Deltares

Enabling Delta Life

Ecological potential of mastic asphalt for rich revetments

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Key words
Mastic asphalt, macro algae, benthic fauna, substrate, intertidal area, dike revetment, rich revetments, building for nature

Summary
Within the scope of Building for Nature along the dikes in Zeeland, the aim is to enhance the ecological potential of the shorelines with hard substrate by creating rich revetments. To this end, several pilot projects and studies have been developed with different innovative revetments, with the aim to study the ecological potential of such revetments and the drivers behind this. This report focusses on the outcomes of two parallel studies, which focussed in particular on the mastic asphalt applied to the lower parts of the dike.
Mastic asphalt is often applied for strength due to its properties with respect to easy application, costs and durability. Mastic asphalt is thought to be sub-optimal for enhancing the ecological potential of dikes, due to the traits of the substrate (limited porosity, high temperatures, smooth, untextured surface).
In this study, different types of substrates are tested in an experimental set-up on their potential to increase both coverage of flora and fauna and biodiversity. Different substrates have been chosen based on their expected potential for enhancing ecological potential of revetments.
The two studies differed in scale and analysis methods, but compared colonisation of similar substrates. These comprised: bare mastic asphalt, asphalt with either larger or smaller lava stones incorporated, asphalt with either oyster shells or cockle shells incorporated and in the smaller scale trials with tiles at Yerseke also a commercially available top layer “Elastocoast” was assessed. In general the tests confirmed the underlying hypothesis that a more physically complex environment is inductive to higher biodiversity. Also the mastic asphalt was generally colonised much slower that the other surfaces, although in the trials in Yerseke particularly this surface was colonised extensively by a non-native species, the acorn barnacle from New Zealand. This was not observed at the other test site in Zierikzee. There are still question marks regarding the ultimate cover and biodiversity in a few years’ time, when the communities have reached a steady-state. However, the initial results indicate that relatively simple adaptations to mastic asphalt can have an impact on its ecological potential.

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1 Introduction

1.1 Building for Nature with Rich Revetments

Building for Nature is the concept in which infrastructural designs are modified with the aim to benefit nature and increase ecological functioning, in addition to fulfilling the primary infrastructural purpose of the design (Rijkswaterstaat, 2012). Ecological functioning can be defined as the maintenance and regulation of ecosystem processes (Naeem et al., 1999). Measuring ecological functioning is complex, often relates to chemical, biological and physical characteristics and as a results there is not just one indicator for ecological functioning (Bremner, 2008).

An example of a Building for Nature solution is the Rich Revetment. Many parts of the Dutch coastline are enforced with dikes and levees to protect the hinterland from flooding. Traditionally, the design of dikes and levees involves hard revetments that can withstand the forces that are put on a dyke during so called “super storms” (Projectbureau Zeeweringen). These monotonous revetments are generally considered unattractive from a habitat point of view, due to limited presence of shapes and gradients to facilitate ecological development (Wiersma et al., 2014). Loke and Todd (2016) showed that in artificial substrates, greater habitat complexity can facilitate higher species richness.

With regards to Rich Revetments, the focus of ecological functioning has been aimed on species diversity and coverage of the revetments. The potential for good ecological functioning could be increased by creating favourable environmental characteristics that enhance diversity and coverage. Therefore the concept of Rich Revetments has focussed on creating more diverse habitats dikes on locations where dikes and their associated hard substrates are necessary for safety (Wiersma et al., 2014).

1.2 Habitat diversity and environmental gradients

In practice complexity can be increased for example by creating physical gradients for example through using different shapes, creating tide pools or adding holes to the substrate where organisms can hide. Furthermore, changes in the substrate used as revetment could contribute to habitat diversification.

Studies have shown that environmental characteristics are driving factors behind habitat diversity (Ballesteros et al., 2007, Baptist et al., 2007, Cefalì et al., 2016, Meijer et al., 2011). These characteristics include the following:

- Slope of the coastline
- Orientation
- Salinity
- Wave exposure
- Nutrient availability
- Temperature
- Substrate

The most important elements of the dikes for dike-safety are the height of the dyke and revetment on the higher slopes (Baptist et al., 2007). This leaves most freedom for alternative building for nature design at the lower intertidal part of the dyke Figure 1.1.

In the intertidal zone of the dike, conditions create an environment that can contain a rich ecological community. Differences in species occurrence are the result of both gradients in

environmental characteristics, and competition between the species that are best adapted to these conditions. This leads to a zonation of species on the dike. Species that can generally occur in the intertidal zone on hard substrate include shellfish such as *Littorina sp., Mytilus edulis*, green weeds such as *Ulva sp.*, brown weeds including *Fucus sp.* and barncacles (*Semibalanus balanoides*) (Baptist et al., 2007).
In the province of Zeeland, dikes with high wave action generally contain *Ulva sp.* at the upper parts, followed by *Fucus spiralis*, next *Fucus vesiculosus* and at the lower parts *Fucus serratus* (Van der Loos, n.d.). Dikes that are less exposed will often have *Ascophyllum nodosum* instead of the band of *Fucus vesiculosus*.

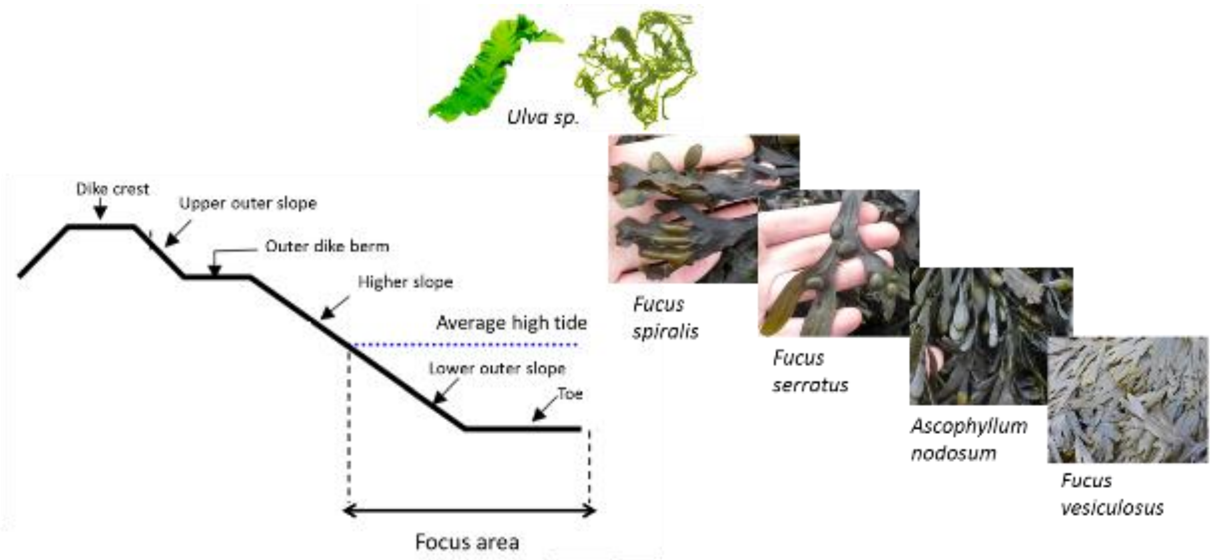


Figure 1.1 Cross section of a traditional dyke and its sections. The focus of this research is on the lower intertidal part of the dyke and seaweed species that can occur in the intertidal area have been specified together with their usual zonation (modified from (Van der Loos, n.d., Meijer et al., 2011).

Of all environmental characteristics, substrate of the revetment is the parameter that can most easily be modified and optimized in the design process, whereas the other characteristics are often environmentally determined. Characteristics of the substrate determine the degree to which it is likely to be beneficial for facilitating species (Leewis et al. 1989).

1.3 Dike revetments: mastic asphalt

Currently the lower outer slope of the dyke is often enforced with either concrete hydro-blocks, or basalt rubble topped with mastic asphalt. The toe of the dyke generally is made up of loose basalt blocks (Meijer et al., 2011). The use of mastic asphalt as overtopping of basalt rubble at the lower slope of the dyke has greatly increased between 1990 and 2009 (from 0.2% to 11.2%) in the Western Scheldt (Meijer et al., 2011). Mastic asphalt is relatively cheap and easy to apply at the lower parts of the dyke (Meijer and Didderen, 2012).

Table 1.1 Parameters of revetment substrates and the desired characteristics from an ecological point of view and a civil engineering point of view (based on (Baptist et al., 2007)

Revetment parameters	Desired characteristics for ecology:	Desired characteristics for civil engineering:
Roughness of the substrate	Material is preferably rough: - Potential for attachment to the material by organisms - Reduce wave speed which exerts force on biota.	Rough material mitigates wave speeds
Presence of structures (holes, microstructures)	Placement of material or choice of material preferably has holes and structures facilitating attachment and creating hiding spaces.	More open structures prevent water pressure under the revetments and are therefore preferable.
Water retention potential	Ecological point of view: water retention creates more preferable conditions for attachment of vegetation.	Water retention makes the substrate less strong, thus absorption should be below 0.5%.
Hardness	In order for species to be able to attach to the rock it should not be too hard.	Hard rocks are considered as strong and therefore preferable.
Colour	Dark colours can create large differences in temperature, which is suboptimal for vegetation.	-
Size	Variation in sizes of rock provides more gradients	Especially thickness of the material is important for safety and durability. Large rocks are more difficult to place.
Slope	Shallower gradient gives more surface area per height class and easier feeding conditions for birds.	Wider dykes are more stable and less prone to piping.
Chemical composition	Chemically harmful substances could potentially hinder growth of vegetation	-

Table 1.1 shows that some desired characteristics for enhancing ecological potential differ from required characteristics from a civil engineering point of view. This is also the case for mastic asphalt, which provides sub-optimal conditions for ecological value (Baptist et al., 2007). The dark colour of the material can heat up to high temperatures when exposed to sunlight, which could be detrimental to organisms attached to the substrate (Meijer et al., 2011). Furthermore, mastic asphalt is not a rough material. Per unit overall surface area the total area of attachment surface is low and there is little microtexture to aid initial attachment. Mastic asphalt could therefore limit potential for settlement on the material (Baptist et al., 2007).
Mastic asphalt is not porous and therefore its water retention potential is also limited. Depending on the application of the mastic asphalt, there are no micro-structures and holes available. Jentink (2005) has previously advocated leaving parts of the basalt blocks “clean” when overlaid with mastic asphalt, since this could lead to a more rapid recovery of seaweed communities. In line with this recommendation, mastic asphalt has at some locations along the dikes in Zeeland been topped with lava stone (Meijer et al., 2011). However, monitoring in the Western Scheldt showed that this material can detach when not applied properly. When this happens it can end up as loose rubble at the bottom up the dyke and put pressure on the vegetation when waves containing rubble hit the slope (Meijer et al., 2011).

