Figure 7. In the coming 2 years, additional tests will be done with other distances and opening sizes. The effects on sedimentation will be monitored so the

results can be evaluated and used to improve the spatial lay-out of the structures.

Figure 8 Permeable structure a few months after construction. At the landward side (to the right) sediment has settled above low water.

A second measure we use to restore the mangrove forest is to fill the ponds along the coast and the rivers with sediment. This can be achieved by creating openings in the pond bunds to allow river water and tides to naturally bring sediment into the former ponds. This could be supported by placement of sediment in the pond by means of human intervention, for example with an excavator. The bunds still need to be opened to assure tidal movement within the enclosed area to ensure provision of mangrove propagules and frequent inundation. In the coming years various tests will be done with filling ponds.

A third measure to restore the mangrove forest is by sediment nourishment. Fine sediment is dredged further offshore and pumped into the system where the tides can still pick it up and bring it further to the shoreline. The natural processes bring the sediment to the best location. The heaviest sediment size-fraction will settle out first while the finest grain-sizes will only settle in the calmest waters. This measure is analogous to the "Sand Motor" along the Dutch coast where a peninsula of 1 km by 2 km is created in a single operation. Nature will take the sand to the right place [13]. With this measure the amount of sediment in the active system is increased but final sediment transport is done by nature.

The way the permeable structures are built up and the materials used, are based on experience in the Netherlands and Vietnam as well as on the knowledge of the local community. The structures consist of 2 rows of poles between which the fill material is packed. The fill material creates the permeability and is kept in place with nets tied down with wire. At the ends of the structures, mostly at the openings, a perpendicular T is made of 5 meters to each side to give extra support and keep erosion away from the main part of the structure.

The construction of the permeable structures is done by the local community. In this way they get involved and engaged and also earn extra income. The local community is also involved in the inspection and maintenance. By linking the local community to their own coastal safety in this way, it creates awareness knowledge and local support for coastal safety.
Besides the physical system (abiotic and biotic) also the institutional system is important. The permeable structures are now being constructed at locations that are in open water, but which were aquaculture ponds for decades. These ponds were owned by the local community. Due to the decrease of productivity or even total loss of land to the sea, the ownership rights to numerous plots have been sold to investors. The challenges that arise are how to find, identify and locate these new often absent owners and how to convince them to not remove the mangrove forest when the land is reclaimed. Currently, the local community is assisted in developing village regulations to protect the permeable structures and the new reclaimed land. Also, the process to identify all owners has started.

4.2 Livelihood

In Indonesia the field school process is commonly used to train and empower local communities. It is a group-based learning process that has been successfully used by governments, NGOs and international agencies to promote knowledge of agro-ecology among rural farmers. In Indonesia Farmer Field Schools (FFS) are embedded in legislation. However the concept of "coastal field schools", as modelled on the FFS and used in this project, is new. The coastal field schools are used in this project to train local community groups in sustainable aquaculture practices and other livelihoods. A school starts with the selection of a group of participants. They all come from the same village but differ in background and include both genders. The training offered, lasts the duration of an aquaculture cycle. This is about 4 months. Every week, the groups come together and share their knowledge and experience. They are introduced to critical thinking and learn to come up with alternatives. They "learn by doing"; they test their ideas in demonstration plots and jointly evaluate the results of different alternatives. By testing their ideas, they learn to think critically and to understand the natural processes that drive the system. They learn to use natural local means to generate or grow feed for fish and shrimp, thereby saving on feed costs. The first coastal field schools have resulted in a significant increase in the production of shrimp and milkfish with lower costs (Figure 9). This allows the income of the participants to increase.

With this new-learned knowledge, the members of the community group are successfully implementing new concepts and methods in their own ponds. They also freely share their experience and knowledge so that other villagers can adopt the new practices. Replication of the effective alternatives is taking place in an organic fashion through communication and knowledge sharing.

