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BUILDING WITH NATURE: SUSTAINABLE PROTECTION OF MANGROVE COASTS

ABSTRACT

This paper was presented in HATHI: The 5th International Seminar in Bali in July 2016. It is reprinted here in an adapted version with permission.

The following article describes Building with Nature (BwN) as an innovative approach to restoring eroding mangrove-mud coasts. This approach combines ecosystem-based engineering and sustainable land use solutions to create a productive and stable coastline for local communities.

The article highlights the current five-year BwN project being carried out along the degraded coastline of the Demak district in central Java, Indonesia, to illustrate the approach. In 2014, the project started with an advanced systems analysis that helped to establish a comprehensive management design that combines both engineering and ecological principles. This involved the construction of permeable dams that trap sediments along the shore, followed by efforts to restore a protective mangrove belt on the muddy substrate. Additionally, the project team proposed adopting more sustainable aquaculture regimes that prevent soil subsidence, hydrological disturbance and damage to remaining ecosystems, thereby addressing the root causes to the erosion problems.

The designs are currently being implemented together with the government of Indonesia, communities and other local stakeholders as part of an adaptive master planning process. Based on extensive monitoring efforts the project team is also gradually scaling up their interventions, thereby steadily paving the way towards a productive and sustainable economy along northern Java's coastline. Consequently, coastal security for 70,000 people in Demak will be improved and potentially for many more people in the long-term. Also, the positive interventions will help avoid further coastal flooding and erosion in central Java and provide a long-term perspective for sustainable economic development.

The project team believes that the integrated BwN approach offers a sustainable, cost-effective and climate adaptive solution that may transform the way in which the engineering community addresses erosion problems along mud coasts across the tropics.

Above: A bird's eye view of the eroding and flooded coastline in Demak, central Java, Indonesia and permeable dams that have been built to help restore the area.

INTRODUCTION

Anthropogenic disturbances, such as over-harvesting mangroves for wood, the establishment of aquaculture ponds, hard infrastructure and groundwater extraction, has induced large-scale erosion and subsidence of tropical muddy coastlines in Asia and Latin America. Landsat satellite images of northern Java highlight this decline (Figure 1) showing a total loss of 55 km^2 of coastal area in the beginning of the 21st century. This loss of productive land and the demise of ecosystems and their services renders coastal populations highly vulnerable.

Mud coasts are typically dynamic and naturally subject to erosion and accretion. However, mangrove conversion and unsustainable land-use and implementation of hard infrastructures changes various factors including fine sediment balance, hydrology and soil structure. These changes may flip accreting coastlines towards an alternate state where net erosion takes place.

Authorities and local communities are aware that the massive erosion can be attributed to mangrove loss and land-use change. Thus far, traditional mitigating measures have been utilised to halt the erosion.