The characteristics of mastic asphalt are not in line with the previously determined substrate traits that are thought to enhance the ecological potential for growth of flora and fauna (Table 1.2), however the material is regularly applied in the field. This research has therefore focussed on Building for Nature design modifications to the traditional mastic asphalt, in order to determine the ecological potential of mastic asphalt for creating rich revetments.

1.4 Ultimate aim

The goal of this research was to study and compare different potential top-layer substrates for mastic asphalt on their ability to facilitate growth of flora and fauna both in the field and in an experimental set-up. Combined results from both studies will provide insight in the ability of the different substrates to serve as Building for Nature solutions and enhance ecological potential of dyke revetments.

2 Methods

2.1 Choosing mastic asphalt “ecotops”

During a design session at the Building for Nature conference organized by the HZ University of Applied sciences a number of materials were suggested to add as topping to the mastic asphalt. Some promising materials suggested were oyster shells and cockles. Oysters and cockles were suggested due to the fact that they are a natural hard substrate in marine and coastal zones and shell material is often readily available.

Mastic asphalt on the dikes in Zeeland is sometimes covered with lava stones as an “ecotop”. Lava stone is a very porous material and can therefore remain moist even during low tides. Lava stones in the field showed to have a variety of macro algae growing on the material. However, workshop participants had also observed that the material sometimes disappears or ends up and the bottom of the dike. Due to the proven potential of the material in the field, the lava stones were chosen as a topping for mastic asphalt that required further prove of concept. Both small lava stones (± 3-5 cm in diameter) and large lava stones (± 10-20 cm in diameter) were chosen as a topping material, since there might be a difference in their durability in the asphalt.

Finally, there is another material that was tested which could potentially serve as an alternative to mastic asphalt and was therefore not used as a topping. This material is referred to as Elastocoast and was developed by BASF and Heijmans. The Elastocoast material consists of rocks covered and pasted together with polyurethane-glue. The material has many open spaces where fauna can potentially hide and is thought to be able to facilitate growth of sea weeds (Heijmans, 2016). It is being applied along 13 km of dyke in Friesland where it is expected to be a sustainable alterative to open asphalt with an expected lifetime of 50 years, which is twice as long as the alternative material (Groenervaren, 2016).

Mastic asphalt without top layer as it is most often applied in the field was included in the study as a control.

2.2 Parallel studies: field experiment and dyke monitoring study

The described potential “ecotops” were studied in in the field in two parallel studies with the aim to answer the following research question: Which substrate facilitates both the highest biodiversity and coverage in flora and fauna under equal intertidal environmental conditions at the end of the monitored time period? The focus lies at the end of the monitored time period, since at the onset especially pioneer species are expected to occupy the substrate. These species are expected not to all remain during a climax stage.

Two separate studies took place parallel to one another in the province of Zeeland in 2016. One study involved a field experiment where all other conditions except for the substrate were kept the same. An experimental set-up in the field with several tiles of different “eco-top” substrates can provide information on the ecological potential of a substrate when keeping all other factor the same over time. The aim of the monitoring of the experimental set-up was to determine whether the different substrates would lead to a difference in flora and fauna coverage and diversity as measures for ecological functioning.

The other study involved monitoring on the dikes. It is important to investigate the different mastic asphalt substrates in a realistic situation. Therefore an experiment was set up with different mastic asphalt substrates placed on a dyke in the field to gain a realistic impression of how the biota would develop in a realistic dyke situation.

Both studies will be discussed separately with respect to methods and results.

2.3 Field experiment at Yerseke

The field experiment was set up with the aim to answer the following research question: Which substrate facilitates both the highest biodiversity and coverage in flora and fauna under equal intertidal environmental conditions at the end of the monitored time period (11 months)?

In order to answer the research question, a number of hypotheses that describe the differences between flora and fauna on the substrates over time have been tested. These hypotheses are aimed to analyse coverage and biodiversity over time, and to test whether there is a difference in species that were able to settle on the substrate over a total time period of 11 months.

1. There is no difference in **total coverage** (%) between the **different substrates after 11 months**.
2. There is no difference in the **overall species composition** (average coverage m^2 per species) between the **different substrates after 11 months**.
3. There is no difference in **diversity** (richness and Shannon-Wiener diversity index) **different substrates after 11 months**.

2.3.1 Experimental set-up

The tiles were set-up in December 2015 at the field location in Yerseke, Zeeland Figure 2.1. Tiles with different substrates and dimensions of 0.5 x 0.5 m were placed on a metal frame at 0.0263 m NAP with an exposure time of 53.3%. The frame was placed at an intertidal location and the tiles are horizontally placed parallel to the surface water. This way the tiles mimic a revetment at the bottom of the dyke with respect to their orientation. However, they are located higher relative to the sea surface.

Figure 2.1 Location of the experimental set-up in the field at Yerseke.

All substrates were placed randomly on the framework according to the overview below.

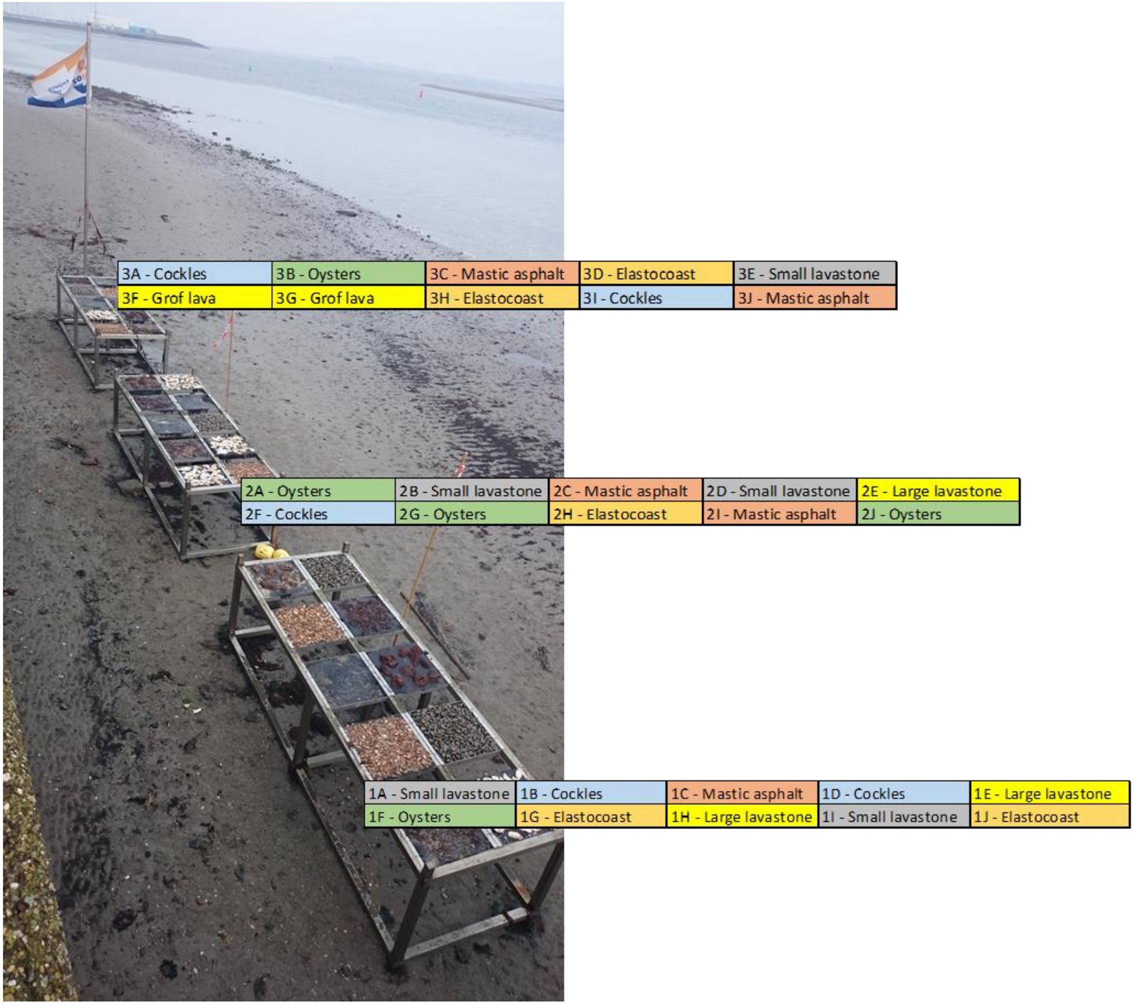
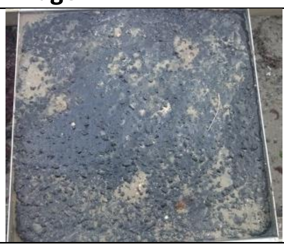


Figure 2.2 Overview of the placement of tiles at the field location.

A total of five substrates were selected, based on the process described in Chapter 2.1. Five replicates were installed for each type of substrate. The five substrates are shown in Figure 2.3.

Substrates:	**Image**
Mastic asphalt (reference substrate without addition)	

Small lava stone (on mastic asphalt)	
Large lava stone (on mastic asphalt)	
Oysters (on mastic asphalt)	
Elastocoast (rocks covered and pasted together with polyurethane-glue)	

Figure 2.3 Overview of the substrates studied.

All tiles were created previous to placement except for the Elastocoast tiles. Heijmans was present at the location to create the Elastocoast glue and tiles. Elastocoast tiles contained a lot of empty space compared to the other tiles and water could accumulate due to the solid bottom of the tile. Therefore holes were drilled in the bottom of the tiles during placement to prevent large unnatural differences in water retention on the tile between the substrates.

2.3.2 Monitoring and species identification

Monitoring has taken place over the course of one year, roughly once every three months.

