Memo

Aan
Matthijs Boersema, Joost Stronkhorst, Tjeerd Bouma, Joao Salvador de Paiva, Tjark van den Heuvel, Tim van Ooijen, Jacob Capelle, Anneke Brink, Marijn Tangelder,

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Van	**Doorkiesnummer**	**E-mail**
Sophie Vergouwen	+31(0)88335 7259	sophie.vergouwen@deltares.nl

Onderwerp
On the relationship between dike revetments and ecology: lessons learned for design and follow-up monitoring for asphalt covered locations

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1 Introduction

1.1 Dike enforcement

The Netherlands have been using dikes to protect their country from flooding events for a long time. Although the province of Zeeland is currently protected from flooding due to the dikes that have been constructed along its estuaria, these dikes are still being enforced with hard structures. The reason for this is the current safety standard, which states that the dikes of Zeeland are required to endure during a so called “super storm”, an event that in theory occurs 1/4000 year (Projectbureau Zeeweringen). In the nineties, dike enforcement were needed to ensure such protection, therefore maintenance measures have been taken to improve 325 km of dikes, mostly along the Western and Eastern Scheldt (M. Meijer, Grunsven, Meininger, & Persijn, 2011). This maintenance involved placing new revetment to enforce the primary function of the dikes, which is providing water safety. The dikes in Zeeland are enforced with blocks of concrete or large rubble stones, on different locations in the profile Figure 1.1. To improve all dikes along the Zeeland coastline the organisation “Zeeweringen” has been established and in 2015 all dikes ought to be very safe and meet the safety standards (M. Meijer et al., 2011).

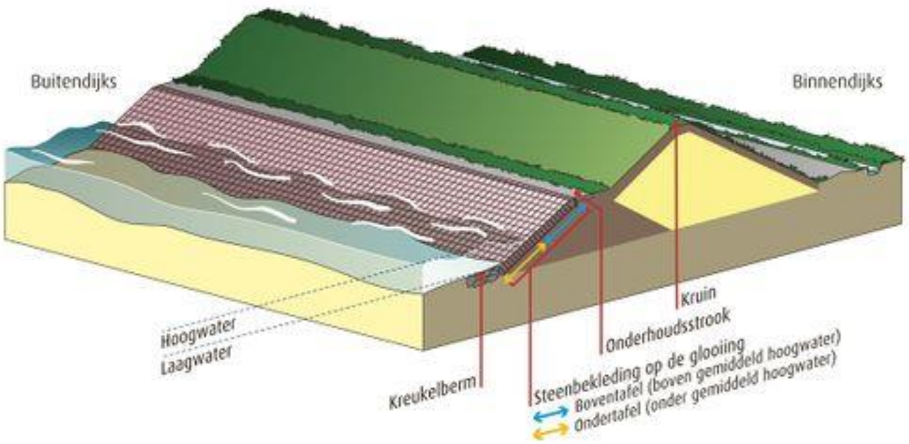

Figure 1.1 Dike anatomy (bron: zeeweringenwiki.nl)

1.2 Interactions with ecology

Beside dike enforcement for water safety, there is an ecological aspect to dike revetments. There are many areas in the province of Zeeland that have a high ecological value such as the Natura2000 areas Eastern Scheldt and the Western Scheldt. For these Natura 2000 areas nature quality requirements have been established based on the Habitat Directive and the Bird Directive. The dikes of Zeeland often border the Natura 2000 areas of the Eastern and Western Scheldt, but do not contain any qualifying habitats themselves. The interaction between these rich areas and the often not ecologically optimal structures of the dikes are an interesting field to investigate the possibilities for improving revetment design for ecology, while maintaining water safety. By including smart design that ensures both water safety and creates an opportunity for ecology, so called Building for Nature solutions can create an added value for nature and society.
This review will focus on the ecology of the coverage of the lower parts of the dike Figure 1.1. The review will specifically focus on asphalt applications or related applications such as Elastocoast, because there is an increasing interest in this topic. Moreover, less is known about the ecological performance of these new types of covering compared to concrete blocks for example. The latter have been evaluated for example by Jentink (2012) and are being studied with respect to new designs by Hogeschool Zeeland. Likewise, findings of ecological inventories on different hard substrates along the coast of Zeeland that have been performed in the past will be integrated and translated to appoint drivers for new designs for asphalt too. Finally, this will result in an overview of current lessons learned will serve as input for guidelines for Building for Nature solutions for the dike revetments of the province of Zeeland, which can be used to build test designs for optimal water safety and ecology. Furthermore, it will propose actions for future monitoring.

