EARLY COLONIZATION OF LITTORAL COMMUNITIES ON POLYURETHANE COATED SUBSTRATES
A FIELD AND LABORATORY STUDY

BASF/ELASTOGRAN GMBH

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ARCADIS

Contents

1 Abstract

Materials used for urbanized coastal structures often create a hard substrate ready to be colonized. Elastocoast, a new coastal protection material made from stones and polyurethane, is such a material. This study examined the recovery and growth during the winter of 2007-2008 of the biological community on two dykes in the Netherlands which were refurbished with Elastocoast at the beginning of the storm season, and describes an algal colonization experiment done with Elastocoast in the laboratory.
In the field, 4 months after the construction of the Elastocoast top layer, dyke vegetation has returned, though strongly zonated and leaving large patches without any vegetation. Main algal species are *Enteromorpha minima* and *Fucus spiralis*. Animals found on the Elastocoast layer mainly consisted of *Littorina sp.* and *Patella Vulgata*. The Elastocoast pilots in the field were examined for 25 weeks, it is expected that the biological community will recover further when given enough time.
The laboratory experiment showed that by colonization by micro-algae under favorable circumstances can be fast and substantial, by numerous micro algae and animals. Elastocoast therefore seems to be a material which allows community recovery to be fast and according to the typical vegetation of that area.

2 Introduction

2.1 ELASTOCOAST, THE PROJECT

Elastocoast is a new coastal protection material, made of stones coated with polyurethane. It is launched on the market by Elastogran GmbH, a daughter company of the German chemical company BASF (for more information about the material Elastocoast, see box 1). In order to find out if Elastocoast may be a useful material for Dutch shores, a pilot is carried out on two different locations in the Netherlands. ARCADIS, a consultant agency specialized in giving advice on structural and environmental matters carries out these pilots. Apart from gathering knowledge about how Elastocoast handles waves and possible erosion and wave-damage, the pilots are also used for ecological research. This research will examine growth and recovery of the biological community on Elastocoast in the field, as well as in the laboratory.

gure 1 Elastocoast, made from lyurethane and stones.

Box 1. Elastocoast, the Material

The material Elastocoast is made of rock and polyurethane (figure 1). The rock is preferably basalt or granite (often used in waterworks), but also limestone (kalksteen) is used. The rocks are bound together with polyurethane which is made from two components, the A-component (Polyol) and the B-component (Isocyanaat PMDI). The volume ratio for the mixing of the two components is A : B = 2:1. These two components are mixed together on the construction site, and after that the polyurethane is mixed with the stones (39). For a certain amount of stones, a polyurethane volume of 3% is needed (e.g. for 1m3 of stone 30 l. of polyurethane is required) (15). After the mixing of the polyurethane with the stones (called 'tumbling') the mixture (Elastocoast) is applied on the desired location, where it hardens.

In order to get the best results, it is important the stones are dry and clean, to secure good binding of the polyurethane to the stones. Also, the base layer on which Elastocoast is applied, is preferably dry and clean (13). When this is not the case, the Elastocoast layer will not attach to the base. This doesn't necessarily have to be a problem, the Elastocoast layer will then just rest on the base layer, which doesn't seem to affect the effectiveness of the Elastocoast layer (39).

Once the Elastocoast is hardened, it has a relatively open pore structure and the surface is smooth (6). Due to this open structure, Elastocoast is better able to handle with wave pressure than conventional materials, because it is more flexible and redirects the wave pressure through the pores. Elastocoast is supposed to sustain less damage than conventional coastal-protection materials (such as bitumen). Since some parts of the Netherlands are below sea-level, Elastocoast may be a sustainable material for the Dutch coastlines (35). Polyurethane is a material which is often used for experiments in the marine environment (1, 10, 18). The material is then often used in its foam-form, which is rough, soft and sponge-like and provides a good substrate which many small marine organisms inhabit. Elastocoast, however, has a very smooth and hard surface, a bit comparable to glass, a material also often used for experiments and also proves to be a substrate suitable for fast algal attachment (15). When additional sand is distributed over Elastocoast while drying, the sand particles create a somewhat rougher surface, which might aid algal attachment (11).

2.2 ECOLOGY OF BENTHIC COMMUNITIES ON URBAN COASTAL STRUCTURES

2.2.1 URBAN COASTAL STRUCTURES

Of the world's human population, over 44% lives near the coast, and this number is still growing (23). Due to this coastal urbanization, coastlines themselves become more and more urban structures. Despite a strong ecologists view that urban structures cannot be seen as a 'natural' habitat, urban ecology presents a new and interesting field of research, especially when combined with the growing concern about our seas and coastal habitats. Coastal urban structures are rarely researched and often placed without any knowledge or concern about the coastal environment. These coastal structures, which are increasing in number and are very conspicuous, are a poorly understood component of the marine environment. Not every structure is the same, and different kinds of structures support different diversities and abundances of sessile marine organisms (20).

Dykes are specific urban coastline structures. A dyke is usually described as a rocky subtidal area. The biological composition of the communities in rocky subtidal areas is determined by many factors: disturbance, climate, substratum, predation, disease and human activities (2). Rocky subtidal areas are important for many marine species, and urban structures can act as surrogate habitats with human-generated heterogeneity. This heterogeneity creates or removes occupation opportunities for the different marine organisms, which influences biodiversity. Biodiversity may change due change of substrates in regard of composition and abundance of marine species, and new urban coastal structures may provide habitats for introduced species (20).

2.2.2 COLONIZATION OF NEW COASTAL STRUCTURES

Colonization of new benthic habitats, also coastal urban structures, always begins with the formation of a biofilm which is comprised of bacteria and micro-algae. The formation of a biofilm on surfaces in the marine environment is thought to be an important factor driving colonization and recruitment of (sessile) marine communities (37). The formation of a biofilms begins with the adsorption of a conditioning film. This conditioning film is made of polysaccharides, proteins, lipids, humic acids, nucleic acids and aromatic amino acids. It is to this conditioning film to which the early colonizing bacteria attach (4, 8). These microorganisms form micro-colonies which are multilayered. Other bacteria, although they can be planktonic, grow better in interfaces with a biofilm, which provides them with food and a possible form of protection (7, 34).

In the marine environment, biofilms play a role of settlement inducer for a large number of sessile macro-algae and sessile invertebrates (35, 37). These macro-algae provide food and hiding places for large marine invertebrates and fishes (27). It appears that seasonal changes affect the chemical composition of the conditioning film, and these changes affect the initial adhering community composition. Also, the type of chemicals in the biofilm depends on the type of substrate and seasonal changes, for different early colonizing bacteria seem to have preferences for certain types of substrates and climates (5, 8).

2.2.3 PATTERNS OF COLONIZATION

It is hard to make a proper prediction of what macro algae will grow and how. For the locations used in this research (dykes in the Oosterschelde and the Northsea) it is expected

that 'normal' dyke vegetation will also grow on the Elastocoast layer. The Oosterschelde and the Northsea can be described as temperate marine waters (28, 29, 33).
Previous research done in temperate waters in Canada (31) showed that rocks in mid-shore areas which were cleared from previous canopy were occupied by a succession of diatoms, green and blue-green ephemeral algae, and were then covered with *Fucus* canopy. Often, the *Fucus* canopy had an understory of mussels, barnacles and crustose algae. Clear patches in these canopies were often occupied by ephemeral algae. There were also seasonal changes, suggesting that not only succession determines which species occupy a certain area. It was also found that the formation of *Fucus* canopy was faster in areas with more moisture availability (20, 31). The amount of moist depends on wave exposure (may also contribute to a 'swash zone'), shore height, drainage, shading, and tidal regime. *Fucus* canopy seems to be important for the rocky subtidal canopy, for they create mosaics of habitats and have a major influence on the understory by shading competitors, providing shelter from dehydration, wave battering, thermal stress and increasing the biomass, productivity and physical structure and dimensionality of the habitat (27, 32). The abundance and patterns of *Fucus* colonization however, was hard to explain.
This also has been found in other studies (2, 20, 27). Mosaics of patches result from complex interaction between disturbances, climate and type of substrate. Especially disturbance seems to affect the characteristics of patches. Much damage and disturbance in urban areas is afflicted by humans, and knowledge about the effects of these disturbances on urban structures are especially interesting. Patches created by disturbance or damage can differ from each other by many characteristics, such as size, shape, boundary characteristics, microhabitat structure, position and time of creation (and when submerged; current) (2). All of these traits can influence succession and species abundance in a newly created patch.