Time (T)	**Date**	**Month**
T0	16 December 2015	0
T1	15 March 2016	3
T2	13 May 2016	5
T3	20 September 2016	9
T4	24 November 2016	11

During monitoring, species were determined for biodiversity measures and pictures were taken for detailed determination of coverage. The sampling sheet used during monitoring is attached in **Annex** Error! Reference source not found.**.**

Determination of species and coverage was done visually by the same individual to prevent differences due to changing observers. When uncertain about species, they were double checked by species experts from Stichting Anemoon. Most macro algae species were not determined to species level due to difficulty of determining the differences with juveniles and due to later photograph based analyses where details cannot be observed.
Ulva sp. includes both *Ulva intestinalis* (gutweed) and *Ulva lactuca* (sea lettuce). The *Porphyra* (red algae) species identified were most likely *Porphyra umbilicalis*. Only *Fucus vesiculosus* (bladder wrack) was identified at the species level due to clear distinction from the other *Fucus* species, especially in a later stage in monitoring.
Common fauna species were determined to species level: *Elminius modestus* (the Australasian or New Zealand barnacle; currently named: *Austrominius modestus*), *Littorina littorea* (winkle) and *Mytilus edulis* (mussel).
Coverage determined from photographs was set at a maximum of 100% per tile. Thus flora species overlapped by other flora species will not be identified in coverage per species when not visible on the analysed photographs.

2.3.3 Data analysis

To test the hypotheses of this field experiment, a number of analyses have been performed which are described in Table 2.1.

Table 2.1 Overview of hypotheses and analyses performed per hypothesis

Hypotheses:	***Analysis:***
1. There is no difference in **total coverage** (%) between the **different substrates, after 11 months**.	Visual presentation of bar-charts with average (n=5) total coverage (%) per substrate per moment in time (T) of all flora and fauna summed up in bar charts. Qualitative description of development over time per substrate and between substrates.
	Kruskal-Wallis test on average total coverage (m^2) per substrate (independent factor) after 11 months.
2. There is no difference in the **overall species composition** (average % coverage per species) between the **different substrates after 11 months**.	Analysis of similarity (ANOSIM) and multi-dimensional scaling (MDS) plot of average coverage (m^2) per species (variable) per substrate (variable) after 11 months.
	Visual presentation of bar-charts with average (n=5) total coverage (%) per species per substrate summed up in bar charts. Qualitative description of species composition per substrate and development over time.
3. There is no difference in **diversity** (richness and Shannon-Wiener diversity index) **different substrates, after 11 months**.	Average (n=5) species richness (n) per substrate moment in time (T). Qualitative description of differences.
	Average (n=5) Shannon-Wiener diversity index (H) after 11 months and overall (all months combined).
	One-way ANOVA on average Shannon-Wiener diversity (H) per substrate (independent factor).

Coverage
Pictures of each tile ($1m^2$) were analysed for their coverage. Total coverage was set to 100%, thus algae overlapping each other on the tile were not added as a surplus %. Coverage can therefore be measured as a % of $1m^2$ or a surface area. Species were analysed
For coverage determination per species, the tiles were divided into 25 tiles, each representing 5% of the total coverage (see **Annex B)**.
Biodiversity analysis
Species richness describes the number of unique species found in at a substrate (n). The diversity of species on the different substrates can be illustrated with the Shannon-Wiener diversity index. This index is calculated based on the number of species present (n) and their coverage (m^2) through the following formula:

$$H' = -\sum p_i \ln p_i$$

Where H' is the Shannon-Wiener diversity index and p_i is the proportion of individuals of a species in a sample.

Statistical analysis
The monitoring is performed on the same tiles (with different substrates) over time and can therefore be considered as a repeated measures design.
Difference between substrates is considered as more important than difference between moments in time. In order to both get more specific insight in the differences in coverage, composition and biodiversity between different substrates, and overall development at the end of the monitoring period (11 months), univariate and multivariate tests were performed.

2.3.3.1 Univariate analysis
Total coverage of species (%) after 11 months was tested for normality using the Shapiro-Wilkinson test. Data were not normally distributed after an arcsin transformation. In order to determine the differences in total species coverage (%) between substrates after 11 months, a Kruskal-Wallis non-parametric test was performed on log10 transformed data.
The Shannon-Wiener diversity index based on species coverage per substrate after 11 months was statistically analysed with an analysis of variance (ANOVA), after testing for normality with a Shapiro-Wilkinson test. Homogeneity of variances was tested through Levene's test. A Tukey post-hoc pairwise test between substrates was performed because variances were equal (confidence interval 95%). Tests were performed in IBM SPSS Statistics 22.

2.3.3.2 Multivariate analysis
A multidimensional scaling plot (MDS) plot was made of the coverage (% / 100) per species per substrate after 11 months. An MDS plot can provide insight in the level of similarity between datasets by visually showing the resemblance between data points in a distance matrix. The distance between the data points provides gives an indication of the difference between the data points. Previous to the analysis, data were transformed with a log10 function and resemblance in species composition based on coverage per species, was determined through a Bray-Curtis dissimilarity analysis in Primer. After the Bray-Curtis analysis and configuration of the MDS plot, a one-way Analysis of Similarity (ANOSIM) was performed on the factor "substrate" to determine whether there was a significant difference in species composition between the different substrates at the monitoring of 11 months.

2.4 Dike monitoring study Zierikzee

The field monitoring study was carried out to answer the research question: Which substrate facilitates both the highest biodiversity and coverage in flora and fauna, and at which height on the dyke at the end of the monitored time period (after nine months)?
The aim of the monitoring of this experimental set-up was to determine whether flora and fauna on the different substrate types developed differently with respect to coverage and diversity of species. Five different substrate types were placed on the dyke in the field at Zierikzee, and monitored for the type and coverage of algal species and the fauna present at six and nine months after placement along a transect covering different heights on the dyke.

In order to answer the research question, a number of hypotheses that describe the differences between flora and fauna on the substrates over time were tested. These hypotheses are aimed to analyse coverage and biodiversity over time, and to test whether there is a difference in species that were able to settle on the substrate over a total time period of nine months.

1. There is no difference in **total algae coverage** (%) between the **different substrates** after six and nine months.
2. There is no difference in the **composition of the algae species** comprising the total coverage (%) on **different heights** on the dyke, after six and nine months.
3. There is no difference in **species richness** of fauna on different substrates, and heights after six and nine months.

2.4.1 Experimental set up

Asphalt with different treatments was applied at the sea side of a longitudinal dam at "Haven De Val", a former ferry harbour (Figure 2.4). The different treatments were applied to the dyke in cross sections of 5-10m wide along the slope of the dyke from NAP +1,7m to the toe of the dyke which began at an average height of NAP -0,35m.
Mastic asphalt was mixed with different components to produce different substrate types on the dyke. These components included: large lava stones (four sections), cockle shells (three sections), nothing (bare mastic asphalt to be used as a reference; five sections), small lava stones (three sections) and oyster shells (one section, Figure 2.5).
Each surface type presented varying degrees of structural heterogeneity, exposed mastic asphalt and size and quantity of an alternative surface type (rocks or shells) (see Results Figure 3.3) along the height of the dyke (see Figure 2.6).

Figure 2.4 Location of the field experiment on the breakwater dyke at Haven de Val, Zierikzee

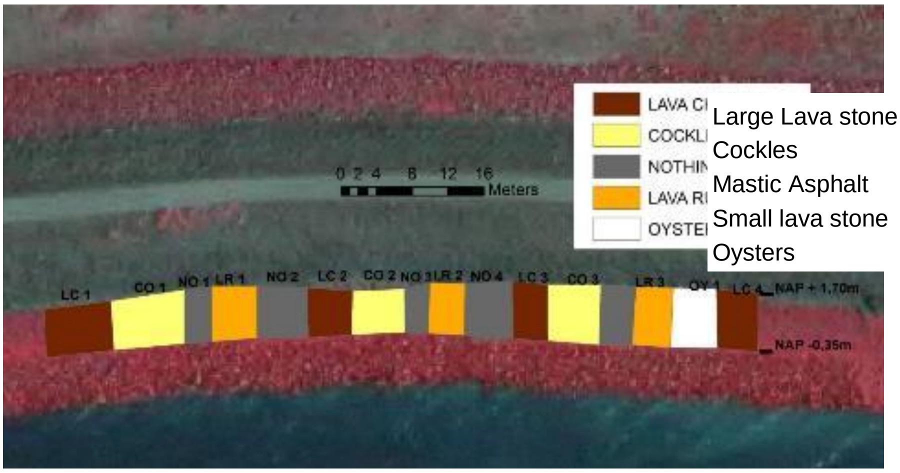


Figure 2.5. The exact field setup with the different treatments. The different treatments are: Large lava stone, cockle shells, bare mastic asphalt (control), small lava stone and oyster shells (only one treatment). The treatments were applied from NAP +1,7m till the toe of the dyke which begins at an average height of NAP -0,35m.

2.4.2 Monitoring and species identification

The different mastic asphalt surface types were monitored by taking and analysing photographs, and by manual inspection of flora and fauna during transect surveys. Detailed photographs of quadrants along a transect we taken shortly after, and six and nine months after the application of asphalt. Photographs of the more general and large scale spatial coverage were also taken six and nine months after the application of asphalt. Manual inspection of quadrants along a transect was conducted once, six months after the application of the asphalt (Figure 2.6).

Table 2.2. Summary of monitoring activity during the experiment.

Date	**Activity 1**	**Activity 2**	**Activity 3**

1st week dec 2015	*Application of asphalt*		
17 dec 2015 (T0)	Quadrant photos		
20 jun 2016	-	-	FF - transect survey
28 jun 2016 (T1)	Quadrant photos	Spatial coverage photos	
22 sep 2016 (T2)	Quadrant photos	Spatial coverage photos	

2.4.2.1 *Quadrant photos*

In the middle of every section photos were taken of a quadrant of 50 x 50cm at 2m and 4m from the top of the section along a transect line. To be able to consistently take the photos of the same area of the dyke, the top of a transect was marked with blue paint. One transect was used per section of substrate treatment, but because there was only one treatment with oyster shells as the substrate, two transects were used in the same section. Every transect always began at the same height of Nap +1,5m (Figure 2.6). Photos were used to illustrate the colonization of the algae in detail, and to study the treatments, i.e. the degradation of the treatment material.