Figure 9 Shrimp and milkfish grown in aquaculture demonstration plots.

In return for their training, the community group is expected to give back to the larger community in various ways. This may be in the form of a small part of extra income that is created or in the form of labour to protect the mangrove forest and maintain the permeable structures. So a prosperous local economy with arrangements for exchange of benefits enables the sustainable maintenance of the mangrove greenbelt.

Figure 10 Villagers have constructed their own fishing platform in the shallow waters near the permeable structures to have an alternative livelihood.

Other livelihood options are also created or enhanced in the process. In areas with unproductive fish ponds new options for sustainable production are being explored. This is particularly important for the owners of pond close to shore that need to be converted to mangroves, as this precludes aquaculture use. An example can be seen at the locations where the permeable structures are creating shallow water. This shallow water attracts marine life like fish, crabs and shellfish. The local community is very aware of the increase in marine life. As a consequence, many villagers are financing and constructing their own fishing platforms to fish in these areas (Figure 10). They also appear to be making more use of the mud flats for the collection of shellfish. The firm elements of the permeable structures represent hard substrate which is good for molluscs and other shellfish. In the coming years, additional research will be done to develop shellfish culture as a new alternative livelihood.

5. Discussion

This pilot project in Demak is a novel multidisciplinary project taking place in a complex and changing muddy coastal system that is under pressure: the coast is eroding, land is subsiding, salinisation is taking place, aquaculture productivity is decreasing, the land is being sold. All the while, this project aims to implement measures in the bio-physical, socio-economic and institutional systems that jointly remove the negative feedback loops that have been leading to spiralling decline, and redirect these into positive feedback loops as a basis for sustainable recovery and resilience. As explained above, our project involves a multitude of effort in all three interdependent subsystems required for sustainable development. While this may seem complex, all these interventions interact synergistically and ultimately simplify into two major positive forces. One force stimulates expansion and faster growth of mangroves and the other reduces the force of stressors and declines them. Both of these can further be seen to reinforce each other, which should mean that as time progresses, mangrove recovery will likely speed up.

This requires continuous learning, sharing and adapting. Strongly embedding the required knowledge and understanding in the communities and formalizing the exchange and sharing of benefits will be the only way to guarantee lasting sustainable results. This way the results achieved will persist and not be destroyed by new owners that are not aware of the necessity of a sustainable coastal system. Throughout the project, the team has to cope with gaps in knowledge. These were addressed by the combination of experiments and trials, monitoring and adaptation. For example, the permeable structures were built first based on the knowledge in the Netherlands and Vietnam. The sediment trapping was good, but the material of the structures was weakened by shipworms [10]. More resistant materials were found to assure that the process towards the restored mangrove forest can continue. A similar example, is very fast replication at other locations along the North coast of Java because the sediment trapping at our

Demak site was observed to be good. The initial structures had first been copied to locations that were sandy or more exposed systems. These conditions were soon seen to be unsatisfactory but showed the way to more effective site selection for dam construction. By involving all partners and stakeholders from other regions, continuous training and the active sharing of experience and lessons learnt, sustainable replication has become achievable.

6. Conclusions and recommendations

This paper illustrates the Building with Nature approach as an viable alternative engineering approach, making the services that nature provides an integral part of the design of hydraulic infrastructure, thereby creating benefits for nature and society. The initial results of the implementation of such an approach at the pilot project in Demak, Java are positive. Our pilot project shows that the tropical muddy coastal mangrove system is complex and that the causes for the destruction of the mangrove systems are typically multifaceted. Therefore, under these conditions, coastal zone mangrove rehabilitation requires a multifaceted approach.
We find that sustainable coastal zone rehabilitation can be achieved by linking the coastal safety to the development of alternative livelihoods, knowledge sharing and institutional systems in a way that reinforce positive feed-back loops for system resilience.