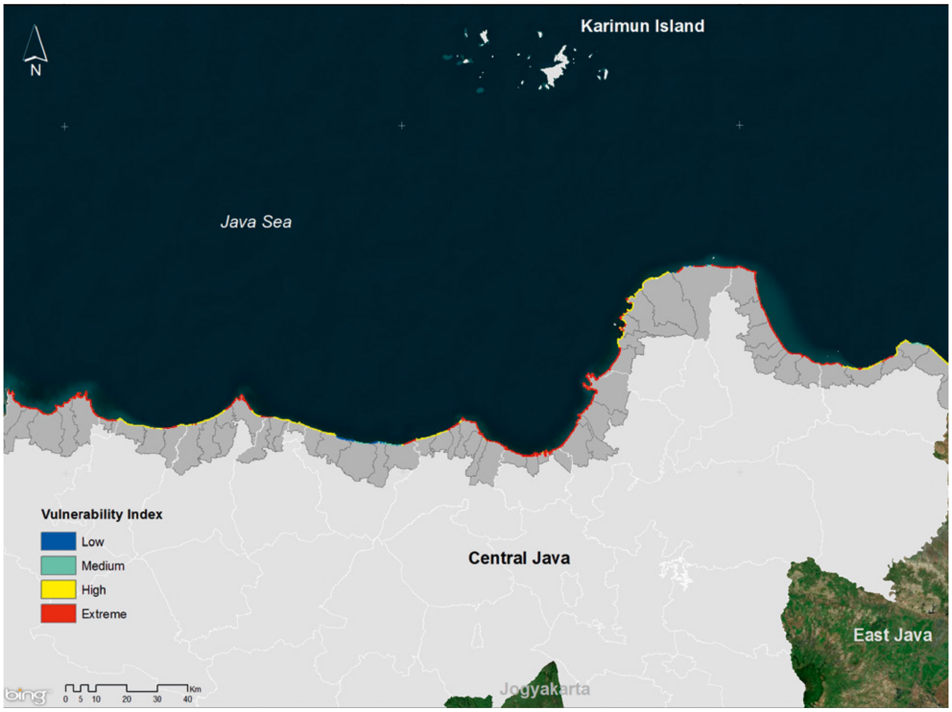

Figure 1. Current coastal vulnerability of central Java

BUILDING WITH NATURE (BwN) APPROACH

A primary reason for the failure of coastal protection measures that were mentioned above is that local physical, ecological and social conditions are often not adequately accounted for. Therefore, the project team decided to assess the applicability of BwN (see box) – an inclusive coastal zone management approach that is based on in-depth understanding of the functioning of the wider coastal system.

Based on the team's preliminary systems understanding, a philosophy was defined that reads as follows: "Restoring eroding tropical-mud coasts requires revival of a healthy mangrove belt. This is achieved by putting in place permeable sediment capturing dams to restore the fine sediment balance, thereby providing a substrate for the mangroves to grow and bolster the coast".

They are:
1. (Re)planting mangroves where they were lost.
2. Protecting the remaining mangrove fringes with hard structures.
3. Protecting the hinterland with levees, revetments and other similar structures.

Unfortunately, measures have failed massively (Winterwerp et al., 2005, 2013). Reviews of mangrove rehabilitation efforts show low success rates in different parts of the world. In the Philippines, for example, replanting efforts totalling 44,000 hectares of land were found to have survival rates that typically ranged between 5 to 10% only. Restoration has proven near to impossible along eroding coastlines, as mangrove seedlings are readily swept away by the forces of the sea.

Likewise, hard structures have largely failed to curb erosion problems as they are unstable on the muddy soils, while contributing to a further disturbance of the sediment balance. Additionally, they might negatively impact ecosystems and their vital services – fish, timber, wood for fuel, coastal protection and water purification – they provide to millions of people.

ABOUT BUILDING WITH NATURE (BwN):

Building with Nature (BwN) is an integral coastal zone management approach that provides coastal resilience by combining smart engineering and ecological rehabilitation, while introducing sustainable land-use practice. It offers an alternative to conventional hard-infrastructure approaches to coastal security. Instead of 'fighting' nature with dams and dykes, BwN solutions work with and along the dynamics of nature. The solution could be, for example, allowing river flows and sea currents to reinforce coastlines with sediment. Another solution could be the restoration of ecosystems so that they once more provide protection against extreme events and offer valuable 'natural capital' in the form of shell-fish, timber and recreational opportunities. BwN solutions are climate-adaptive, and are often cheaper to construct and maintain compared to static infrastructure solutions. The environmental benefits enable more productive and multi-functional land-use. Local stakeholders – including disadvantaged communities – are involved in design, construction and maintenance of measures. This renders the approach financially, institutionally, environmentally, technically as well as socially highly sustainable. It also shortens permitting procedures and addresses concerns related to human rights that are often associated with large infrastructure projects.

BwN solutions can be applied in myriad ways. Coastal solutions may consist of levees, lined with wetland foreshores and oyster reefs further down the coast. The key to solving river issues may involve restored floodplains that capture flood waters alongside embanked urban centres.

The case study from Indonesia that is described in this article forms part of the BwN innovation programme, a public-private partnership that is coordinated by Ecoshape. The programme explores inclusive engineering approaches to promote sustainable coastal development in the Netherlands and abroad.

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By reviving the natural processes that nurture the coast and by addressing human disturbances, this method optimises the benefits provided by nature and minimises costs for construction and maintenance of engineering works.

Building with Nature is a no-regret approach as the interventions are reversible. This allows a learning-by-doing strategy: should errors occur, they are not detrimental as the interventions can be reversed and changed. Hence, a BwN project is flexible and adaptive and is updated frequently with lessons learned. Of course, this implicitly means that monitoring the results of BwN works and evaluating the recovery of the coastal systems is crucial.