2.2.4 VEGETATION OF THE ZUIDBOUT DYKE AND THE DYKE NEAR PETTEN

The Zuidbout dyke is situated in the Oosterschelde, and has a typical vegetation for that area. The green macroalgae species that occupy the intertidal zone of most of the Oosterschelde coastline can be catagorised in four main categories: *Ulva spp.*, *Enteromorpha spp.*, *Cheatomorpha spp.*, and *Cladophora spp.* There brown macro-algae are mainly Fucoid species (12).

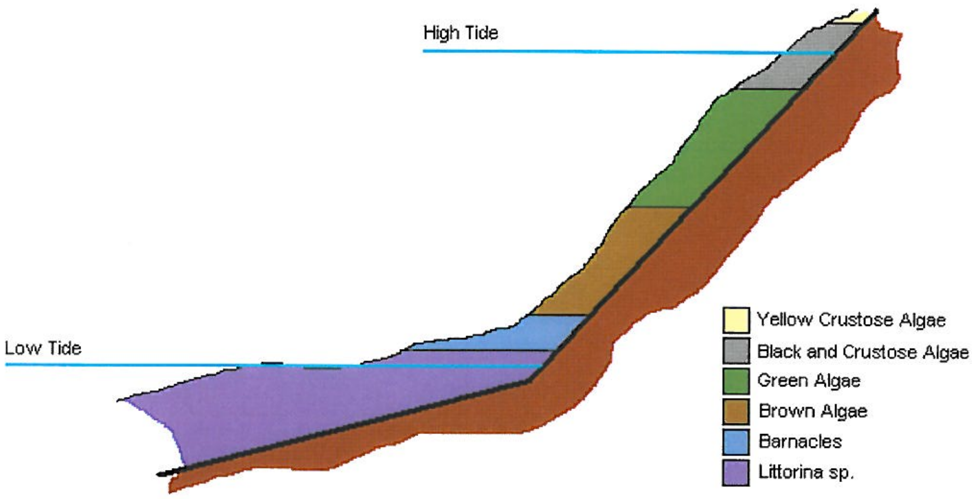


Figure 2. Schematic and simplified overview of the typical vegetation on dykes along the Dutch coasts (after 28, 29 and 32)

The littoral zone of the Zuidbout dyke itself mainly consists of species *Fucus vesiculosus* (Blaasjeswier), *Fucus spiralis* (Kleine Zee-eik), *Enteromorpha compressa* (Plat darmwier),

Enteromorpha minima (synonym *Blidingia minima*, Klein Darmwier), *Pelvetia canaliculat* (Groefwier), *Scytosiphon lomentari* (Saucijsjeswier), *Catenella caespitosa, Gracilaria verrucosa* (Knoopwier) and *Mastocarpus stellatus* (Kernwier). At one point of the dyke, also *Chondrus crispus* (Iers mos) is found. The dyke consists of many different types of stone, and on limestone as well as on some barnacles (*Semibalanus balanoides*) the encrusting *Pyrenocollema halodytes* can be found. Animals are mostly found in the lower part of the subtidal zone (on large rock). These animals, next to *Semibalanus balanoides* are *Patella vulgate* (Schaalhoorn), *Crassostrea gigas* (Japanse Oester), *Littorina* spp. (Alikruiken), *Mytilus edulis* (Mussel), and *Sabellaria alveolata* (Zandkokerworm) (very rare). In the lower parts, also *Verrucaria halizoa* (Kleine Stippelkorst) was found. There is a typical zonation (figure 2) (28, 29, 33).
The dyke near Petten, which is situated in the Northsea, didn't have a large amount of vegetation prior to the Elastocoast application. The dyke is made up from basalt rocks, with some wooden piles on the side. On the basalt rocks the green macro-algae *Enteromorpha minima* was growing. On the sides of the dyke the rocks are colonized by many mussels (*Mytilus edulis).* The dyke sustains a lot of wave action and currents, which makes the dyke near Petten probably less favourable for algae growth. Between the rocks there are a number of smashed mollusks, providing food for the many seagulls. Crabs can also be found crawling on the dyke, as well as the mollusks *Littorina spp.* and *Nucella lapillus* (rare) (22, 25).

2.3 RESEARCH QUESTIONS

The pilot locations were realized prior to the stormseason of winter 2007-2008. This ecological monitoring study took place during that stormseason. Researching the Elastocoast pilot sites as well as a lab experiment had to answer next questions:

1. Does Elastocoast have an effect on the settlement and growth of marine benthic organisms and community?
2. Which organisms are recolonising the Elastocoat layer, and at what growth rate?
3. Is the colonization of the Elastocoast layer comparable to colonization of non-Elastocoast toplayers?
4. Are these organisms in species and amounts relatively the same as on locations of dykes without Elastocoast layer, but where organisms are removed?
5. Is there some kind of succession (increase/decrease) of the different organisms in time?
6. Is the community after a certain amount of time the same again as it was before any Elastocoast application?
7. Does Elastocoast have an effect on the growth of algae in a laboratory experiment?
8. In what material category can Elastocoast be placed (as used by Rijkswaterstaat for coastal protection materials)?

It is expected that low temperatures and low light intensity during winter may inhibit the formation of a biofilm and macro-algae growth. However, some species are known as fast colonizers (2, 22, 31), such as *Enteromorpha minima*. Since *Enteromorpha minima* is naturally present on both pilot locations, there is a possibility that this species is one of the first colonizers on the new Elastocoast toplayer even during the stormseason.
Elastocoast is a very smooth material, and this smoothness may slow colonization down. It is expected that areas of Elastocoast which also has a thin layer of sand on top, may be colonized faster because the surface is less smooth.
During this winterseason some colonization is expected. Because the blooming period starts in spring, and limited time for this study, community recovery won't be fully monitored.

3 Materials and Methods

3.1 ELASTOCOAST PILOT SITES

The Elastocoast layer was placed on top of the existing top layer on the dykes which has been cleaned prior to the application of Elastocoast. The organisms that were settled on the old top layer of the dyke were removed in order to place the Elastocoast layer. In that way, the Elastocoast layer presented a new area for recolonization. The Elastocoast layer differed from the surrounding materials on the dyke, because its surface consists of polyurethane, which provided a smooth surface.

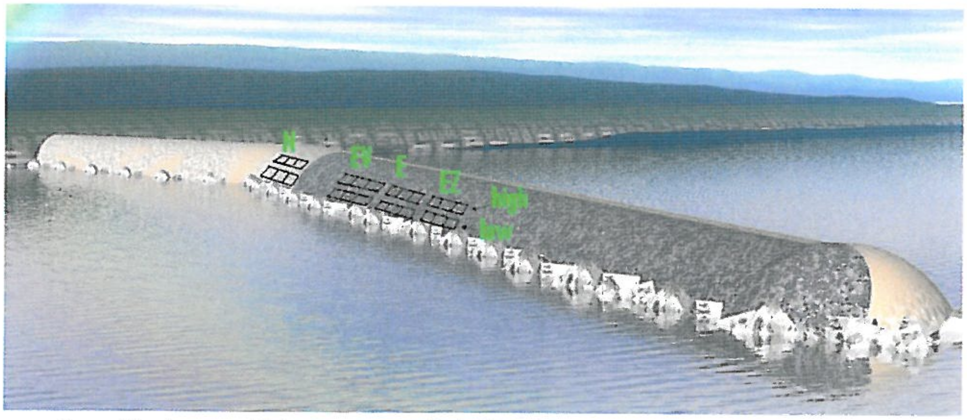
The two pilot locations of Elastocoast in the Nethelands are located on the dyke called the 'Zuidbout' (realized September 2007 in the Oosterschelde near Ouwerkerk (Zeeland)) and on a dyke near Petten, which is part of a series of dykes called the 'Hondsbossche en Pettemer Zeewering' in the North Sea (Noord-Holland) and was realized October 2007. On both pilot sites, sand was distributed by hand over most areas of the Elastocoast layer after placement when the polyurethane is still hardening.