To restore the mangrove forest and its function as coastal protection, we deployed permeable structures according to a concept developed in the Wadden Sea, Northwest Europe. The structures have proven effective in trapping sediment and creating conditions suitable for mangrove recolonisation. Through testing, monitoring and evaluation, the spatial and structural designs are being improved and the system understanding is increasing. This is continuous learning by doing and adapting based on lessons learnt. This requires having the flexibility and willingness to adjust and adapt. All partners involved have to be open for this. Another important factor is the active involvement and engagement of local community and other stakeholders. This is done by communication, coastal field schools and other ways of knowledge transfer.

7. Acknowledgements

Building with Nature Indonesia is a co-operation between the Ministry of Marine Affairs and Fisheries (MMAF) and the Ministry of Public Work and Human Settlement (PUPR) on behalf of the Government of Indonesia and the EcoShape Consortium. Wetlands International coordinates the initiative in partnership with consultancy agency Witteveen+Bos, knowledge institutes Deltares, Wageningen University & Research Centre, UNESCO-IHE, Blue Forest, the Diponegoro University, and is supported by the Local Government of Central Java and Demak District, and local communities.
Building with Nature Indonesia is made possible by the Dutch Sustainable Water Fund, the Waterloo Foundation, the Otter Foundation, the Dutch Top Consortium for Knowledge and Innovation, and Mangroves for the Future.

8. References

[1] Ellison A.M., 2000. Mangrove restoration: do we know enough? Restoration Ecology, Vol 8(3): 219-229.

[2] Lewis III, R.R., 2005. Ecological engineering for successful management and resto-ration of mangrove forests. Ecol. Eng., Vol. 24: 403-418.

[3] Marfai, M.A., 2011. Impact of coastal inundation on ecology and agricultural land use case study in central Java, Indonesia. Quaest. Geogr., Vol. 30: 19-32.

[4] PIANC (2008) PIANC Positioning Paper Working with Nature. October 2008; revised January 2011. Link http://www.pianc.org/downloads/envicom/WwN%20Final%20position%20paper%20January%202011.pdf

[5] Samson, M.S. and Rollon, R.N., 2008. Growth performance of planted mangroves in the Philippines: revisiting forest management strategies. Ambio, Vol. 37: 234 – 240.

[6] Vriend, H. de, Koningsveld, M., Aarninkhof, S.G., Babtist, M. (2015) Sustainable Hydraulic Engineering, through Building with Nature, Journal of Hydro-environment Research 9:159-171, June 2015

[7] Wesenbeeck van, B.K., Balke, T., Van Eijk, P., Tonneijck, F.H., Siry, H.Y., Rudianto, M.E. Winterwerp, J.C., 2015. Aquaculture induced erosion of tropical coastlines throws coastal communities back into poverty. Ocean & Coastal Management, Vol. 116: 466-469.

[8] Winterwerp, J.C., Borst, W.G., de Vries, M.B., 2005. Pilot study on the erosion and rehabilitation of a mangrove mud coast. J. Coast. Res. Vol. 21: 223-230.

[9] Winterwerp, J.C., Erftemeijer, P.L.A., Suryadiputra, N., Van Eijk, P. and Zhang, L., 2013. Defining eco-morphodynamic requirements for rehabilitating eroding mangrove-mud coasts. Wetlands Vol. 33: 515-526.

[10] Winterwerp, H., Wilms, T, Siri, H.Y. , Van Thiel-de Vries, J., Noor, Y.R., Van Wesenbeeck, B., Cronin, K., Van Eijk, P., Tonneijck, F. (2016). Building with Nature: Sustainable Protection of Mangrove Coasts, Terra et Aqua, number 144, pp 5-15.

[11] https://www.ecoshape.org/en/about-ecoshape/

[12] https://www.ecoshape.org/en/design-guidelines/

[13] http://www.dezandmotor.nl/en/

[14] https://www.wetlands.org/publications/building-with-nature-for-coastal-resilience/

[15] https://www.wetlands.org/publications/mangroves-for-coastal-defence/