2 Ecology of the artificial rocky shores in Zeeland

In order to evaluate the ecological drivers behind growth of flora and fauna on the foreshores of the dike (Figure 2.1), the ecology of this area will shortly be described along with the environmental conditions that determine the presence of species.

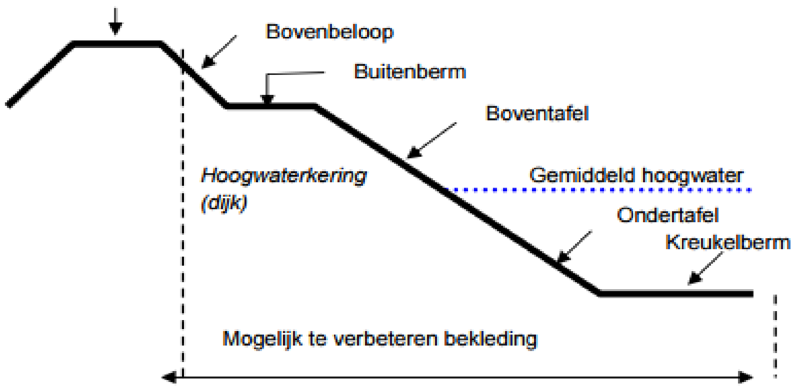

Figure 2.1 Intersection of a typical dike. The area that is being discussed in this review is the area below the average high water line (dotted line) (Meijer et al, 2011)

2.1 Ecology of rocky shores

Originally the hard rocky structures associated with dike revetments in Zeeland do not naturally occur along the Dutch coasts. However, artificial rocky shorelines can be compared with the rocky shores of areas such as Bretagne or Normandy (M. Meijer et al., 2011). Rocky shores often have dynamic environmental conditions with waves, winds and intertidal water levels and changes in temperature and light availability. These specific environmental conditions together with the structure and shelter the rocks offer can create a niche habitat for specific species such as certain seaweeds, lichens, barnacles and mussels. Furthermore, a rocky shore can have several ecosystem functions such as providing a feeding area for fish and birds. However, a prerequisite for these functions is the presence of species that enable such functions. The presence of species is dependent on a number of environmental conditions that make up the habitat, in addition to factors such as connectivity of the area and the presence of certain species in the region.
When designed in way resembling natural rocky shores, artificial rocky coasts can contain a rich flora and fauna with different algae, weeds, mussels and anemones (Meininger, 2013). Especially in the Eastern Scheldt, macro algae species richness is high and some species are protected. Therefore, in order to include ecology in the design of artificial rocky shores along the dikes of the province of Zeeland, the driving environmental conditions of ecological communities that are present on rocky shores should be used to optimize design for ecology.

2.2 Environmental conditions and community typology

Whether a habitat can achieve a high quality with presence of a rich species community depends on a number of environmental conditions that have been specified for the Western Scheldt by Meijer et al (2011):

- Salinity
- Tidal dynamics (vertical and horizontal)
- Exposition to the wind direction (salt spray, waves)
- Sedimentation
- Nutrient availability and pollution
- Type of foreshore
- Presence of large rocks or blocks at the toe of the dike (“kreukelberm”)
- Type of revetment and properties of the substrate (rough/slippery, colour, porousness, size, structure)
- Gradient of the slope

Monitoring of species together with environmental parameters can provide insight in the driving factors behind the presence of certain species. These findings can be used to create criteria for Building for Nature design solutions for the artificial rocky shores of Zeeland. The presence of species on different artificial rocky shores in the Eastern and Western Scheldt has been monitored on occasion since the eighties based on a community typology protocol created for both the Eastern and Western Scheldt (Meijer & Van Beek, 1988). This typology is based on the idea that species occur in certain combinations dependent on their required environmental conditions and can as such be categorized into characteristic communities (M. Meijer et al., 2011). Thirteen species communities are named after their dominant species and are described in more detail by Meijer et al. (2011). Inventories of species on a variety of artificial rocky substrates in the province of Zeeland have been done for different case studies and on a more general level along the coastlines of the area.