3.2 RESEARCH OF THE PILOT SITES

Both pilot locations were monitored during the storm season (October 15^{th} – April 15^{th}). On both pilot locations certain areas were picked for monitoring. These areas were 0.5m. by 0.5m. and marked with waterproof paint. In these areas, the growth of algae and occurrence of animals was measured. The growth of algae was quantified by calculating the percentage in the area that was covered by all species together (mainly *Fucus sp.* and *Enteromorpha sp.*). The abundance of animals was quantified by counting the number of animals of a species in the areas.

3.2.1 FIELD RESEARCH ZUIDBOUT

On the Zuidbout location there is 510 m^2 of Elastocoast, divided into three areas. The Elastocoast layer begins 25m. from the Zuidbout's head. From there, there are 3 areas of 40m. long each. These areas have a different layer thickness, varying from 10 to 30 cm. All areas are applied in a range between NAP + 0,5 and NAP + 1,5. An area in the thickest part of about 2.5m. has been covered with Vilvoordse limestone, which is believed to promote algal growth. Four different surfaces have been investigated. Firstly, there is an area where the surface of the old toplayer has been cleaned, and where there hasn't been Elastocoast application. The surface is a type of limestone, and all the existing flora and fauna has been removed, simulating similar disturbance as on the part with the Elastocoast application. This area was called N. Secondly, there is a surface with the application of Elastocoast but, while drying, Vilvoordse limestone was put on top of the Elastocoast layer. Vilvoordse limestone is known to be a good substrate for macro-algae, and is believed to promote



igure 3. A schematic overview f the Zuidbout dyke. The four ifferent areas are shown, lower nd higher up the dyke. The N rea is the 'natural' area, where o Elastocoast has been applied, ut is cleaned from all organisms. he EV area has limestone on top f the Elastocoast layer, the E rea is Elastocoast with very little and. Finally, the EZ area has a iyer of sand on top of the astocoast layer.

growth on Elastocoast. This area was called EV. Then there is a surface where there the Elastocoast layer has very little sand (almost none) (called E). Finally, there is a surface of Elastocoast which has been covered with plenty of sand, providing a rough surface. This area was called EZ. The areas on these surfaces were chosen to be as close to each other as possible, and of the same type of surface 6 areas were monitored, 3 of which were on the low part of the subtidal zone, and 3 of which were higher up the dyke (figure 3).
The Zuidbout was visited on 26-09-2007, 16-10-2007, 16-11-2007, 13-12-2007, 16-01-2008 and 13-03-2008. All of the marked areas were examined as described in 3.2.

3.2.2 FIELD RESEARCH PETTEN

On the dyke near Petten an Elastocoast layer has been placed on the outermost part of the dyke which heads into the sea. This layer has a surface of about 350 m2, and is situated on NAP -0.30.

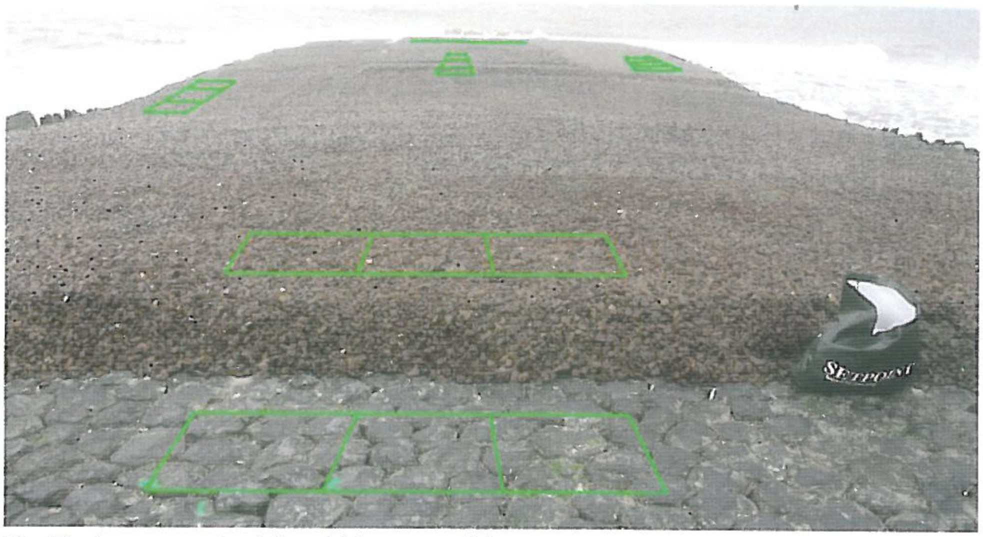


Figure 4. An overview of all the examined sites on the dyke near Petten in the Northsea.

The Elastocoast on the dyke which is part of the 'Hondsbossche en Pettemer Zeewering' is a 'flat' layer situated at approximately -0.30 NAP. On this dyke 18 areas were marked for research (figure 4). These areas were chosen in order to monitor different growth patterns on the dyke, influenced by wave action, currents, closer/further away to land etc. The area in front of the Elastocoast layer is the original top layer of the dyke, made of basalt. The dyke was visited on 15-10-2007, 15-11-2007, 14-12-2007, 15-01-2008, 06-02-2008, 22-02-2008, 12-04-2008. All of the marked areas were examined as described in 3.2.

3.3 LABORATORY EXPERIMENT

Four different types of rock were used, these were Vilvoordse, Basalt, Concrete and Doornikse. Vilvoordse is a soft limestone, concrete is middle-hard, and basalt and Doornikse are hard substrates. From each of these rocks, 3 small tiles were cut (4x4x1cm, except from Doornikse (2x2x0.5cm.)). These 3 tiles received a different treatment, which were: untreated, coated with Elastocoast and coated with Elastocoast and sand (figure 5).

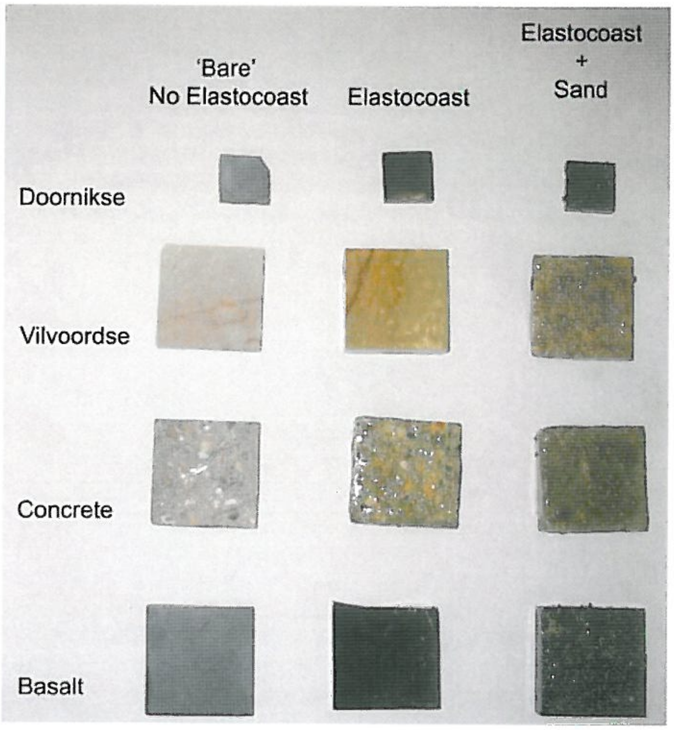


Figure 5. An overview of all the treatments in the laboratory experiment. Horizontally, the different types of rock are shown. Vertically, the three different treatments are shown.