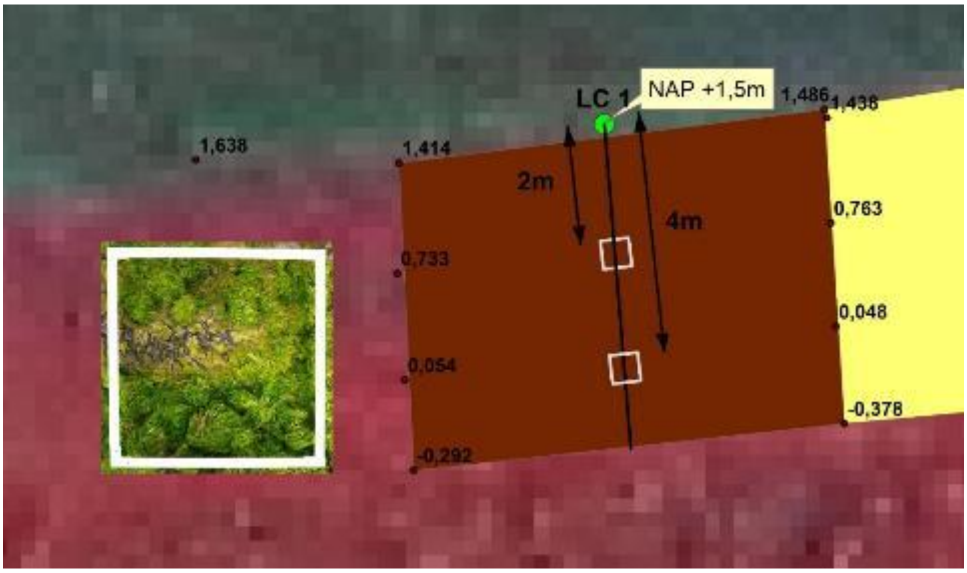


Figure 2.6. Placement of the transect in each mastic asphalt section. The insert photo is an example photo of a quadrant. The Oyster shell treatment has only one section, but in this section are two transects located (4 quadrant photo locations in this one section).

2.4.2.2 *Spatial coverage photos*

To get a full image of every section a dSLR camera was mounted to a 4m long “selfie stick” and a photo was taken of every 2m which overlaped the former photo by 60%. This way it is possible to stitch the images together to get full images of every section.

Most macro algae species were not determined to species level due to difficulty of determining the differences with juveniles and due to later photograph based analyses where details cannot be observed. *Ulva sp.* includes both *Ulva intestinalis* (gutweed) and *Ulva lactuca* (sea lettuce).

The *Porphyra* species identified were most likely *Porphyra umbilicalis* and Fucus was most likely *Fucus vesiculosus* (bladder wrack).

Because of the different colours of *Ulva sp.* (green) and *Fucus sp.* (brown) and *Porphyra sp.* (red) it was possible to use an image color classification in ArcGis to classify the different algal species and thereby calculate an estimated coverage percentage per species from photographs. When combined with height information coverage can also be linked to inundation time.

2.4.2.3 Transect surveys

Flora and fauna transect surveys were carried out in the field to be able to compare species distribution per section and per 50 cm height class. The presence and abundance of flora and fauna was recorded using the Braun-Blanquet cover-abundance scale. This method involves a semi-quantative visual estimation of the coverage or abundance of organisms using an abundance code which is later interpreted into quantitative data. The Braun-Blanquet cover-abundance method is an efficient and sufficiently accurate technique to gain information on abundance and vegetation coverage in the field (Wikum & Shanholtzer, 1978).

Transects were placed on the dyke as described above (see Quadrant photos). Quadrats of 50 x 50 cm were placed along each transect. Each quadrat was examined manually and inspected for all organisms present. All species occurring in the quadrat were identified to species level, recorded, and a score based on the cover of the species in that quadrat was assigned (Table 2.3). Cover, as defined for this purpose, is the fraction of the total quadrat area that is obscured by a particular species when viewed from directly above.

Table 2.3. The Braun-Blanquet method used to estimate the presence and abundance of flora and fauna in the quadrates along the transect on the dyke.

Braun-Blanquet	Abundance category	Cover: interpreted interval	OTV cover interval	OTV
r	1–3 individuals	c ≤ 5%		1
+	few individuals	c ≤ 5%	0.5 < c ≤ 1.5%	2
1	abundant	c ≤ 5%	1.5 < c ≤ 3%	3
2m	very abundant	c ≤ 5%	3 < c ≤ 5%	4
2a	irrelevant	5 < c ≤ 12.5%		5
2b	'	12.5 < c ≤ 25%		6
3	'	25 < c ≤ 50%		7
4	'	50 < c ≤ 75%		8
5	'	c > 75%		9

2.4.3 Data analysis

To test the hypotheses of this field experiment, a number of analyses were performed which are described in Table 2.4Table 2.1.

Table 2.4 Overview of hypotheses and analyses performed per hypothesis

Hypotheses:	Analysis:
1. There is no difference in **total algae coverage** (%) between the **different substrates** after six and nine months.	Qualitative description of development over time per substrate and between substrates.
	Visual presentation of representative photographs taken of quadrats on different substrate types directly after asphalt application, and six and nine months after asphalt application.
2. There is no difference in the **composition of the algae species** comprising the total coverage (%) on **different heights** on the dyke, after six and nine months.	Visual presentation of representative photographs taken of sections of the entire slope of the dyke with different substrate types directly after asphalt application, and six and nine months after asphalt application. Qualitative description of development over time per substrate and between substrates.
	Stacked bar graph presenting the semi-quantative analysis using ArcGIS of photos taken of photographs taken of quadrats along a transect down the slope of the dyke at six and nine months after asphalt application
	Stacked bar graph showing the results of the estimated percent coverage of different algae species using the Braun-Blanquet cover-abundance scale during manual inspection of quadrats along a transect down the slope of the dyke six months after asphalt application.
3. There is no difference in **species richness** of fauna on different substrates, and heights after six and nine months.	Stacked bar graph showing the results of the organisms recorded using the Braun-Blanquet cover-abundance scale during manual inspection of quadrats along a transect down the slope of the dyke six months after asphalt application.

3 Results

3.1 Field experiment at Yerseke

3.1.1 Species coverage

Figure 3.1 illustrates the coverage of species (flora and fauna) over time in %. After 3 months average coverage per substrate is around 50% and high standard deviations (3-36%) indicate that differences between the tiles of the same substrate were large. Coverage has decreased slightly after 5 months due to the loss of *Ectocarpus sp.* which put a brown layer on many of the tiles (observations during monitoring). After 9 and 11 months, coverage starts to increase especially in the substrates with lava stone (small and large) and shells (oyster and cockles). Both mastic asphalt and Elastocoast stay behind in coverage with average coverage of respectively 13 and 23%.

Shapiro-Wilkins test shows that the total coverage of T4 was not normally distributed after transformation ($P<0.05$). A Kruskal-Wallis test showed that there was a significant difference between the total coverage of the different substrates after 11 months ($P=0.001$). Post-hoc pairwise comparisons show that the total coverage of mastic asphalt differs significantly from that of both small lava stone ($P=0.021$) and cockle shells ($P=0.012$). Together with the coverage shown in Figure 3.1 these results shows that small lava stone and cockles both have a significantly higher coverage of total flora and fauna then mastic asphalt.

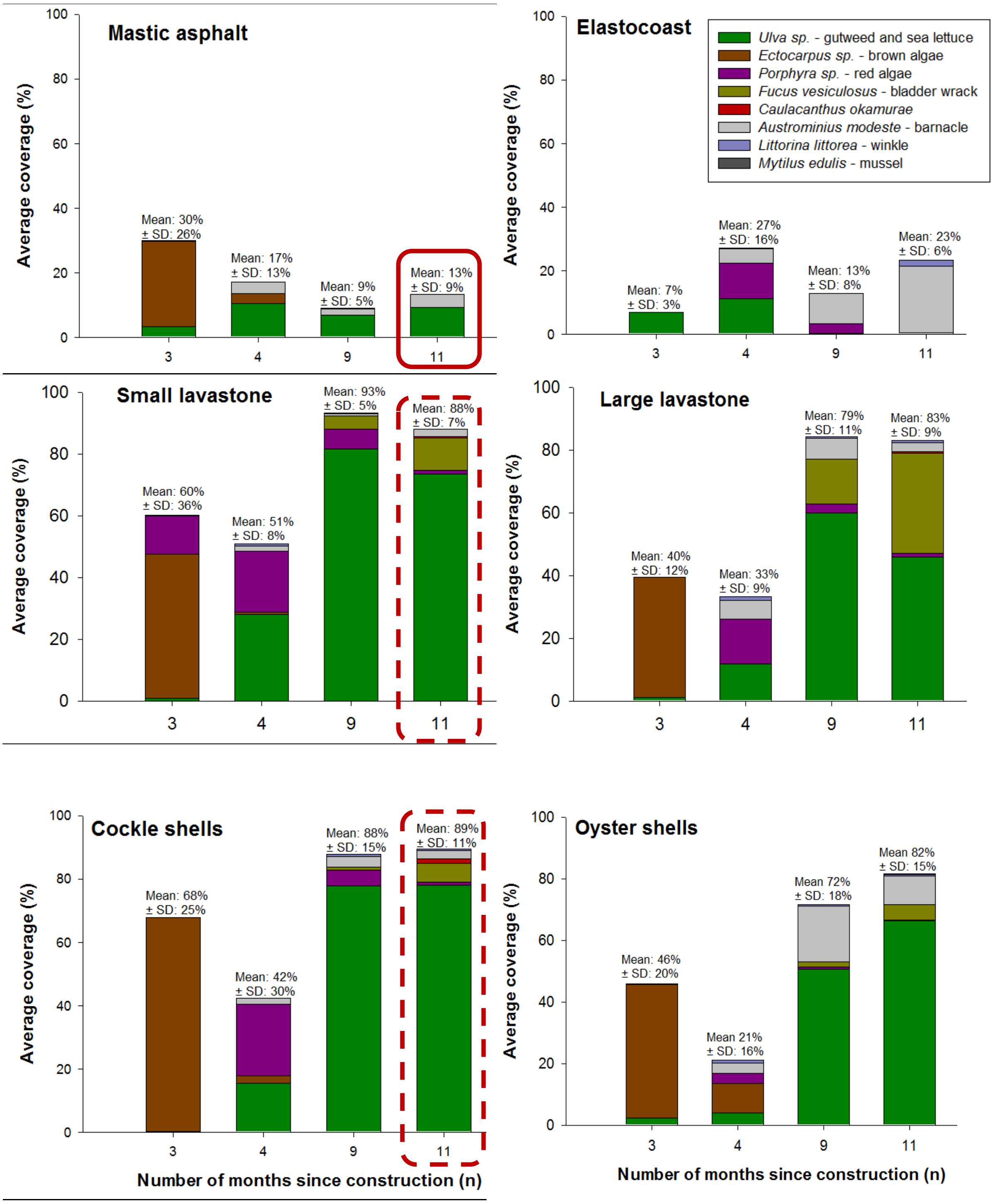


Figure 3.1 Average coverage (%) per substrate tile of 1 m^2 (n=5) per moment in time (T0: December; T1: March; T2: May; T3: September; T4: November). A red dashed box is drawn around the total coverage of small lava stone and cockle shells after 11 months that indicating a significant (p<0.05) difference from the total coverage found on mastic asphalt substrate.