At many places across the world, mangrove-mud coasts are eroding and have been eroding for several decades, with the result that large amounts of sediment have been lost from these coastal systems. Bringing back the sediments by natural processes takes time. Thus, it may take several years, even decades for the mangrove forests to recover. It is therefore essential to adopt a phased, long-term master planning method for BwN projects. Such a plan would typically contain the following elements:

- A detailed description of the (original) ecosystems and the social and biophysical processes that take place across the coastal landscape.
- A description of changes that have occurred as a result of anthropogenic disturbances.
- A description of how natural processes can be used for restoring the coastal system. This includes the identification of appropriate engineering and ecosystem restoration measures in a design and engineering plan.
- A monitoring plan, which is required as input to the adaptive and learning-by-doing BwN approach.
- A maintenance plan so that the structures remain functional long enough to have a chance to be effective.
- A training and capacity building plan to make the BwN approach familiar to authorities and communities as this method is still novel.
- A socio-economic plan for the sustainable use of the coast after recovery.

UNDERSTANDING THE PHYSICAL AND BIOLOGICAL SYSTEM

The pristine mangrove-mud coast

Alluvial coasts in the tropics are often muddy and covered with mangrove forests. The habitat of mangroves is typically found between Mean High Water (MHW) and High High Water Spring (HHWS), although at times the mangroves may grow at lower altitudes (Lewis III, 2005). A resilient mangrove forest is biodiverse with a profound succession in species yielding pioneers, e.g., *Avicennia*, closer to the waterline, and climax vegetation, e.g., *Rhizophora,* higher up on the mud flats, though many other species can occur as well. Connectivity with the hinterland is important for the hydrological functioning of the forest, bringing in fresh water and/or draining a surplus of water.

These highly diverse mangrove habitats are found along river banks, along river deltas, in lagoons, around tidal inlets and along open coasts. This article focuses on open coasts with mudflats, as these are relevant for the work in Demak. The mudflat sediments stem from terrestrial erosion, carried by rivers to the coastal zone. These coastal deposits are often hundreds to sometimes thousands of years old. Today, although fine sediments are supplied to the coastal zone, their quantities are generally small compared to the relic deposits. Hence, on shorter time scales, the sediment source for these open coasts is of marine origin.

As mud is very fine, it can only accumulate under fairly calm hydrodynamic conditions, building fairly mild (1:1000 – 1:1500) and wide slopes with its deposits. Because of these mild and wide slopes, the tidal motion is largely perpendicular to the coastline and tidal velocities are low. Wind waves and swell are damped over the soft muddy bed, and refract towards the coastline. As a result, wave-induced long-shore sediment transport is generally low.

A mangrove-mud coast is not static. Sediments are deposited and eroded by tide and waves. Waves play a dual role. Even the smallest (capillary) waves can erode sediments from in between the mangrove roots as these sediments are very fine. Also, big waves erode these sediments but also stir up fines from the mudflat. These mobilised sediments are carried onshore with the rising tide. As a result, small waves only take whereas big waves give and take. Coast-parallel breakwaters therefore work counterproductive as they kill the onshore supply of fine sediment.

Coastal waters become fresher during the wet season from run-off and from the tributaries around. Thus, a cross-shore salinity gradient is induced. This gradient drives a cross-shore gravitational circulation with an undertow towards the coast bringing sediments onshore together with the tidal motion. During every high water, which is once a day along Java's north coast, large amounts of sediments are deposited on the mudflat. However, the majority of these deposits are eroded again during ebb tide and are carried away from the shoreline. The net difference between deposition and erosion determines the actual coastal accretion or retreat. This net difference is much smaller than the gross deposition or erosion rates.

Figure 2 shows some numbers for the coastal system in the north of South America (Winterwerp et al., 2015). This huge difference between net and gross sedimentation rates, and thus erosion rates, implies that slight changes in these gross rates will have significant effects.

Such slight changes in gross sedimentation and erosion rates determine whether the coastline accretes or retreats.