3 Ecological inventories

A number inventories with different designs of artificial shores and in different areas along the Zeeland coastline have been done over the years (De Kluiver & Verduin, 2010; Jentink, 2005; A. J. . Meijer & Didderen, 2012; M. Meijer et al., 2011). Findings from some of these inventories will next be discussed and lessons learned with respect to design will be described. Discussions will be limited to the inventories that have been performed on the lower zones of the dike, mainly on macro algae in the littoral areas. It must be kept in mind that there are several environmental conditions that could play a role in the presence or absence of certain species and the cause-effect relationship is not always obvious. As a result, a sub-optimal substrate can be a limiting factor causing the absence of species in one location. However, this is not necessarily the only parameter that could have caused this variation. The presence or absence of species therefore is not a clear indicator for the suitability of the substrate only, since the cause-effect relationship between these factors is not one on one.
Observations however, have led to a greater understanding of the role of revetment design. Therefore, general conclusions and lessons learned from each inventory will be explained and summed up in Table 4.1. This table will provide insight in found trends with respect to ecology of the artificial rocky foreshores and could provide input for criteria for Building for Nature design.

3.1 Inventories along the dikes of the Western Scheldt

One of the larger inventories that have been performed is the inventory of the weeds along the dikes of the Western Scheldt in both 1990 and 2008 by Meijer et al (2011), Figure 3.1. This monitoring was based on the community typology work of Meijer & Van Beek (1988) and has qualified vegetation on different substrates in 1990 and 2008. Between 1990 and 2008 much of the patchy revetments on dikes have been replaced (Meijer et al. 2011). Performed inventories have made a link to the substrate on which the communities where found. Along with that, some comments are made on design which will be included in Table 4.1.

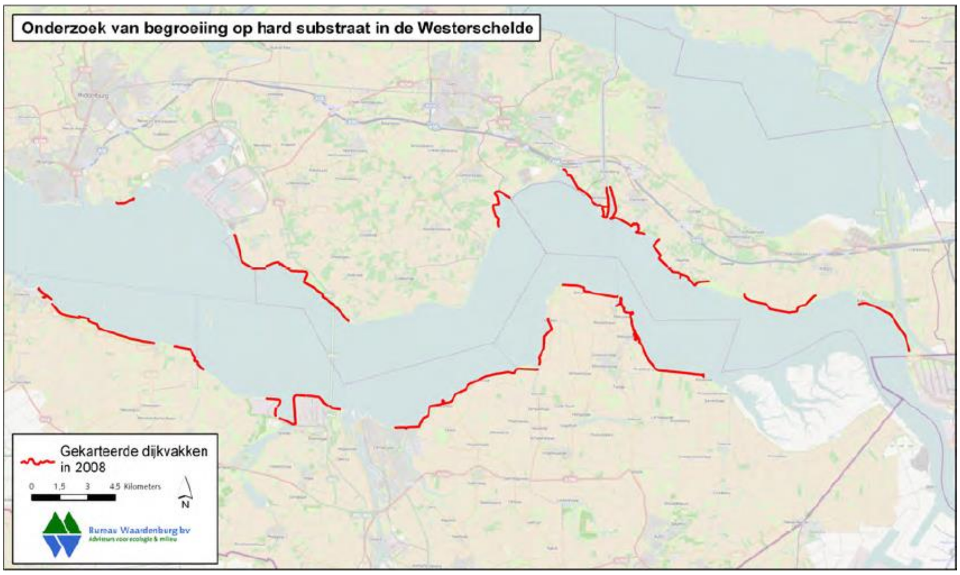

Figure 3.1 Monitored hard substrate along the Western Scheldt coastline in 1990 and 2008 (Meijer et al, 2011).

Design
Many different substrates such as ecotops or general revetments were used along these coastlines which made comparisons between the biota of these substrates interesting. Especially rubble stones were used at the toe of the dike and many different substrates have been used at the lower part of the dike. Organisation Zeeweringen has kept the ecological aspects of rocky shores in mind when placing new revetments along the existing dikes which has resulted in placement of so called hydroblocks (with or without an ecotop layer), old concrete blocks, rubble overlaid with mastic asphalt (with or without lava stone) (M. Meijer et al., 2011).There was more rubble at the toe of the dike in 2008 compared to 1990. Furthermore, there has been a large increase in concrete blocks (with and without ecotop layers) and in rubble overlaid with mastic asphalt. Mastic asphalt alone had been reduced by 2008 (M. Meijer et al., 2011).

Ecology
Over time there have been some changes in the dominant communities that were found:

- There has been a large overall reduction in barnacle communities.
- There has been an increase in *Fucus vesiculosus*
- Some less present species communities had decreased all together such as *Fucus serratus*, *Ascophyllum nodosum* and lichens.
- A strong increase in the Japanese oyster was found at the toe of the dike, this is thought to be a development independent of dike development of revetment.
- Mussel communities did not occur.
- Overall, there was an increase in surface area occupied by communities.