3.1.2 Species composition

During the pioneer stage all substrates mostly show the presence of *Ectocarpus sp.* and *Porphyra sp.* and to a lesser extent *Ulva sp.. Ectocarpus sp.* and *Porphyra sp.* have disappeared and reduced respectively after 5-9 months and have mostly been replaced by *Ulva sp.* and *Fucus vesiculosis* (Figure 3.1). With regards to fauna, *Austrominius modestus* (New-Zealand barnacle) start to develop more densely on the substrates after 5 months up to the final monitoring (11 months). Differences in composition appear largest between on the one hand mastic asphalt and Elastocoast and the other substrates (large and small lava stone, cockles and oysters) on the other hand. Mastic asphalt and Elastocoast have less *Ulva sp.* on their surface area and relatively more *Austrominius modestus.* Especially on Elastocoast *Austrominius modestus* is able to develop. Large lava stone has more of the *Fucus vesiculosis* later in the year, relative to the other substrates.

An ANOSIM showed that there is no significant difference between the species composition of the different substrates after 11 months (P>0.05). However the Multidimensional scaling (MDS) plot (Figure 3.2) provides insight in the similarity between the species composition of the different substrates. Figure 3.2 shows that species compositions on Elastocoast and mastic asphalt differ most from the species composition found on the other substrates. *Austrominius modestus, Littorina littorea* and *Mytilus edulis* are most strongly correlated with the difference in species composition of Elastocoast. This is clear when looking at the species composition in Figure 3.1 as well. Elastocoast has a relatively low coverage of flora but a relatively high coverage of fauna, *Austrominius modestus* (the non-native New-Zealand barnacle) in particular (see Figure 3.3 for comparison with large lava stone and cockle shells).
All other substrates (cockle shells, oyster shells, large lava stone and small lava stone) have a high similarity in composition, mostly caused by the presence of the same flora species and especially *Ulva sp*. Large lava stone appears to differ slightly from the previously mentioned similar substrates due to a relatively higher coverage by *Fucus vesiculosus* on the larger lava stones (Figure 3.1 note the average coverage of *Fucus vesiculosus;* Figure 3.2 note the Pearson correlation of *Fucus vesiculosus* with dissimilarities of large lava stone samples; Figure 3.3 note the relatively high coverage by *Fucus vesiculosus* in the middle image).

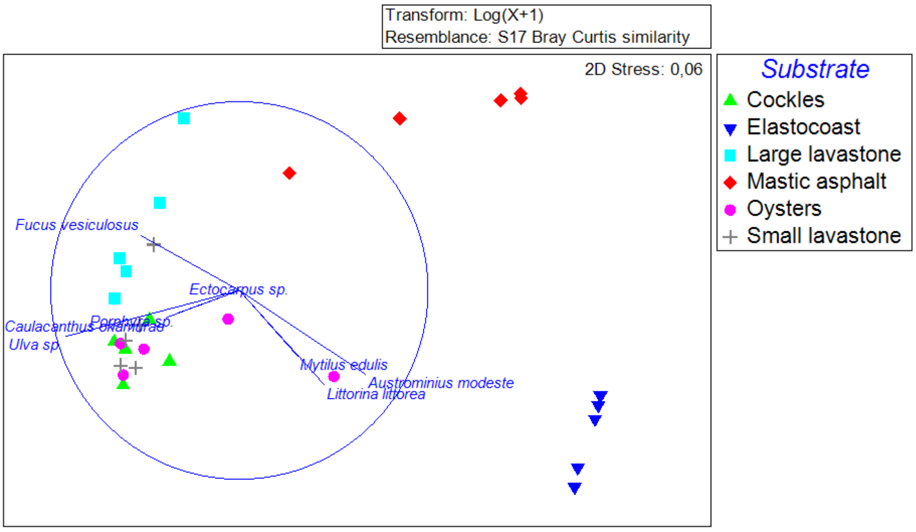


Figure 3.2 MDS plot of the samples of different substrates based on the Bray-Curtis similarity between species composition (average coverage per species per tile) found on different substrates after 11 months. Distances indicate dissimilarity between species composition of the different substrates. The overlay is a Pearson correlation, showing the species correlating most with the distance (thus difference) between samples.

Figure 3.3 Comparison of a selection of tiles monitored after 11 months, showing species coverage on Elastocoast (left), large lava stone (middle) and cockle shells (right).

3.1.3 Diversity

The number of species (flora and fauna) present on the different substrates has on average increased slightly over time (Figure 3.4). The highest number of species (n=7) was found on a large lava stone tile after 11 months of monitoring. On average, Elastocoast and mastic asphalt appear to stay behind in biodiversity monitored.

Figure 3.4 Overview of the average (+SD) species richness (n) on the different substrates over time.

The Shannon-diversity index gives a measure of the species diversity in a community, taking into account both the relative abundance and richness of species. The Shannon-diversity index was found to be highest for large lava stone and lowest for Elastocoast and cockle shells
An ANOVA on the Shannon-diversity indices of the substrates after 11 months showed that there was a significant difference in community diversity between the substrates. Post-hoc comparisons showed that the Shannon-diversity found on large lava stone was significantly different from the Shannon-diversity found on Elastocoast (P=0.012) and cockle shells (P=0.048). Figure 3.1 gives a visual of these differences and shows that both the richness and relative abundance of species found on large lava stone after 11 months is quite high relative to specifically the relatively lower richness found Elastocoast and the large differences in species abundance (dominated by *Ulva sp.*) on cockle shells.

Table 3.1 Overview of the average (n=5) Shannon-diversity index (H') and the standard deviation (SD) of the different substrates after 11 months.

Substrate	**Average Shannon-diversity index (H')**	**SD**
Mastic asphalt	0.62	0.12
Elastocoast	0.42	0.17
Large lava stone	0.87	0.04
Small lava stone	0.54	0.29
Cockle shells	0.49	0.11
Oyster shells	0.53	0.28

3.2 Dike monitoring study at Zierikzee

3.2.1 Algae coverage

Of the different mastic asphalt substrates, those with lava rocks (small and large) and the reference (bare mastic asphalt) remained relatively intact with no obvious disintegration of the substrate material. However the amount of shells in the oyster and cockle shells treatments decreased considerably after six months in the field. These may have eroded away, and/or become dislodged from the asphalt.

Using the photographs of quadrats, the main species of algae observed on the mastic asphalt from the photos were (to varying degrees): *Ulva sp*., *Fucus sp.* and *Porphyra sp.*. Using ArcGIS to analyse the photos, these three species were identified and their spatial coverage calculated.

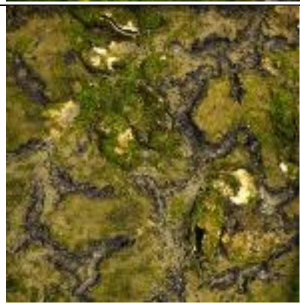
After nine months in the field there were some obvious differences in the type and amount of algal growth on the different substrate types (Table 3.2,

Table 3.3).

Table 3.2. Observations of the different treatment substrates after nine months in the field.

Substrate type	**Observations after nine months**	
	Substrate	**Algal growth**
Bare mastic asphalt	The top layer of the asphalt had cracked open giving a typical structure.	Ulva sp. are present but are much smaller and less developed then other treatments.
Small lava stones	Seemed relatively intact	Ulva sp. seems to develop best with this substrate. Ulva sp. strands are long with high coverage rates, but not as high as with large lava stones.
Large lava stones	Seemed relatively intact	Ulva sp. seems to develop best with this substrate. Ulva sp. strands are long with high coverage rates.
Oysters	There are considerably fewer shells present in June and September 2016 compared with the initial situation.	Ulva sp. seems to develop on the oyster treatments, but less than on the lava treatments.
Cockles	It is difficult to see the Cockle shells from T1 and further. It is not clear if the shells are eroded away or are over grown with seaweeds	Ulva sp. seems to develop on the cockle treatments, but less than on the lava treatments.

Table 3.3. Representative photos of the detailed view of the different mastic asphalt substrates when freshly applied, after six months, and after nine months in the field.

Substrates:	Freshly applied	Six months later	Nine months later
Bare mastic asphalt (reference)			
Small lava stones (on mastic asphalt)			
Large lava stones (on mastic asphalt)			
Oysters (on mastic asphalt)			
Cockles (on mastic asphalt)			

Ulva sp. was obviously the most common algae species on the mastic asphalt, and was present in the first monitoring period six months after the application of the asphalt. In contrast, the brown algae, *Fucus vesiculosus* was first observed in Sept 2016, nine months after the application of the asphalt in the quadrat photos. *F. vesiculosis.* was most commonly observed on the mastic asphalt treated with small lava stones, cockle shells and large lava stones (Table 3.4).

Table 3.4. Number and percentage of quadrates in which Fucus vesiculosus *was observed from photos nine months after application of the asphalt.*

Treatment	Total number of quadrants	Number of quadrats where *F. vesiculosus* present	Percentage of quadrats where *F. vesiculosus* was present
Bare Mastic asphalt	10	2	20
Large lava stones	8	5	63
Small lava stones	6	4	67
Cockle shells	6	4	67
Oyster shells	4	2	50

It should be noted that the number of quadrants observed is not equal, leading to possible bias in the results.

3.2.2 Algae coverage composition on different heights on the dyke

3.2.2.1 Observations

There were obvious differences in algae coverage on different heights of the dyke (Table 3.5). In general more algae were observed lower on the dyke compared with higher on the dyke. Mastic asphalt with large lava stones appeared to be most successful in facilitating the most algal growth compared with the other treatments, while the reference treatment of bare mastic asphalt was least successful in facilitating algal growth. As the cockle and oyster shells tended to have (partially) disintegrated during the monitoring period, these treatments became functionally comparable to the bare asphalt reference treatment.

Table 3.5. The different mastic asphalt surfaces as placed along the entire height of the dyke when freshly applied, after six months, and after nine months in the field.