Disturbed mangrove-mud coasts

Across the globe, mangrove-mud coasts erode or retreat for various reasons.
Main reasons for this erosion have been identified as:

1. Cutting mangroves at too large a scale in order to use the wood for various purposes such as timber and charcoal production.
2. Infrastructural works such as roads, ports and other human factors such as urbanisation, often affect the hydrology of and/or sediment supply to the coastal system.
3. Subsidence, natural or through ground water subtraction. This is a major problem around Jakarta and Semarang and other places on Java as well.
4. Land-use change, i.e., large-scale conversion of mangrove forests into agricultural land or aquaculture ponds, in particular too close to the waterline.

Winterwerp et al. (2005, 2013) deduce from the large difference between the gross and net sediment dynamics as described above, that infrastructural works, subsidence and land-use can largely disturb the gross sedimentation and erosion rates in coastal systems, thereby changing earlier stable or accreting coastal systems into an erosive

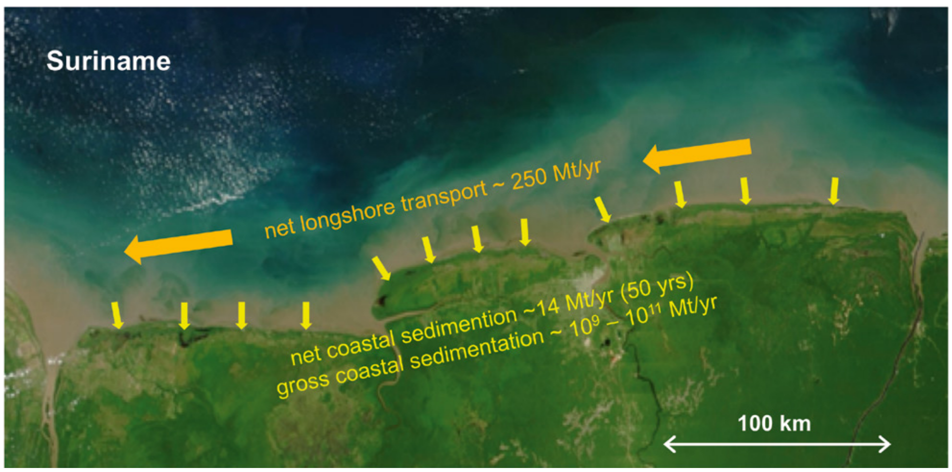

Figure 2. Gross and net coastal sedimentation along the coastline of Suriname averaged over a period of 50 years. For instance, a 1% reduction in gross coastal sedimentation can flip the 14 Mton/yr of net coastal sedimentation into large, uncontrollable coastal erosion

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leads the programme for the protection of coastal wetlands at Wetlands International. Her current focus is to enhance coastal resilience by stimulating sound mangrove management. Her personal drive is to link science, policy and practice to trigger change at a large scale. Mangroves intrigue her because of their many services they offer to society and she believes they are essential in the evolution to a truly sustainable world.

Figure 3. Construction of permeable dams by local contractor under supervision of the BwN team. Training-on-the-job is an important part of the BwN approach. (Photo: Tom Wilms)

mode. In other words, these human interventions unfavourably disturb the fine sediment balance in the coastal system.

Case study: Initial results from Demak district

The target site in Indonesia was selected by the Indonesian Ministry of Marine Affairs and Fisheries in the Demak district in central Java where the coastline has retreated from the beginning of this century by 1-1.5km. Around 70,000 people suffer from coastal flooding and erosion hazards in Demak and entire villages have been swallowed by the sea. Many people have experienced a major loss in income, reaching up to 60-80% in some villages. Also, the agri- and aquaculture sectors which are key economic engines in Indonesia have suffered multi-billion dollar losses. Along the entire coastline of northern Java 30 million people face the risk of losing their houses, roads, arable land and livelihood.

This small-scale pilot was started in 2013 which is being scaled up in the current five year programme (2015 – 2019). The strategy for the area was to restore the sediment balance and through that, the mangrove habitat by constructing permeable brushwood dams (Figure 3). The permeable dams are laid out in grids of about 100×100 m^2 that form still water basins where sediments can accumulate, increasing the gross sedimentation rate. Thus, muddy substrate for mangroves to grow is restored. Other configurations may be applied as well. As such, optimal use is being made of the large difference between the gross and net effects of the local sediment dynamics.