An appreciation system was included in the analysis of the inventory, where especially larger *Fucus* species were appreciated higher. An increase in *Fucus vesiculosus* has increased the overall value of the area, although the few highest quality areas were not there anymore. The toe of the area has improved. The increase in *Fucus vesiculosus* can be due to the fact that habitat area has increased due to improved substrate. Due to improvement of the substrate and increase in rubble at the toe of the dike, habitat area has improved.

Lessons learned
After changing a large part of the substrate and over time, environmental conditions and natural development have led to an increase in *Fucus vesiculosus*, *Phaeophyta* and Japanese oysters and an overall increase in area occupied by biota. Increase in rubble stones at the toe of the dike appeared to be good for ecology, likely due to the increase in structures that offer shelter and holdfast area. These results were also found in the Building for Nature solutions of the eco basins that include tidal pools, where tidal pools were made with rubble stones at the toe of the dikes in Zeeland (De Vries et al, 2010). Monitoring has shown that there has been an increase in the number of species and biomass in these tidal pools, thus the building a design that enhances nature was successful (Van Oord et al.). Concluding remarks with respect to design are included in Table 4.1.

3.2 Inventories along the dikes of the Eastern Scheldt

Design
In the Eastern Scheldt a similar inventory has been done as in the Western Scheldt (Meijer & Didderen, 2012). Mostly hydro-blocks were used, relatively few with ecotop layers.

Furthermore basalton was used. There was also a relatively large area of rubble stones overlaid with mastic asphalt, some with lava stone and some overlaid fully with mastic asphalt without clean rubble.

Ecology
Areas with ecotop layers or lava stone have the highest appreciation compared to other top layers. It is unclear whether this is due to the fact that ecotop layers are usually placed in locations where communities of weeds that have a high appreciation were already present. Since highly appreciated weeds were already present, it is likely that the location had favourable environmental conditions such as temperature and wave exposure previous to the placement of the ecotops. Thus it is unclear whether the ecotops either have enhanced ecological communities or kept environmental conditions favourable with regard to conditions previous to the ecotops (Meijer & Didderen, 2012).

- 50% of the lower dikes do not contain any hard substrate species.
- Lichens and *Fucus spiralus* made up a relatively large part and also *Fucus vessiculosus* of the lower dike Figure 3.2.
- *Fucus vessiculosus* and the shellfish community including Japanse oyster, mussels and barnacles make up a large part of the toe of the dike.

Figure 3.2 From left to right: Ascophyllum nodosum, Fucus vesiculosus, Fucus spiralis (sources: massnature.com; seaweed.ie)

Lessons learned
Especially the toe of the dike that includes rubble is scored very high and is scored as having lot of potential. Areas without rubble at the toe of the dike are scored badly and have lower potential as well. Adding lava above the high water line did not add any value. Loose material at the bottom of the dike is often mentioned as the reason for limited potential for further development of the vegetation. Additional remarks with respect to design are included in Table 4.1.

Figure 3.3 Monitored hard substrate along the Eastern Scheldt coastline in 2012 (Meijer & Didderen, 2012)

3.3 Inventories of general mastic asphalt applications

Mastic asphalt has been applied on many locations along the coasts of Zeeland (Figure 3.4). Mastic asphalt itself is not thought to provide a suitable habitat for many weeds due to the suboptimal environmental conditions it provides such as a high temperature and a slippery surface. However, it can often be the only option from a safety perspective (M. Meijer et al., 2011). This is in part due to the sometimes limited period of time that revetments can be placed due to storm safety measures (April 1st to October 1st) and breeding season which overlaps the safety period in part (Jentink, 2005).

Design

There are several design options for mastic asphalt, most including some sort of overlay on Rubble stones. Traditionally, rubble stones were in overlaid entirely with mastic asphalt, leaving no clean spaces on the rubble stones (Figure 3.5, left). Sprangers et al (1997) found that the slippery surface of the asphalt and the high temperatures associated with mastic asphalt in complete overlays would result in limited growth of weeds on this asphalt. Rubble stones are thought to be more suitable for vegetation to grow on then the mastic asphalt itself. Therefore, to reduce the amount of mastic asphalt surface heads of the rubble stones were brushed clean after the overlay, resulting in so called “clean heads” of the rubble stones (Jentink, 2005). This application of mastic asphalt is thought to be better for ecology. From an technical point of view, the cleaning of the rubble head however was very labour-intensive and stones had to be cleaned while the asphalt was still hot (expert judgement). Therefore, this design is suboptimal.