Substrate	Bare mastic asphalt (reference)	Small lava stones (on mastic asphalt)	Large lava stones (on mastic asphalt)	Oysters (on mastic asphalt)	Cockles (on mastic asphalt)
Freshly applied					
Six months later					
Nine months later					

3.2.2.2 *ArcGIS analysis*

From the ArcGIS analysis of the Algae coverage composition on different heights on the dyke photos taken along the transects it appears that the highest algae coverage was observed on the small and large lava stones, and on the cockle shell treatments. The mastic asphalt and the oyster shells showed lower coverage particularly higher on the dyke six months after asphalt application and at NAP -25 to +25 nine months after asphalt application.

At both six and nine months after the initial application of asphalt *Ulva* sp. was the dominant alga present on all substrates at both six and nine months after initial application of the asphalt. *Fucus* sp. was present on all substrates six months after the initial application, but was not observed on the bare mastic asphalt or oyster shells nine months after initial application.
Porphyra sp. was relatively common on both lava stone treatments and cockle shells, and somewhat on the bare mastic asphalt six months after asphalt application, but nine months after application its presence was negligible expect on the bare mastic asphalt and small lava stones (Figure 3.5 and Figure 3.6).

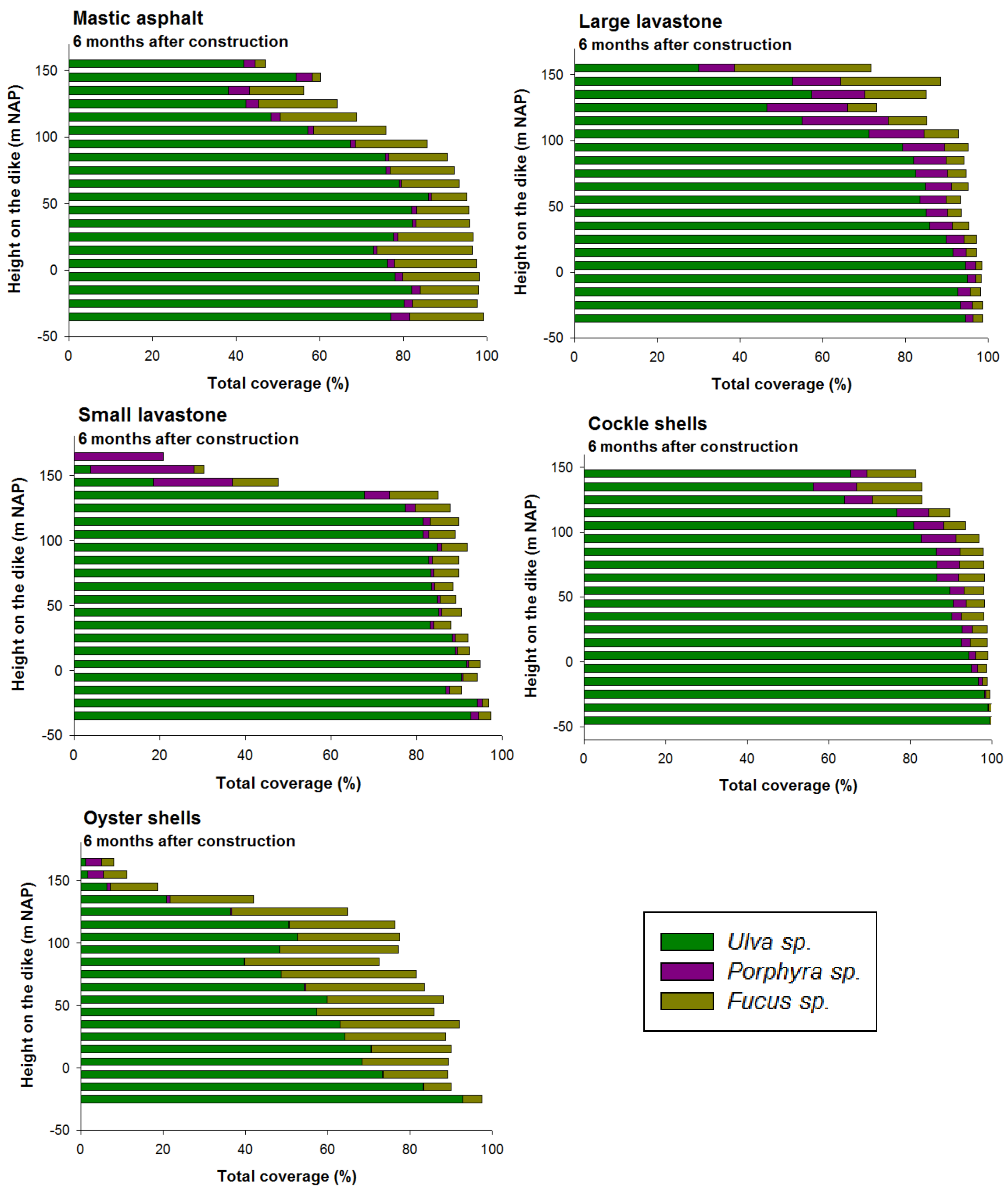


Figure 3.5. Total coverage of three algae types on different mastic asphalt substrates along a transect from high to low on the dyke six months after the application of asphalt.

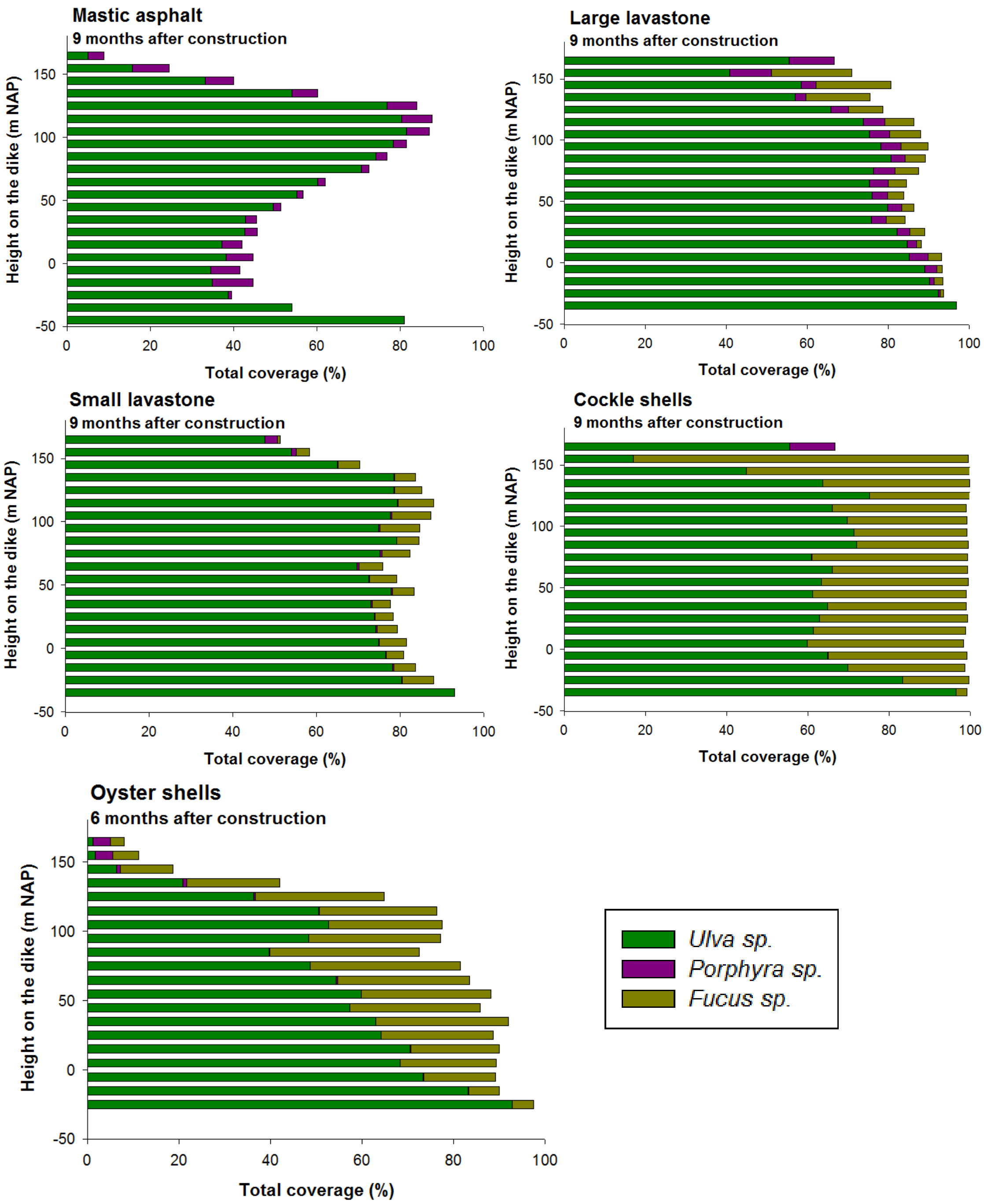


Figure 3.6. Total coverage of three algae types on different mastic asphalt substrates along a transect from high to low on the dyke nine months after the application of asphalt.

3.2.2.3 *Transect survey*

More species were identified during the manual inspection of quadrats on the mastic asphalt along the transect line than in the analysis of the photos. The abundance codes recorded during the field analysis were later interpreted into quantitative data using the Braun-Blanquet cover-abundance scale. Due to the scoring methodology cover scores for individual species range between 0 and 100%, but the cumulative scores for all species can be higher than 100%. No hindsight normalisation has been carried out. The data are therefore quantitatively directly comparable to the cover percentages in the Yerseke experiment. It was also possible to observe the change in abundance or coverage of different species at different heights on the dyke.

The dominant algal species observed during the transect surveys six months after the application of the mastic asphalt included: *Ulva linza*, *Ulva intestinalis*, *Blidingia minima*, *Porphyra umbilicalis* and *Ulva lactuca*. On most treatments *B. minima* was a dominant species as most heights on the dyke, particularly on the bare asphalt, the cockle shells and the oyster shells treatments. On the treatments with large and small lava stones *Ulva linza* was also comprised a large proportion of the algae coverage. *Ulva intestinalis* was present on the treatment with large lava stones at heights of -50 to -150 NAP, but its presence at other heights and on other treatments was relatively negligible (Figure 3.7).