In the near future, these dams will be overgrown by the mangrove forest. The dams are of temporary nature: once a stable mangrove belt has formed, they take over from the dams, buffering waves and capturing sediments on their own. Hence, the permeable dams need to stay in place at least long enough for mangroves to take over, which is a sum of the sediment accretion rate (2 - 5 years) and rate of mangrove recovery (3 - 5 years). Once a first line of defense has been established, new lines of permeable dams might be created on the seaward side in several consecutive steps until a stable muddy foreshore is restored.

It is very important to stress that this approach should only be applied as a means to restore the sediment balance along eroding coasts. It should never serve to reclaim mudflats, seagrass beds and other ecosystems that are found on the seaward side of natural mangrove coasts. These ecosystems are part and parcel of a protective coastline, support local fisheries and have critical biodiversity values.

A priority scheme was developed and tailored for the project in the Demak district. The scheme states the following:

1. Protect houses and infrastructure (roads) from further erosion through constructions of temporary permeable dams at strategic locations.
2. Recover the habitat of mangroves locally so that mangrove fringes can grow to become the ultimate coastal defence.
3. Recover a sustainable mangrove forest, building out on the mangrove fringes developed as described in point 2, while creating connections to the hinterland.
4. Develop sustainable socio-economic activities financing coastal recovery.

Three objectives were set for the BwN works carried out up till now (2013 through 2016). They are:

1. Stop erosion at locations most critical for communities and infrastructure.
2. Show that the BwN approach is feasible for coastal protection.
3. Learn from the pilot projects in Demak for upscaling elsewhere.

As a first pilot project, three grids were constructed in November 2013, inducing a net sedimentation rate of about 0.5m within 12 months, with some early mangrove colonisation at specific locations such as the one shown in Figure 4a. Though this pilot was highly successful from a hydro-sedimentological point of view (Figure 4b), the project team was unpleasantly surprised by the devastating effects of shipworm, destabilising the permeable dams.

The favourable results of the 2013 activities led to plans for constructing new

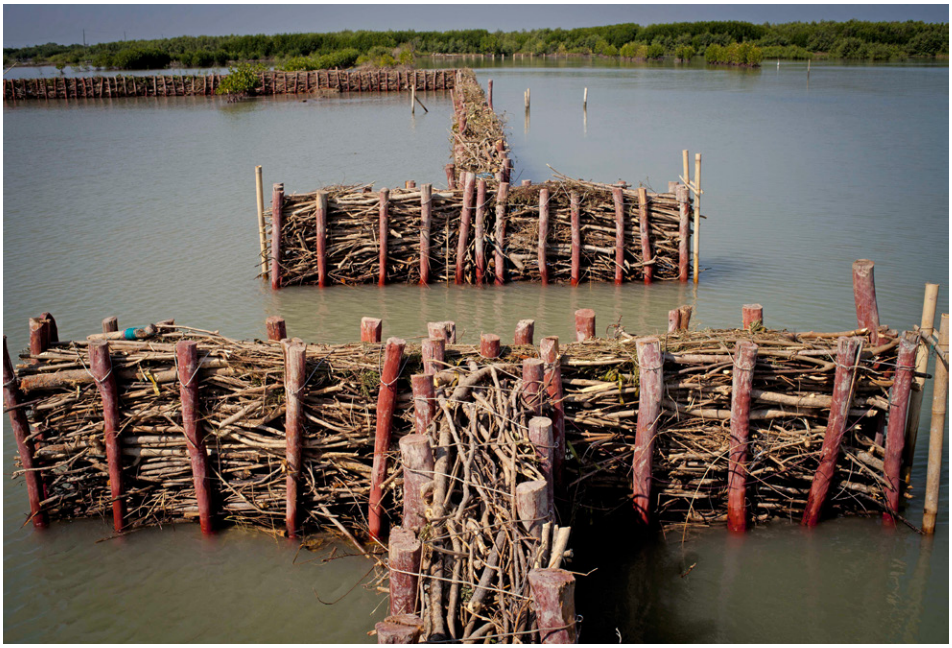

Figure 4a. An example of a permeable groin structure erected in 2013.