Figure 3.4 Selection of revetments along the coasts of Zeeland in the maintenance area of the water board: overview of known mastic asphalt locations in Zeeland (map adjusted from map by Scheldestromen).

Another way to provide more suitable surface for biota to attach, is by topping mastic asphalt overlays with lava-stones. The porous material can hold more water and reaches less high temperatures than the asphalt itself. Furthermore, the material is more irregular in surface and as a result, it is thought to offer better circumstances for biota to attach (Meijer & Didderen, 2012). Rubble stones with clean heads or topped off with lava stone make up 18,6% of the revetments in the Eastern Scheldt in 2012 (Meijer & Didderen, 2012). From available maps it is unclear up to now where these locations are.

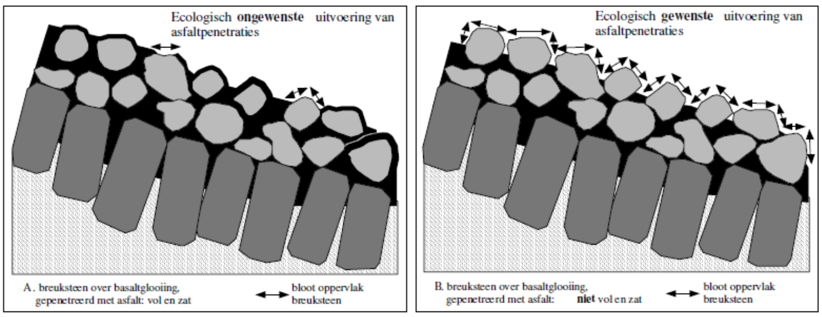

Figure 3.5 Different ways to overlay rubble stones with asphalt: full overlay with no clean rubble on the left, overlay with clean rubble heads on the right (Jentink, 2005).

Ecology

From an ecological point of view, mastic asphalt topped off with lava stone appears to be better than using a substrate without such a layer (Meijer & Didderen, 2012). Topping mastic asphalt with lava above the high-water line does not add value for ecology (Meijer & Didderen, 2012). A comparison between 1985 which was a starting situation with a relatively high species richness in the Eastern Scheldt, and in 2005 on locations where "clean heads" were applied showed a recovery of the species richness (Jentink, 2005). A complete recovery of the vegetation is thought to last 15-20 years based on these findings (Jentink, 2005). Some of the typical species from 1985 did not return, such as *Ascophyllum nodosum (*Figure 3.2*).* After 20 years *Fucus* species are dominant in most areas with clean heads (Jentink, 2005).

Lessons learned
In general the feedback on mastic asphalt with any types of "clean heads" for example due to lava stone is positive, since it reduces the negative conditions associated with asphalt. Some remarks have been made with respect to the ability for the topping material to detach (A. J. . Meijer & Didderen, 2012; M. Meijer et al., 2011). When topping material detaches and accumulates below the dike, it can serve as a disturbance factor for vegetation due to the consistent slamming of this material against the dike. Therefore, it is important to test this design and derivatives of such design for its sustainability. Furthermore, from a management point of view, loose small stones should be removed from the toe of the dike to prevent disturbance. Another aspect of sustainability is the ability of the revetment to last for a long period of time. Since Jentink (2005) showed that weed populations were able to recover after a time period of 15-20 years, continuing disturbance is likely to hinder this recovery. Thus, when applying new revetments from both an ecological and an economical point of view, it is best to build a revetment that will last.

3.4 Polyurethane Bonded Aggregate (PBA) inventories (Elastocoast)

Design
Elastocoast is a brand name for Polyurethane Bonded Aggregate (PBA) material that has been applied in a couple of pilot locations in the Netherlands, among which the Zuidbout in Zeeland and in Petten (Lock, 2008). Furthermore, it is being used along the shores of the province North-Holland to expand the feeding area for certain species of birds as a compensation measure for the new dunes that are being installed (expert judgement). The material has been designed in Germany by BASF and is a relatively new coastal protection material that is made of a combination of stones coated with polyurethane (Lock et al, 2008). Generally PBA or Elastocoast is made off of basalt stone or granite bound with a sort of "glue" called polyurethane, resulting in a porous but flat material that was designed to optimally handle wave pressure (Lock et al, 2008).