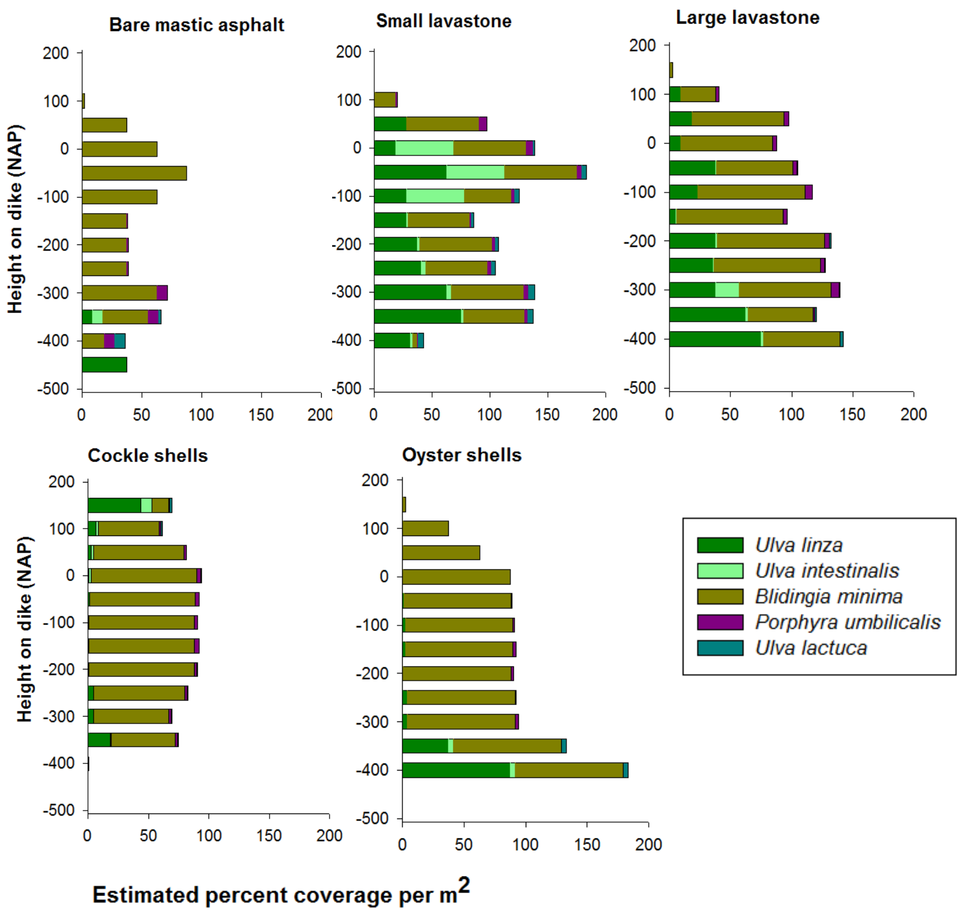


Figure 3.7. Average proportion of the most common algae species recorded using the Braun-Blanquet cover-abundance scale on the different mastic asphalt treatments during the transect survey six months after the application of the asphalt.

3.2.3 Fauna

The fauna present on each of the treatments was also identified and recorded during the transect survey using the Braun-Blanquet cover-abundance method.
The total species richness was highest on the bare mastic asphalt (seven species), followed by the small lava stones (six species), large lava stones (five species), cockle shells (five species) and oyster shells (three species).

The most common organisms found on the asphalt in general were springtails, *Anurida maritima*, and barnacles, *Semibalanus balanoides*. Other organisms observed on the asphalt included various crustaceans (the crabs *Hemigrapsus sanguineus* and *Carcinus maenas*, as well as amphipods and isopods), and gastropods (the periwinkles *Littorina littorea* and *L. saxatilis* and the limpet *Patella vulgata*).

Anurida maritima was found most commonly on the bare mastic asphalt throughout the height of the dike, and was also common on the small lava stones and the cockle shells. *Semibalanus balanoides* was found on all treatments at various heights, particularly on the small lava stones and on the cockle shells.

There was no obvious trend between species of fauna present and height on the dike; most species present were observed at various heights (Figure 3.8).

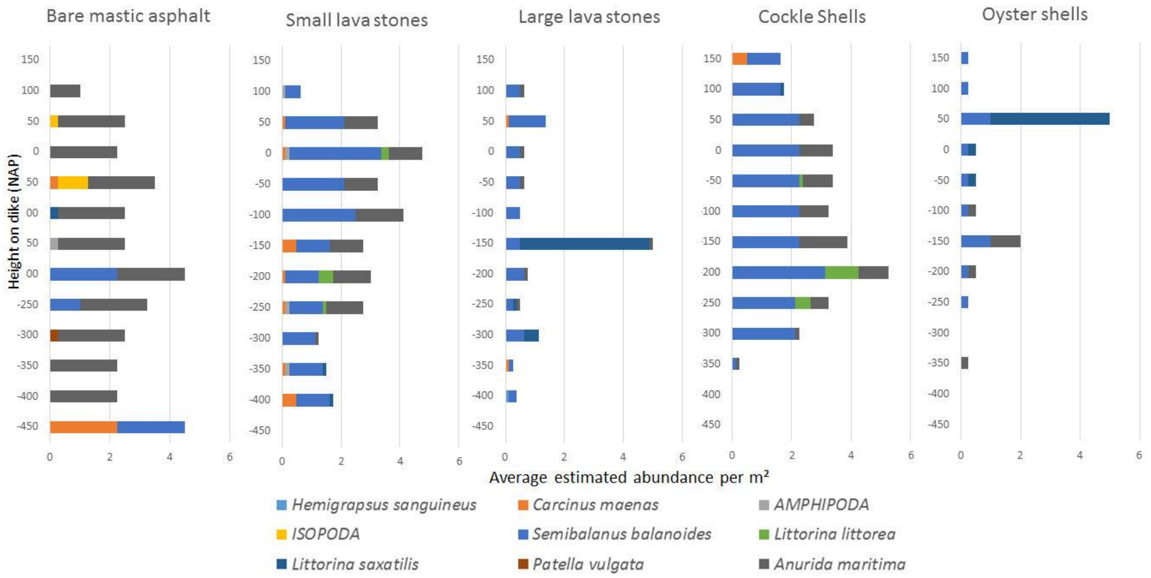


Figure 3.8. Average proportion of fauna recorded using the Braun-Blanquet cover-abundance scale on the different mastic asphalt treatments during the transect survey six months after the application of the asphalt.

4 Conclusions

4.1 Conclusion of field experiment at Yerseke

The field experiment at Yerseke was set up with the aim to answer the following research question: Which substrate facilitates both the highest biodiversity and coverage in flora and fauna under equal intertidal environmental conditions at the end of the monitored time period (11 months)?

The total coverage (%) between the different substrates after 11 months showed an increase for all, but both mastic asphalt and Elastocoast (average coverage of respectively 13 and 23%) have a significantly lower coverage than the other substrates (average coverage of 83-89%). Total coverage on mastic asphalt substrate was the lowest of all substrates and on cockle shells the highest.

Data on species composition after 11 months on the different substrates indicated that mastic asphalt and Elastocoast had less of the *Ulva sp.* compared to the other substrates. Especially Elastocoast had a relatively high presence of *Austrominius modestus* (New Zealand acorn barnacle) compared to the other substrates. Though differences between species composition of substrates were not significant, an MDS plot showed that cockle shells, oyster shells, small lava stone and large lava stone have a relatively high similarity in species composition and Elastocoast and mastic asphalt are more dissimilar. Especially large lava stone has a relatively high contribution of *Fucus vesiculosis* compared to the other substrates.
Although there are no significant differences in the overall species composition between the different substrates after 11 months, there are indications that the different substrates are able to facilitate growth of different species.
The highest species richness was found on large lava stone after 11 months. Richness of Elastocoast and mastic asphalt appeared to be lower on average. Large lava stone also had the highest Shannon-diversity, which significantly differed from that of Elastocoast and cockle shells. This is likely due to lower richness and low relative abundance of the species present on Elastocoast and cockle shells respectively.

These results lead to the conclusion that with respect to species coverage especially small lava stone and cockle shells are most promising as a substrate. With regards to species diversity there are no significant differences in species community composition; however large lava stone has shown to be able to facilitate the highest species richness and diversity, whereas cockles and Elastocoast were able to facilitate a lower diversity.

4.2 Conclusions of dyke monitoring study at Zierikzee

In overall the observations on the dyke at Zierikzee match the ones at the tiles in Yerseke. In terms of algal cover the lava stones are colonised quicker and after nine months have a more extensive cover than the other substrates. Bare mastic asphalt took the longest to get colonised and was after nine months not completely colonised, while all the other surfaces reached nearly 100% cover on many of the depth strata. The oyster and cockle top-layers performed intermediately.
In terms of species composition, there were also a few marked differences. Again the bare mastic asphalt showed least diversity, at least in terms of algae. The large lava stones seemed to promote the highest diversity, although specifically the cockle shell top layer appeared to promote *Fucus* species. On the lava stones, the oyster shells and the bare asphalt, varies

Ulvacea appeared to dominate (several *Ulva* species as well as *Blidingia minima*). These species are all very small and highly flexible, while members of the *Fucus* genus are much more rigid and structured. They can ultimately become ecosystem engineers themselves and provide shelter and foraging habitat for other species.
Curiously, the species richness for fauna was highest on the mastic asphalt. The composition of species differed markedly between the bare asphalt and the other top layers. On the other top layers (particularly small lava stones and cockles) the dominant species was identified as the native barnacle (*Semibalanus balanoides*).

5 Discussion

5.1 Connection of the parallel studies

Both studies (the tiles in Yerseke and the *in situ* monitoring on the dyke near Zierikzee) cover a similar set of hard substrate surfaces. There are differences in terms of physical scale as well as in the methodology of monitoring and data processing. Also the Yerseke experiment covered a type of surface cover (Elastocoast) that was not included in the *in situ* trial in Zierikzee.

However, broadly speaking both studies largely confirm the working hypothesis that a more spatially complex surface and more porous surface material facilitate the colonisation of a more diverse and rich ecological community. If higher algal and faunal biomass, faster cover and higher species diversity are seen as positive, the lava stones perform best, followed by the oysters and cockles. In both studies, colonisation of the bare mastic asphalt clearly lagged behind development of algal communities on other surfaces. Curiously the Elastocoast material, which is specifically designed to facilitate colonisation, appeared to perform very little better that the bare asphalt.