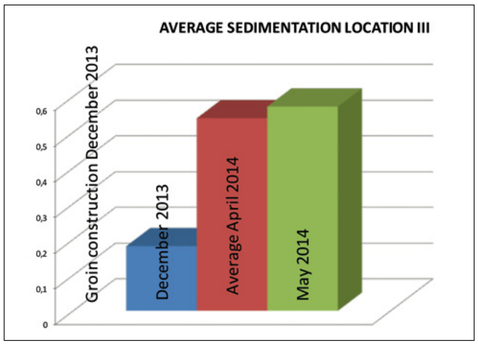

Figure 4b. The sediment accumulation during the monsoon season 2013-2014.

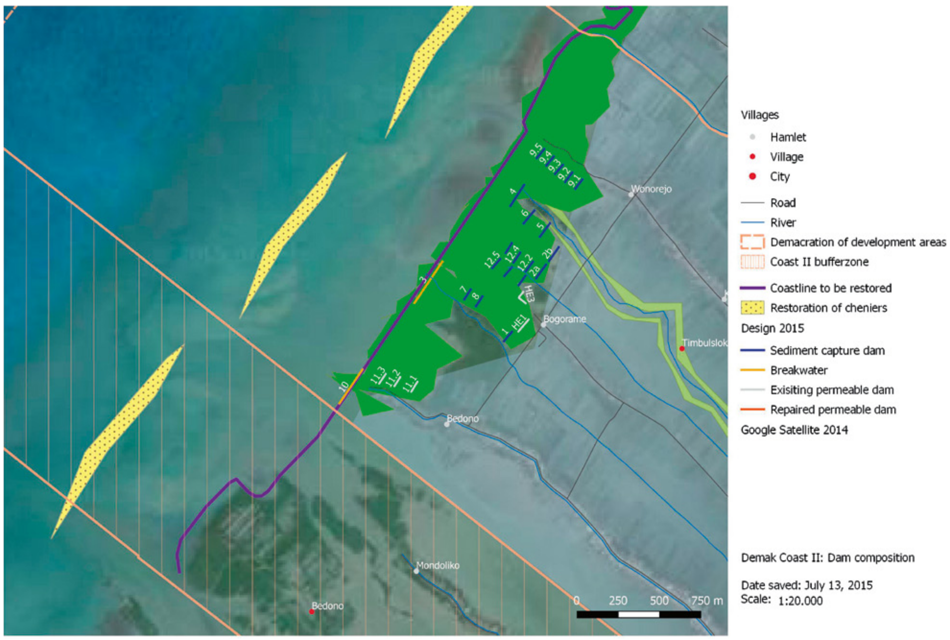

Figure 5. Permeable dam layout (to be) constructed in 2015 and 2016 in the Demak district with a sketch of the final configuration.

permeable dams in Demak at a much larger scale. That work started in 2015. These plans are shown in Figure 5, of which a large part has currently been implemented. The layout of these permeable dams aims at recovering fringes of mangroves in the lost aqua-culture ponds for sustainable coastal protection. Because of the shipworm problems, experiments with various construction materials form part of the 2015/2016 works. This learning-by-doing method is inherent to the BwN approach.

These construction works are accompanied by a maintenance and monitoring plan. Moreover, based on the project team's experience, detailed instructions for the design, construction, and supervision have been drafted. These instructions and lessons learned are shared with local stakeholders at all levels such as the ministries, the local representatives of these ministries, local communities and contractors. These training and capacity building activities are given in the form of courses and practical training, where trainees learn the Building with Nature philosophy and apply its concepts.

In addition, plans for sustainable economic activities in the production systems behind our dams are being developed, which ultimately should generate the funds for upscaling and maintaining the coastal restoration in the target area (Demak) and further down the coast. Through the Coastal Field School local fish farmers will learn to apply sustainable aquaculture models that provide space for mangrove restoration and require decreased use of chemicals.

The Bio-rights approach is a financial incentive mechanism that involves local communities in the implementation of Building with Nature measures. In return for active engagement in conservation and restoration measures, communities receive (financial) support to develop sustainable livelihoods that will generate income. In the case of Demak, this translates into coastal safety activities such as inspection of the BwN structures, small maintenance and monitoring works and support for the development of sustainable aquaculture.

The results of the current BwN activities in the Demak district are encouraging. Sediments are indeed being trapped, restoring the coastal sediment balance and the mangrove habitat locally. The first mangrove seedlings have naturally established. These are the first steps towards the reestablishment of a healthy mangrove. With communities, the project team is establishing a scheme to maintain the buffer and sustainably manage the natural resources (timber, fish etc.) it provides. As the pilot is in full swing, the team expects to be able to share more results and insights over time, as they gain more practical experience and monitoring results.