Ecology
In the laboratory, microalgae were able to grow on the material and it is expected that regular dike vegetation will also grow on the material (Lock et al, 2008). However, opinions are mixed on the ecological potential of this type up revetment up to now (expert judgement). The pilot location in Zuidbout was visited twice (2008 and 2009) and a comparison between observations in both years showed that there was vegetation growing on the material (M. Lock, 2009). It was mentioned by Lock et al (2009) that in places where more sand was available, vegetation showed a better recovery due to an increase in structured substrate. This implies that in other locations, the substrate could have been too slippery for optimal vegetation growth.
The location in Petten has been monitored and analysed for its ecological value with respect to mussel growth on the material and it was found that 88.5% of the sampled substrate was

covered with mussels and highest coverage was found on a layer of 10 cm PBA (Paalvast, 2013). Additionally, a number of different weeds have been found on the substrate such as *Ulva flexuosa* and *Gayralia oxispermum*.

Lessons learned
Vegetation is able to grow on the substrate, however it appears to be slippery and an increase in structured substrate would create possibly create better possibilities for ecology. Mussels were able to grow on the substrate as well which could serve as a food source for for example the oyster catcher. Since the ecological potential of the material has been evaluated using a different inventory method, it would be interesting to compare its potential along the coast of Zeeland using the same method as in other monitoring of the coast. Furthermore, due to a difference in occurring biota it would be interesting to see what could grow on the material when used in Zeeland. Furthermore, since the material is said to be very sustainable, it would require less maintenance and as a result less frequent disturbance of the recovering vegetation. Therefore, it is advised to use this material in a test set up along the coast of Zeeland to further study its ecological potential. Paalvast (2013) advises to use a minimal cover layer of at least 10 cm so that mussels would have ample opportunity to attach to the material.

4 Integration of results: guidelines for design

Findings of inventories on revetments on lower parts of the dike have led to the improvement in understanding of the environmental conditions that are required for vegetation growth along the dikes. Based on these inventories, a list of lessons learned with respect to design has been constructed which can be used to optimize design of future dike revetments. This overview of lessons learned is provided in Table 4.1 and will next be discussed.

General conclusions for design guidelines

A. The type of substrate that is used in dike design is crucial for the ability of biota to attach. Large solid surfaces should be prevented and (micro)-structures should be created. This will offer the vegetation a suitable substrate for attachment and creates shelter. For example the placements of rubble stones at the toe of the dike, or the overtopping of mastic asphalt with lava stone creates such structures.
B. The use of dark colours should be prevented. Dark colours can get warm in the sun which will significantly alter the environmental conditions. These conditions are usually not optimal for the present biota since these temperatures differ largely from the natural conditions.
C. It is important to make a sustainable design that will not require many maintenance activities or includes material that will detach. The presence of small eroded material is often mentioned to be a limiting factor in the growth of vegetation on the substrate. Creating a sustainable design will prevent the communities to have to recover due to a new overlay. Furthermore, it will limit the disturbance to biota due to small material hitting their habitat.

D. Steep slopes (gradient not specified) were mentioned as a reason for not achieving high community densities (Lock, 2009) as a result of high wave action. These conditions could potentially be suboptimal to the biota of the artificial rocky shores in the estuaries of Zeeland, so they should be avoided in the design.

Furthermore, some general remarks with respect to design can be made:

- In order to scientifically determine which types of revetment are optimal for growth of vegetation, their environmental requirements need to be taken into account alongside these lessons learned. It is advised that when testing design, all parameters except for the substrate are kept equal in order to be able to make an honest comparison between design options.
- Shifts in species communities could provide insight in changes in driving environmental factors. However, as mentioned before changes in species cannot only be an indicator for changes in substrate since there are multiple parameters that can cause certain shifts. For example, the increase in Japanese Oysters is likely due to an overall increase in the area and not necessarily due to a change in substrate. Since the cause effect relationship between the presence of species and the change in substrate in the field is hard to determine, it is wise to try to find general conclusions and observations on design and include these in experimental set-ups that can next be tested in a test location where all parameters except for substrate are equal.

Lessons learned - guidelines for design:		Explanation:	Literature:
A	Create holes and structure, prevent creation of a large solid surface and use porous and structured material	Shelter, suitable substrate for attachment by retaining water and microstructures, larger possibilities for ecological value	Meijer et al, 2011; Meijer et al, 2012; Lock et al, 2008; Jentink, 2005; De Vries et al, 2010; Van Oord et al
B	Prevent the use of dark colours	Prevent high temperatures	Meijer et al, 2011
C	Use a sustainable design solution and prevent using material that detaches, remove small loose material	No added disturbance through maintenance, provide recovery time, prevent loose material hitting biota with waves thus causing disturbance	Meijer et al, 2011; Meijer et al, 2012; Jentink, 2005
D	Prevent steep slopes	Higher wave action, different dynamics	Lock, 2009

Table 4.1 Lessons learned from inventories performed on different hard substrates of the lower dikes along the coasts of Zeeland.