In both studies the large lava stones appeared to perform the best (most diverse, highest cover). This is according to expectations, as the larger stones provide more 3-dimensional diversity. However the differences with small lava stones and the shell treatments were not large. Neither test lasted more than one year. Various studies on colonisation of newly created habitat in the Oosterschelde (de Ronde et al. 2013, van der Werff et al. 2015) indicate that it takes about 3-5 years for biotic communities on an intertidal mudflat to resemble those on similar ecotopes nearby. This is due to the fact that longer-living species take a few years to mature and the presence of species such as mussels and oysters will stimulate other species to settle. It is not possible to determine from these results whether the different toppings ultimately will result in a very different species composition, or if the differences are restricted to the speed of development.

5.2 Other ecological functions

Apart from the attached flora and fauna, hard substrate may have functions for mobile fauna as well, such as holes providing living space for fish, crabs and lobsters, feeding surface for fish species, nursery areas for juvenile fish in between the macroalgae and attachment opportunities for eggs of fish and invertebrates. As these were not monitored, we cannot draw such information from these results. The potential function of attachment sites for eggs is clearly restricted to the very lowest areas of the dike. The seaweed cover can protect areas briefly from drying out, but prolonged emergence will be detrimental for the eggs.

The actual effect on 3D complexity of the different top layers is actually very limited, if compared to e.g. a difference between mastic asphalt and a layer of assorted stones. Even the layer of asphalt with large lava stones does not really provide hiding places large enough for lobsters or crevice-dwelling fish.

5.3 Invasive species

One striking result from the Yerseke study was the fact that both bare mastic asphalt and Elastocoast lagged behind in colonisation by macroalgae, but were quickly colonised by *A. modeste*, a non-indigenous species. Artificial structures, particularly near shore, are known to harbour high levels of non-indigenous, potentially invasive species (Firth et al. 2014, Coolen et al. 2016). The assumed reason for this high incidence of exotic species is the fact that these

artificial structures provide ‘free settlement space’. Established hard substrate is generally covered by biota making it more difficult for a new species to establish itself (Bracewell et al. 2013). The New Zealand acorn barnacle *A. modeste* is a prime example. In a study in Liverpool Bay on the art installation “Another Place” by Antony Gormley, this species was shown to rapidly become the dominant species in this area (Bracewell et al. 2012). On the tiles in Yerseke the species also occurs on the other substrates, however proportionally, the cover was less, possibly a consequence of the fact that the substrates with lava stones and shell material were faster covered by algae. The latter substrates will not prevent the settlement of non-indigenous species, but will facilitate settlement to a lesser degree than the bare mastic asphalt or the Elastocoast top.
Remarkably, in the study at Zierikzee, the bare mastic asphalt (although not completely covered by e.g. macroalgae) did not support a large community of non-indigenous barnacles. In fact the highest occurrence of barnacles was found on cockles and small lava stones and these were identified as native species. It is unclear what causes this difference between the two sites. As the crow flies, these sites are roughly 18 km apart. From the study by Bracewell et al (2012) on the Gormley art installation it is clear that *A. modeste* very easily settles on bare metal. A personal observation by Emiel Brummelhuis (NIOZ, Yerseke) indicated that the metal frames holding the tiles, as well as the nearby metal stairs to access the mudflat from the quay are also completely covered by this species. So it is possible that the proximity of the metal surface as well as probably a local population on the stairs have accelerated the colonisation of the mastic asphalt in Yerseke, but not in Zierikzee. However, this cannot be proven without targeted research.

5.4 Requirements for other use – safety, recreation

The primary function of a dyke is clearly safety against flooding. One absolute requirement of any adaptation to enhance ecological functioning of such hard substrate or to increase its visual attractiveness is that it should not in any way compromise its stability or increase “piping” (landward intrusion of water underneath the dike). The observations at Zierikzee revealed that although the oyster shells appeared to promote colonisation of the substrate with macroalgae and fauna, after 9 months a lot of the shell material appeared to have been lost. To some extent this may also have been true for the cockle shells; although it was possible they simply had become indistinguishable underneath the biotic cover. From the current ecological observations it is unclear if the loss of material from the top layer of the dyke in any way compromises its safety function. Although it seems unlikely that the loss of shell material from the top layer influences the total stability of the dike, it is important that also the structural aspects of the dyke (e.g. effects on permeability) are monitored (Baptist 2007).

Apart from flood protection, dikes may also have other functions that will be affected by increased colonisation. Particularly in the vicinity of populated areas or tourist attractions people will play, fish and walk on these structures bordering the sea, Extensive cover with a varied community of biota is attractive and offer also educational opportunities. However, macroalgae can be incredibly slippery and treacherous. In such areas care must be taken that enhanced use of a dyke by tourists or locals does not lead to unacceptable risks.

5.5 Relation to cost-benefit analysis

There are various benefits identified associated with diverse and rich ecological communities on hard substrates, including financial benefits, such as increased values for tourism and for (recreational) fishing (Baptist et al. 2007). One serious issue to consider is the time-scale. As indicated in section 5.1, the community compositions on the various top layers will not have been the ultimate ones. If it turns out that after 5 years the species composition and cover on mastic asphalt does not differ significantly anymore from the other top layers, these benefits will be very limited. It is therefore important to follow up the development of ecological communities on these surfaces for at least 3 years to have any indication of the ultimate benefits.

5.6 Applicability of results

Both studies confirm the hypothesis that a more complex 3-D environment leads to higher diversity as well as higher densities of biota. However, the Elastocoast topping, although designed to promote settlement of biota, performed very similar to bare mastic asphalt in terms of colonisation by organisms. Although this study does not provide any information on the long term effects, the fact that bare mastic asphalt and Elastocoast are very quickly covered by an invasive species also indicate that the other alternatives may be preferable, provided that the layers meet the criteria for the primary function of the dyke – flood protection.

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A Monitoring

Code tegel	**Datum**									
Tegel	**1A**	1B	1C	1D	1E	1F	1G	1H	1I	1J
Soorten	**Aanwezig (schatting %)**									
NL										
groenwieren										
Fucus vesiculosus - Blaaswier										
Acophyllum nodosum - Knotswier										
Fucus spiralis - Kleine zee-eik										
Fucus serratus - Gezaagde zee-eik										
Chaetomorpha sp. - Visdraad										
Ulva sp. - Darmwier										
Ulva sp. - Zeesla										
Rotswier/takwier										
Vederwier										
Roodwieren										
Porphyra sp. - Purperwier										
Puntig korstmoswier										
Korstmoswier										
Buiswier										
Hoorntjeswier										
Knoopwier										
klauwwier										
Bruinwier										
Ecotcarpus sp., bruinwier										
Fauna										
Zeepok										
Alikruik										
Mossel										
Kokkel										
Opmerkingen										

B Example of coverage of a tile

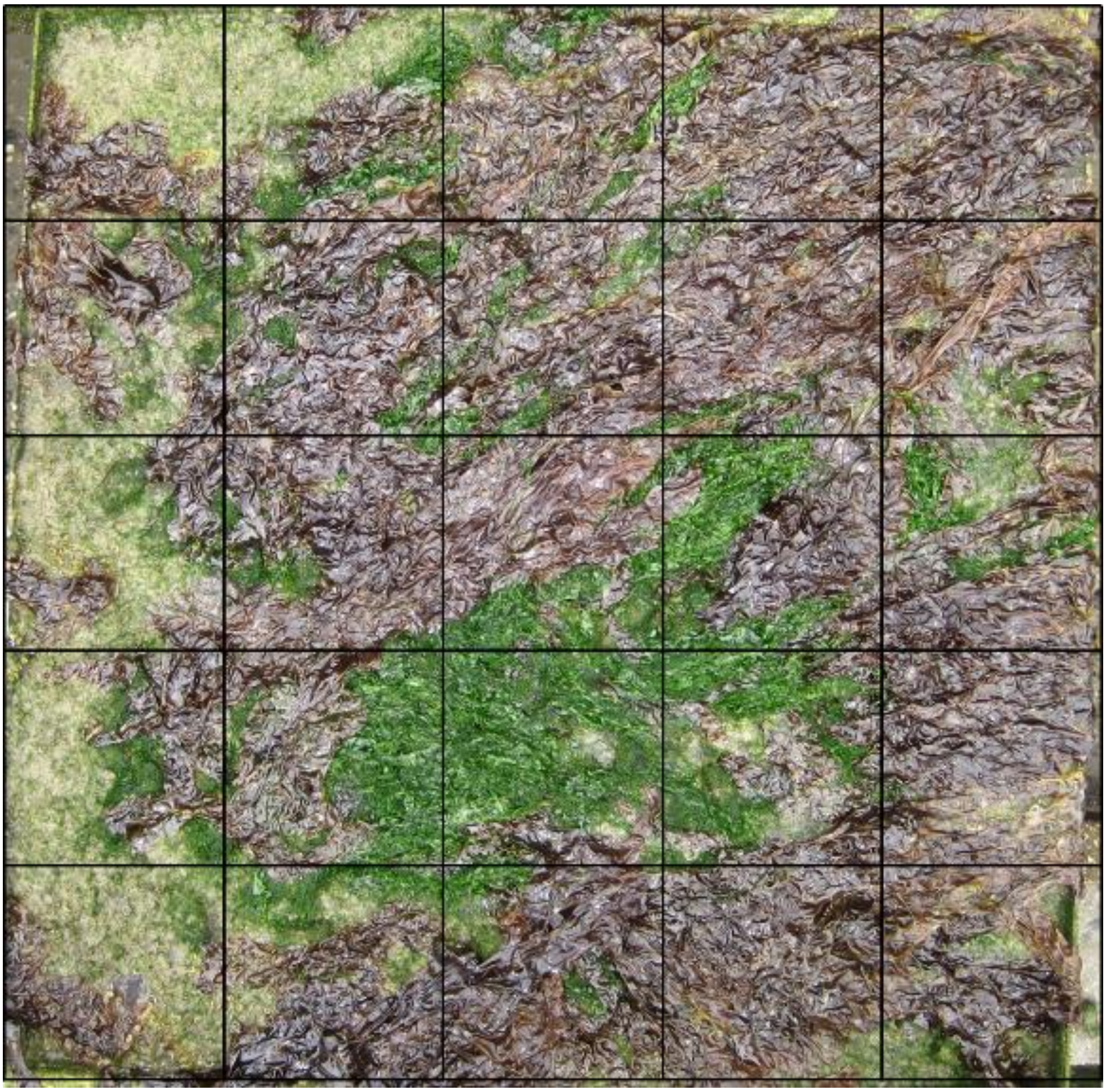

Figure B.1 Example of tile for determination