It is understood that this approach is not always feasible, for example in urban areas that experience high development pressures on available land. In such cases, more traditional coastal protection measures have to be taken. The costs of such traditional measures may easily range from 1-10 million US$ per kilometre (US$/km) length, though they may be much higher e.g., in the case of the ring dyke that is proposed to protect Jakarta from flooding. The permeable dams currently erected in the Demak district cost about 100,000 US$/km. It is anticipated that when more experience is gained, costs may be reduced substantially. While this is still an appreciable amount of money, avoided damages and increased income from economic activities and restored natural capital are expected to be far greater. Hence, BwN is expected to offer a strong business case, in particular in rural areas that do not have access to large budgets for spatial development. BwN is a promising approach to adapting to impacts of climate change – provided that these impacts do not move beyond the natural capacities of mangroves to cope with changes in sea-level and hydrology. As BwN is cost-effective that comes with multiple benefits, the investments are no-regret. Also, as it a learning-by-doing method, project solutions can be flexible. This is impossible with hard infrastructure solutions that are static, provide one service only and are expensive.

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, IMARES and UNESCO-IHE, Blue Forest, the Diponegoro University. The initiative 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.

CONCLUSIONS

Across the world, thousands of kilometres of tropical mangrove-mud coasts face dramatic erosion resulting from mostly anthropogenic disturbances. Coastal managers often try to fight coastal erosion with single-sided traditional mitigating measures such as hard structures. While these might be effective locally if implemented at scale (e.g. in urban contexts), these disturb the balance of incoming and outgoing sediment and may, thereby, cause further erosion. Also, (re)planting mangroves has failed on a large scale along eroding coastlines, as the mangrove seedlings are readily swept away by the forces of the sea.

For successful restoration it is necessary to recreate the conditions for natural mangrove regeneration to take place. This often involves restoration of the hydrology and of the sediment balance to ensure the right soil elevation. It also requires active interventions such as the restoration of creeks or the trapping of sediments along eroding shores.

In addition, plans for sustainable economic activities must be developed, in order to transform the economy that caused the collapse of mangroves, into a climate-smart economy which could ultimately also generate the funds for coastal restoration in rural areas.
In this article, the BwN approach has been highlighted, which offers a sustainable, cost-effective and climate adaptive solution that may transform the way in which the engineering community addresses erosion problems along mud-coasts across the tropics. BwN is a holistic and inclusive coastal zone management method that is based on in-depth understanding of the functioning of the wider coastal system.
It aims at restoring the biophysical conditions for restoring degenerated coastal systems and at boosting sustainable socio-economic conditions. The results of the current BwN activities in the Demak district in central Java are encouraging and show that it possible to restore fringes of mangroves protecting the hinterland and the many communities and infrastructure present.

The project team believes that is essential for coastal managers, and hydraulic engineers of contractors in the industry to make an assessment of costs, benefits and risks to come to a joint understanding of how BwN approaches perform in relation to conventional infrastructure methods.

When considering a BwN approach, it is essential to adopt a phased, long-term master planning method, which includes the full understanding of the natural, socio-economic and institutional setting; the processes that have led to its collapse; the

natural processes that can be used for restoring the coastal system and the maintenance and costs of these measures.
BwN projects should adopt a learning-by-doing strategy, so that interventions can be reversed and changed. This means that monitoring the results of BwN works and evaluating the recovery of the coastal systems must be a crucial part of the plan, so that the project can be updated frequently with lessons learned. Such a strategy is possible, because BwN projects are flexible and are adaptable.

Finally, for adequate planning and design of BwN projects, it is vital to ensure that stakeholders are equipped with thorough understanding of the BwN concept, site-specific systems understanding, design instructions and lessons learned by means of technical guidance, courses and practical training. It should be emphasised that the success of BwN projects to a large extent depends on the active involvement of communities in planning and implementation. Thus, local communities also need to be equipped with knowledge and financial means and work side-by-side with their government and contractors.

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See also: http://www.ecoshape.nl/en_GB and https://www.wetlands.org/video/building-with-nature-indonesia-securing-eroding-delta-coastlines/