5 Follow up: future monitoring possibilities

Over the years many inventories have been done to see what the effects of different types of revetments of the lower parts of the dike have on ecology. It remains interesting to see what current developments are on locations that have been installed for a longer time or with material that has been investigated less. Monitoring of different vegetation communities of mastic asphalt revetments together with the associated environmental conditions and the physical characteristics of the revetments should in this case be monitored. Along with species communities and environmental conditions that are described in paragraph 2.2 a number of characteristics of the revetment need to be monitored, such as:

- Type of mastic asphalt: mixture / “clean”
- Topping of asphalt and characteristics: lavastone / other topping, dimensions of topping and density of the cover, thickness of the topping
- Erosion of the toplayer

Analysing environmental conditions along with ecology can provide further insight in driving factors for ecology associated with mastic asphalt and can give further guidelines for optimizing a Building for Nature design of dike revetments. For future monitoring descriptions of species communities and inventories by Meijer (1993) and in more detail Meijer & van Beek (1988) could be used.

Mastic asphalt topped with lava stone locations
Locations that have been topped off with lava stone could be inventoried on the amount of material that has detached and is now possibly causing disturbance for vegetation. Detached material cannot be measured directly; however the amount of loose material at the toe of the dike could provide insight in this potential design failure. Doing an inventory at these locations that are topped off with lava stone on both loose material and present vegetation could provide more insight in the potential importance of this process. These 5 locations are shown in Figure 5.2, Figure 5.3, Figure 5.4 and Figure 5.5. The location at Kruininge is a test site where other materials have also been tested.

PBA/Elastocoast locations
Finally, an inventory of the vegetation growing on Elastocoast material and associated environmental conditions would show whether this material has the right environmental conditions for ecological recovery of the vegetation. There currently is no map available for the exact locations where Elastocoast has been used, however these locations are in Petten and Zuidbout. Due to their shown potential by Paalvast (2013) it would also be interesting to use this material in a test location along the shore of Zeeland to have a further look at its ecological potential in this region.

Figure 5.1 Elastocoast/PBA pilot locations at Petten and Zuidbout.

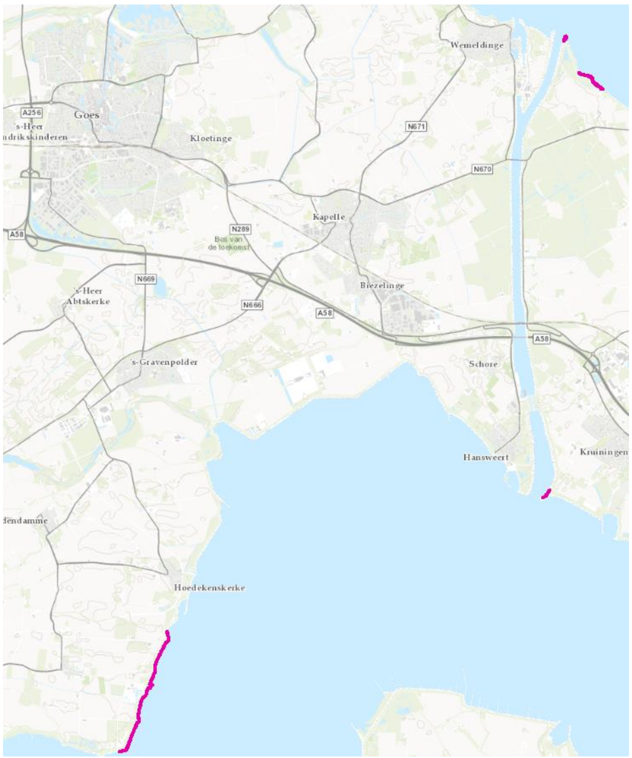

Figure 5.2 Location of rubble stone overlaid with mastic asphalt topped with lava stone (applied in 2003)