Three containers were filled with 17 litres of freshwater medium (15) each. The stones were hung in the medium with the use of steel wire attached with the polyurethane mixture used for Elastocoast. This was done three times, so in total 36 stones were used in 3 containers, each container having twelve stones of four rock types, each type 3 different treatments. The medium in the containers was kept at a temperature of 20°C by the use of an incubator, and was lightly stirred by pumps placed at the bottom of the containers. Light was set at approx. 100 µmol/m^2/s during 8 hours per day. An algae mix of *Nitzschia* (diatom), *Synechococcus* (cyano-bacteria), *Leptolyngbia* (cyano-bacteria), *Pseudoanabeana* (cyano-bacteria) and some other freshwater algae collected from a freshwater ditch was put into the containers in small amounts at the beginning of the experiment (figure 6).

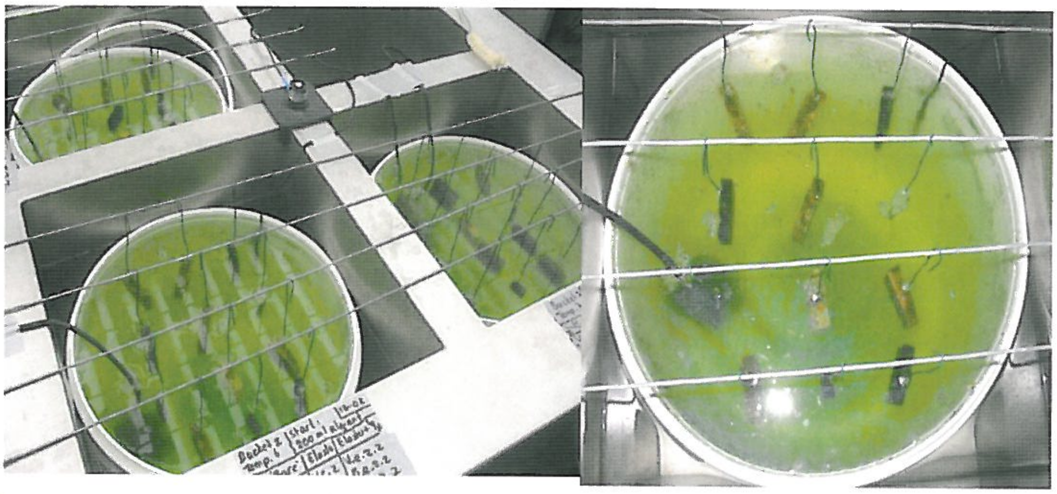


Figure 6. Three of the square compartments of the incubator have a container filled with freshwater medium (27) and an freshwater algae mix. The twelve stones are hung in the container using a hook and steel wires placed on top of the incubator. Each bucket has the same set of stones and treatments.

At days 4, 6, 8, 11, 13, 15, 18, 20 and 27 a Pulse Amplitude Modulated Fluorometer (PAM) was used to determine variable fluorescence (F_v, a relative measure of biomass) and Quantum Yield (a measure of photosynthesis efficiency).
From the F_v, the specific growth rate (SGR) was calculated for all rock types and treatments. The SGR is the slope of the F_v (increase) in the first 8 days after the beginning of the experiment.

3.4 STATISTICAL DATA ANALYSIS

A Mann-Whitney-U test (a two-sample non-parametric test) was used to test differences in algal coverage between investigated areas in the field
The 95% confidence interval (19, Wilson's method) has been used to test the difference between the SGR's of all the treatments for the first 8 days of the laboratory experiment.

4 Results

4.1 FIELD STUDY: ZUIDBOUT

The Zuidbout was visited 6 times during 24 weeks. Below is a description of biological community development for each visit.

26-09-2007: Five days after the realization of the Elastocoast layer. No growth, no animals.
16-10-2007: On the N (natural) areas, there is a lot of growth/recovery of a green algae. There are few animals on N areas, *Patella vulgata*, *Idotea Baltica* (woodlice) and spiders. There are remains of partly removed Japanese Oyster on N areas. No growth on E (Elastocoast), EV (Elastocoast + Vilvoordse) and EZ (Elastocoast + sand) areas.
16-11-2007: N areas show a lot of growth of filamentous green algae (*Blidingia minima*), none of the E areas show algal colonization, apart from a few tiny green patches on the EZ areas.
13-12-2007: The Elastocoast layer was covered in a green/brown haze. There seems however, to be a sharp boundary on the vertical gradient, under which there is no growth. E areas close to N areas show more green patches then E areas further away (seawards). The head of the Zuidbout seems to show more growth of brown algae then in areas towards land, and also shows more growth in general. Hardly any animals.
16-01-2008: The green algae are starting to show a hairlike structure, typical to that of *Blidingia minima*. The outmost sides of the Elastocoast layer seem to have more vegetation then the middle part. Algae coverage is now also present on areas with little sand and higher up the dyke, though very limited, but there is more algae growth higher up the dyke were there is Vilvoordse rock. Above the Elastocoast layer (on the old top layer material), there is coverage of *Blidingia minima*.
The N-areas show a bit different growth pattern than the Elastocoast areas, they are mainly overgrown with green-algae (*Blidingia minima*), and there is hardly any brown-algae zone. Many different snails are present on the lower part of the dyke (around growth boundary). A distinct zonation begins to form on the Elastocoast layer, which from bottom to top is as follows: Water – Granite Blocks (barnacles, Japanese Oyster) – low Elastocoast (no algal coverage) – Underzone (mainly Fucoid species and *Littorina sp*, *Patella vulgata*) – Upper underzone (mainly *Blidingia minima*, some *Patella vulgata*) – Middle zone (*Blidingia minima*, but much less) – higher zone (hardly any algae growth) – above Elastocoast zone (*Blidingia minima* coverage).
The head of the Zuidbout (in the Oosterschelde) shows more and less patchy growth compared to the more landwards areas.
13-03-2008: Growth and recovery on already occupied areas increased a lot. Small patchy coverage has changed into full canopy coverage with *Blidingia minima* showing a distinct hairlike structure and *Fucus spiralis* showing foliage. The sharp boundary under which nothing grows still exists. Above this boundary there are mostly brown-algae, green algae occupy areas above the brown algae. There still is patchiness, areas that didn't show a lot of

growth in December still are behind in algal amount. In the lower E.V. area, Vilvoordse rocks have been removed, resulting in a decrease of algal coverage. Again, the head of the Zuidbout (in the Oosterschelde) shows more and less patchy growth compared to the more landwards areas.