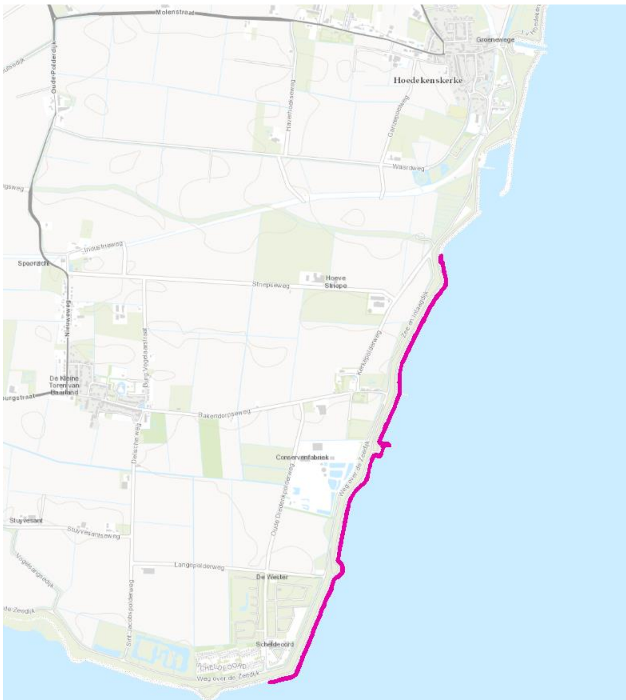

Figure 5.3 Location of rubble stone overlaid with mastic asphalt topped with lava stone close to Hoedekenskerke (applied in 2003 - 2004)

Figure 5.4 Location of rubble stone overlaid with mastic asphalt topped with lava stone at two locations close to Wemeldinge (applied in 2008)

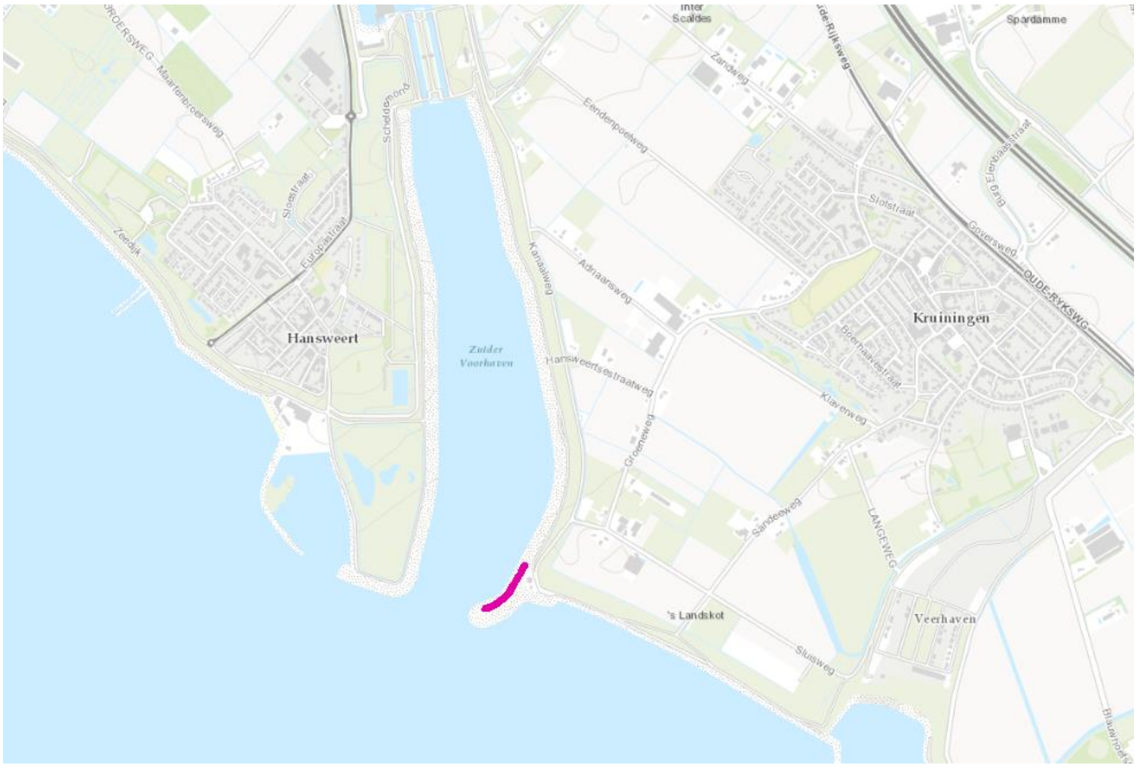

Figure 5.5 Location of rubble stone overlaid with mastic asphalt topped with lava stone at a small area close to Kruininge, this location is a pilot area that also includes other materials (applied in 2006)

6 Literature

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