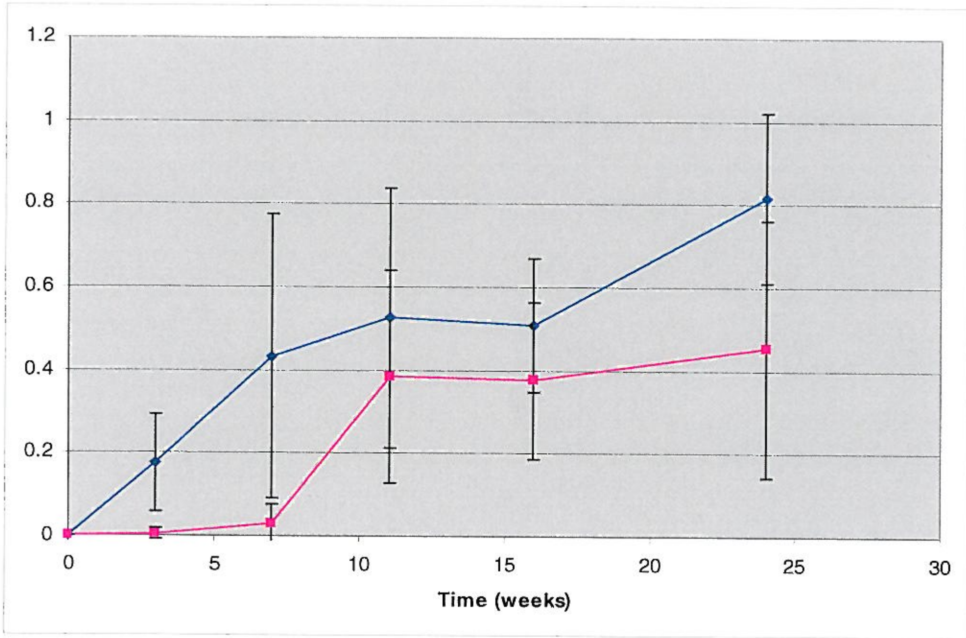
Main species on the Zuidbout up till 13-03-2008 are: *Blidingia minima, Fucus spiralis, Patella vulgata, Littorina sp.* See figure 7 for an overview of growth up till then on the Zuidbout.

jure 7. The Zuidbout at the ginning of the study (26-09-07, top left and right) and at end of the study (13-03-08, bottom left, middle and ht). Note the patchiness in en algae coverage.

4.2 FIELD STUDY DATA: ZUIDBOUT

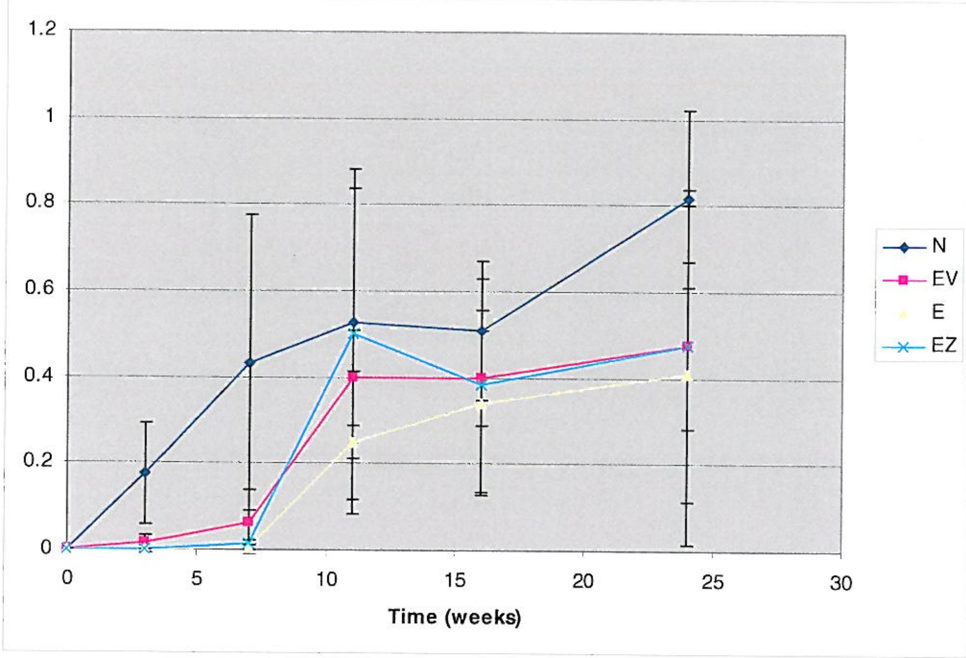
There is no significant difference in algal coverage between the original dyke top layer (N) and the Elastocoast top layer ($p > 0.5$, figure 8), when all different areas (N 'natural, EV 'Elastocoast + Vilvoordse, E 'Elastocoast and EZ 'Elastocoast + sand) of the Elastocoast layer

ure 8. Coverage (%) of the rked areas on the Zuidbout es during the weeks of earch.



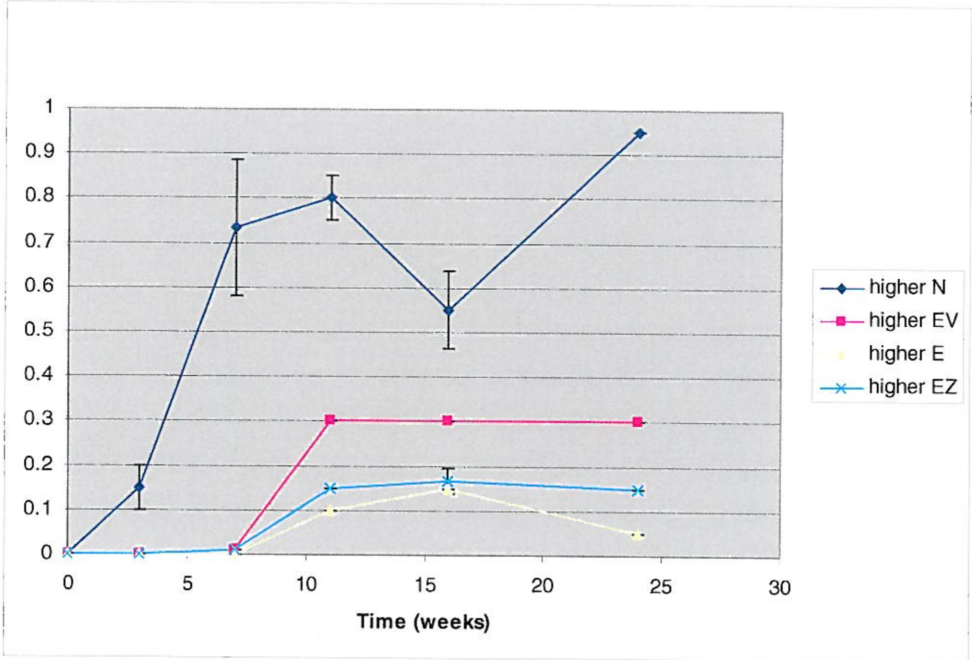
are averaged.

gure 9. Coverage (%) of the ferent treatments (4 different eas) on the Zuidbout



There is no significant difference in algal coverage between the four different investigated areas N, EZ, E and EV ($p > 0.5$, when high and low areas are averaged, figure 9). Visually, there is a difference in algal coverage between the areas which are higher up the dyke and the areas which are lower on the dyke, the higher parts seem to have less vegetation then the lower parts. There is less vegetation on higher N then lower, higher EV then lower EV, higher E then lower E and higher EZ then lower EZ ($p => 0.037$) (figure 10, 11 and 12).

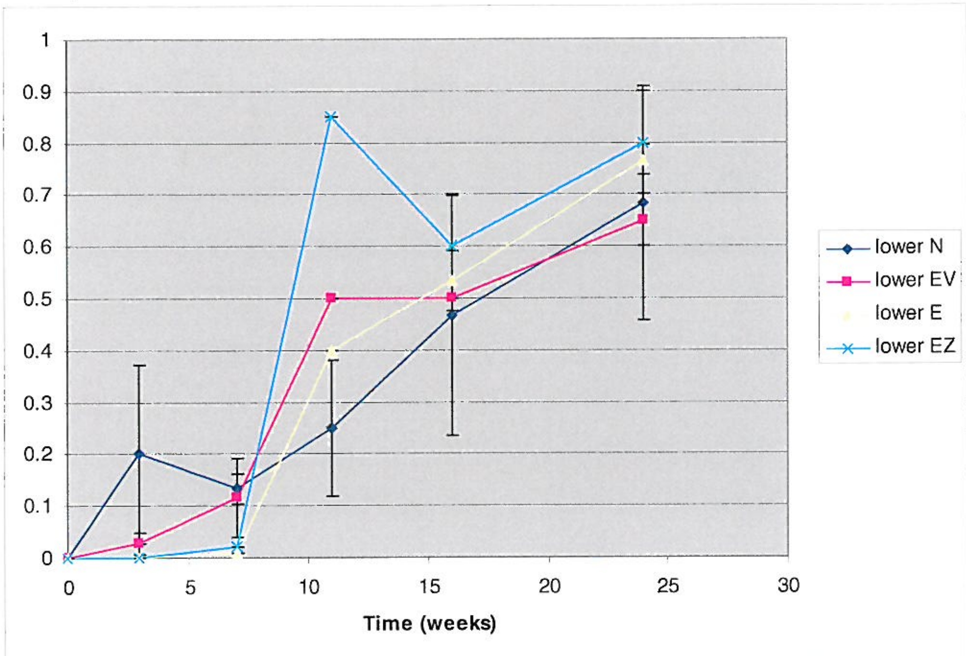
Figure 10. Coverage (%) of all he areas which are higher up he Zuidbout. On the final data point, all areas differ from each other significantly.



When focused on the higher zones only, the N area had more algal coverage then all the other Elastocoast areas ($p = 0.037$). The EV area also had more vegetation then E and EZ areas ($p = 0.025$). The EZ area had more vegetation then the E area ($p = 0.025$).

In other words, on the higher areas the normal Elastocoast treatment (E) had the least vegetation, followed by EZ and EV. N had the most vegetation (igure 10 and 12). When comparing higher N with all the higher Elastocoast areas (E, EV and EZ together), the 'natural' dyke top layer has significantly more growth then the new Elastocoast top layer (p = 0.010).

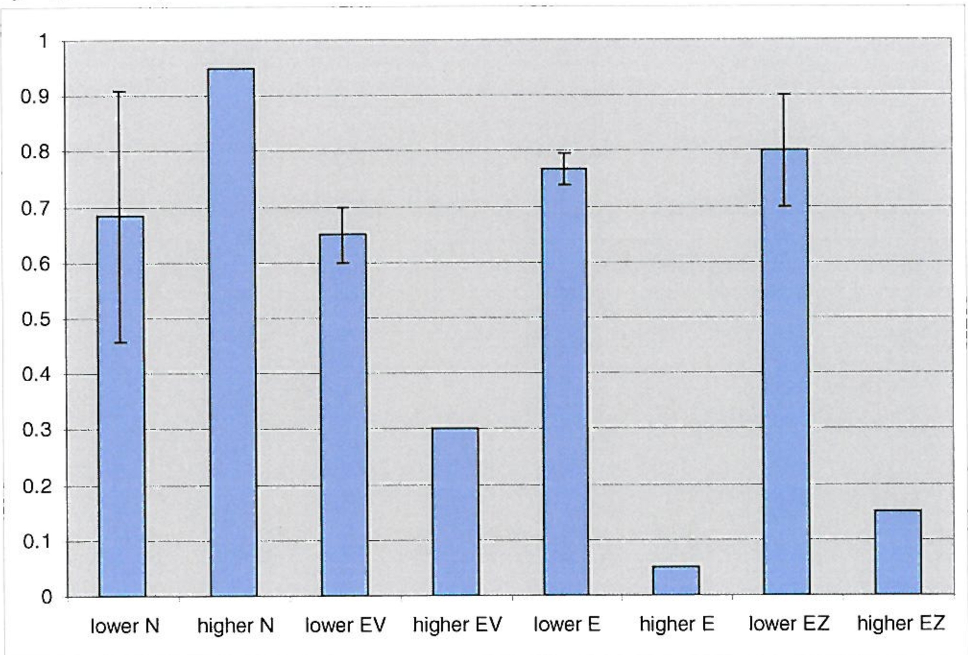
1. Coverage (%) of all ›s which are lower on ›dbout. On the final data all areas differ from each r significantly (p varies from ›25 and 0.037).



When focused on the lower zones only, there is no significant difference in algal coverage percentage between the N, EV, E and EZ areas (p = < 0.077), except for EV and E (p = 0.046), with EV having the least vegetation (see figure 11 and 12).

When comparing lower N with all the lower Elastocoast areas (E, EV and EZ together), there is no significant difference between the 'natural' dyke top layer and the new Elastocoast top layer (p = 0.708).

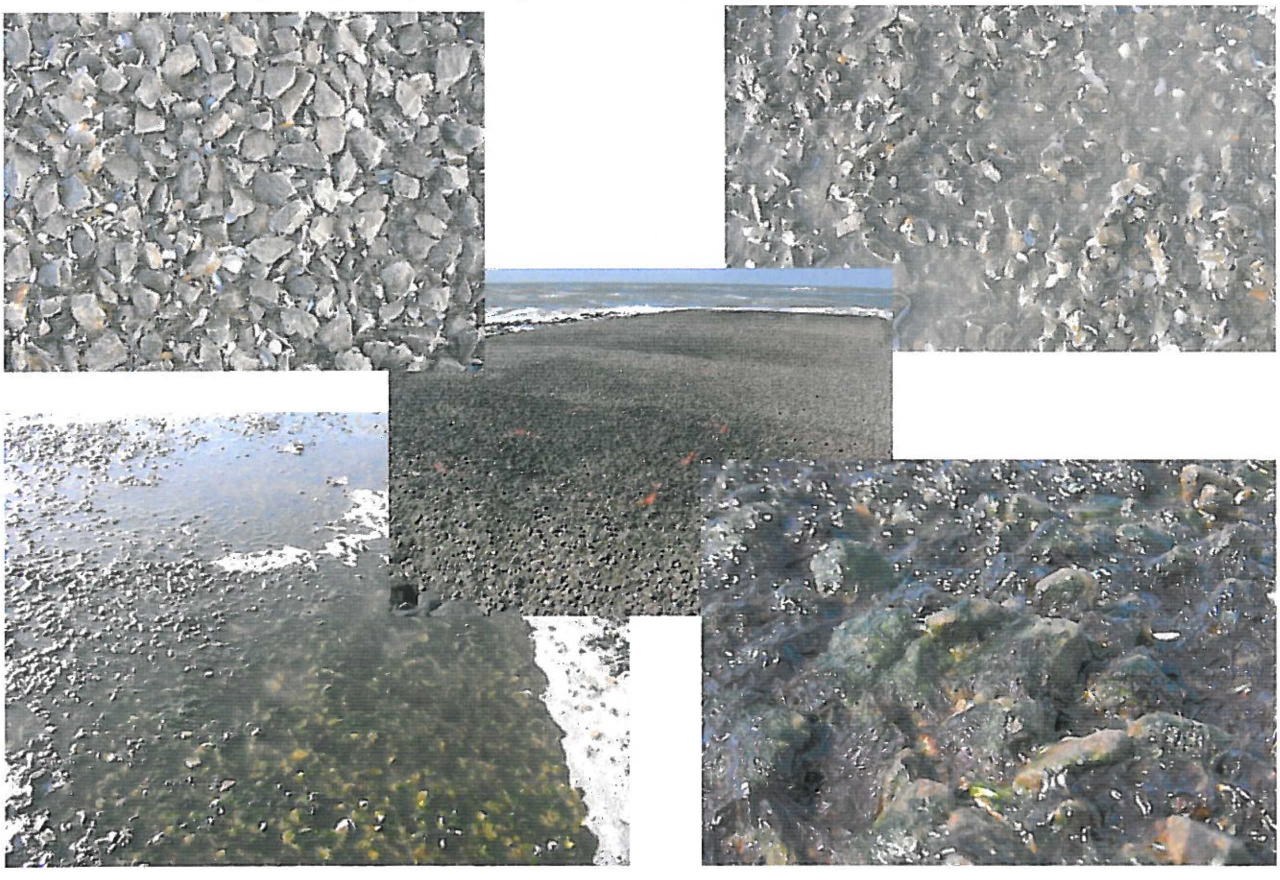
ure 12. Coverage (%) of all the as which on the Zuidbout on 03-2008.



4.3 FIELD STUDY: PETTEN

The dyke near Petten was visited 7 times during 25 weeks. Below is a description of biological community development for each visit.

15-10-2007: Ten days after the realization of Elastocoast top layer, there is not any growth on the Elastocoast layer. On the control areas (N areas) there is little coverage of *Blidingia minima* (figure 4 and 13).
15-11-2007: Still no visible growth on the Elastocoast layer. The layer has been cluttered with smashed shells, sand and other debris (figure 13 and 14). This debris is preventing the water to flow away easily.
14-12-2007: No changes in growth and recovery since last visit. The debris cluttering the layer causes abrasion to the polyurethane layer, causing 'bare' edges on the rocks (figure 13).
15-01-2008: Because of strong winds and high waves the dyke wasn't passable. Close examination on the Elastocoast layer was not possible. However, when looking on the dyke for as far as possible, there didn't seem to be any growth.
06-02-2008: Again, strong winds caused the dyke still to be covered under water. When on the dyke for as far possible, little patches of green algae were visible on the areas close to land. Further on the dyke there seems to be less growth.
22-02-2008: Same as 06-02-2008. Also some small patches of brown-algae are present next to the green patches (*Blidingia minima*).
12-04-2008: The vegetation on the Elastocoast layer shows a remarkable growth, fully grown *Blidingia minima* and Fucoid species cover large areas of the dyke. However, there are also areas with very little growth. Due to cluttering of the Elastocoast layer, water which washes up the layer stays in tidal pools formed by irregularities of the Elastocoast layer.



gure 13. Top left: no algal .overage, cluttering and abrasion of Elastocoast layer. Top right: water stays on the layer. Middle: overview of the Petten revetment at 12-04-2008.
Bottom right, the coverage of the green algae *Blidingia minima* and Fucoid species can be seen.
Bottom left: The tidal pools which are formed by overflowing water prevented of running out of the irregularities

4.4 FIELD STUDY DATA: PETTEN

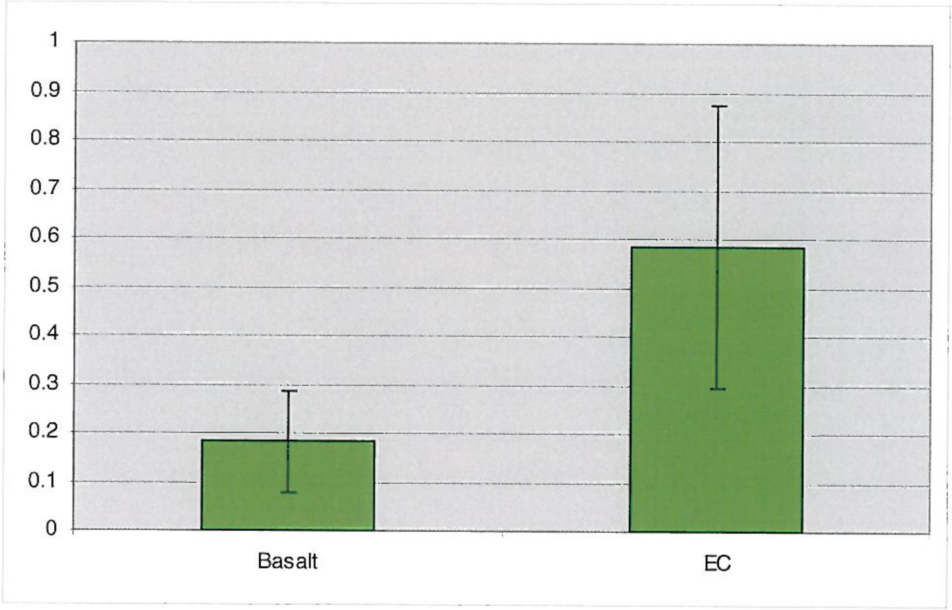


Figure 14. Coverage (%) by algae is shown for the original basalt area and the total Elastocoast (EC) area. There is no significant difference between the areas.

There is no significant difference in algal coverage between the original basalt top layer material and the Elastocoast layer (figure 14, $p = 0.107$, when taken the average of all Elastocoast marked areas).

When comparing all the different areas to each other (figure 15), there is a significant difference between basalt and the right middle ($p = 0.037$). In this case, basalt has more growth then the EC right middle area. In all the other treatments however, basalt has significantly less growth then the Elastocoast layer ($p < 0.05$)).

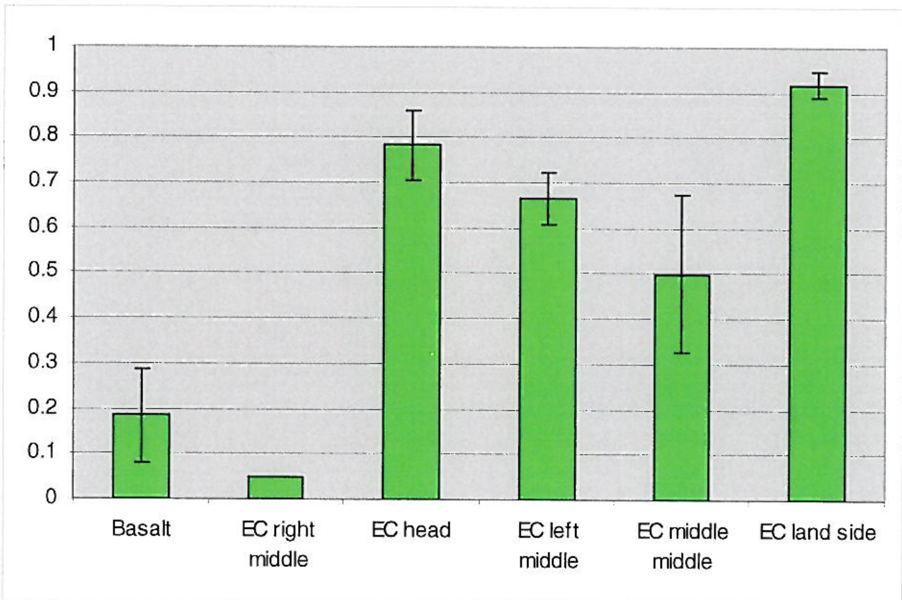


Figure 15. Coverage (%) by algae is shown for the original basalt area and the different Elastocoast (EC) areas.

The Elastocoast area on the right middle of the revetment, has significantly less growth than all the other Elastocoast areas ($p =< 0.037$) except for EC middle middle ($p = 0.480$). EC head, EC left middle and EC middle middle don't significantly differ from each other ($p => 0.072$). EC land side has significantly more growth than EC left middle and EC middle middle ($p =< 0.043$), but doesn't differ from EC head ($p = 0.268$). The patchy distribution becomes clear when looking at the difference in algal coverage percentage on the Elastocoast areas.

4.5 LABORATORY EXPERIMENT

After 27 days of incubation , algae have grown and all stones had visible algae attachment. As can be seen in figure 17, a biofilm had formed on the watersurface. Also, a biofilm has been formed on the stones, and the sides of the bucket. While examining these biofilms under a microscope, different species were found in this biofilm. The formation of the biofilm did not depend on the substrate, all biofilms from the different substrates had the same species and community structure. There was no visual difference between Elastocoast coated substrates and untreated rock surfaces. Species found in the biofilm were 2 species filamentous blue algae, *Scenedesmus sp.* ciliates, flagellates, bacteria (figure 16). One of the two filamentous blue algae is a *Pseudoanabaena*, which forms long bright green filaments. The other filamentous algae is not further identified, it probably came from the river Amstel, as did *Scenedesmus*, the ciliates and flagellates and the radar animals. *Nitzschia*, *Synechococcus* and *Leptolyngbia* were found in very small (negligible) were found. Also rotifers were found feeding on the biofilm.

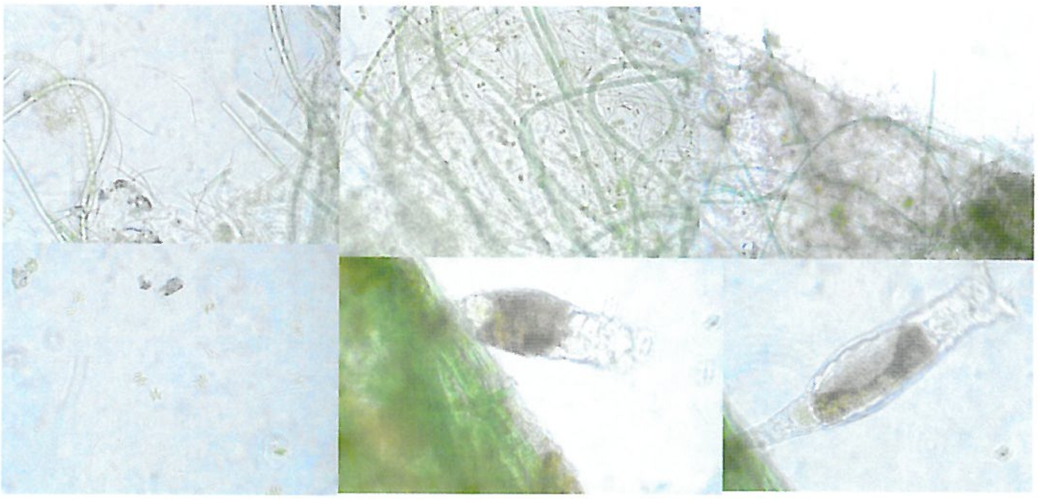


Figure 16. The composition of the biofilm formed in the lab experiment. Top: Filaments of *Pseudoanabaena* (green) and another filamentous algae (brown). Bottom: *Scenedesmus* on the left, the two most right pictures show rotifers feeding on passing cells.

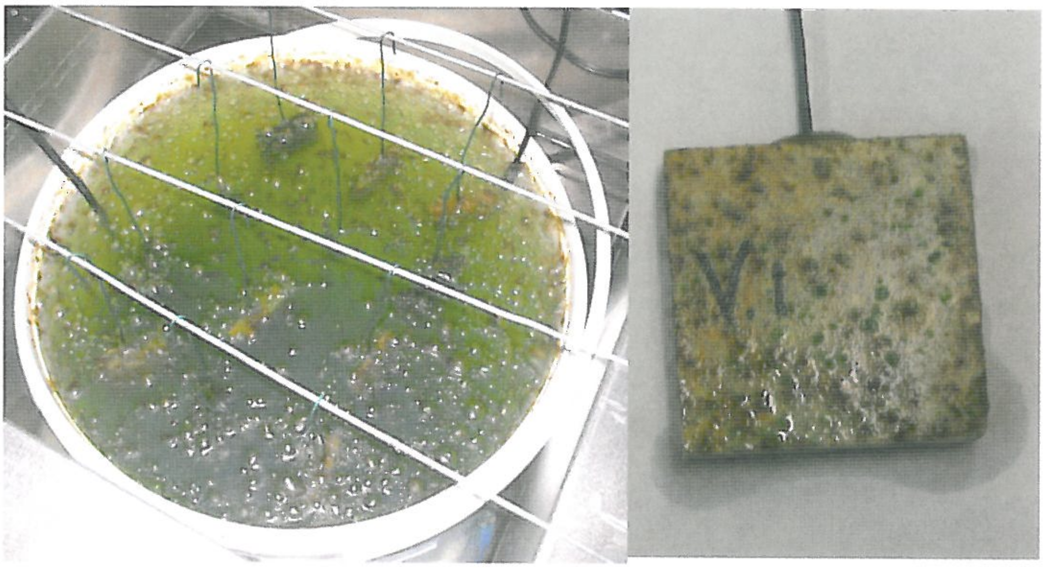
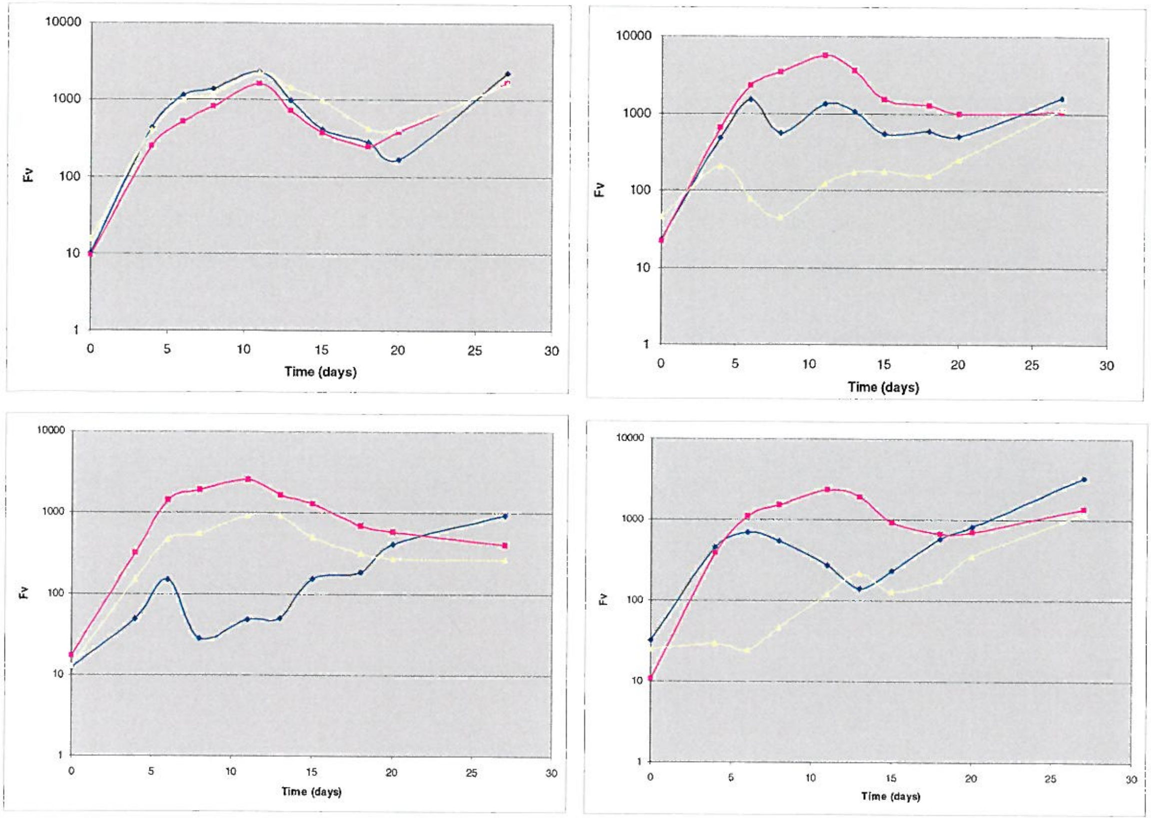


Figure 17. Left: container after 27 days. An oily layer has formed on the surface, and a biofilm has settled on the edges of the container and surface. Right: untreated Vilvoordse stone after the 27 day experiment. Patches of blue-green algae have formed on the surface.

In figures 18 and 19 the variable fluorescence (F_v) and the Quantum Yield for the different rock types and treatments are given. For all rock types and treatments, biomass (F_v) and photosynthesis efficiency (Yield) increase the first 8 days, to decrease again till day 20. After that, both fluorescence and yield increase again.

re **18.** The F_v for the
rent rock types and
ments.
Left: Basalt.
right: Concrete.
om left: Doornikse.
om right: Vilvoordse.



At day 27, the possible differences in F_v and yield between treatments for all the rock types have become a lot less. Doornikse, which is a hard substrate, seems less suitable for algal attachment. The treatment with sand gives inconclusive results, for basalt and Doornikse the sand treatment doesn't stay behind compared to the other treatments, but for concrete and Vilvoordse it does.

= bare 'stone'
= Elastocoast
= Elastocoast + sand

re **19.** The
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ent rock types and
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eft: Basalt.
ight: Concrete.
m left: Doornikse.
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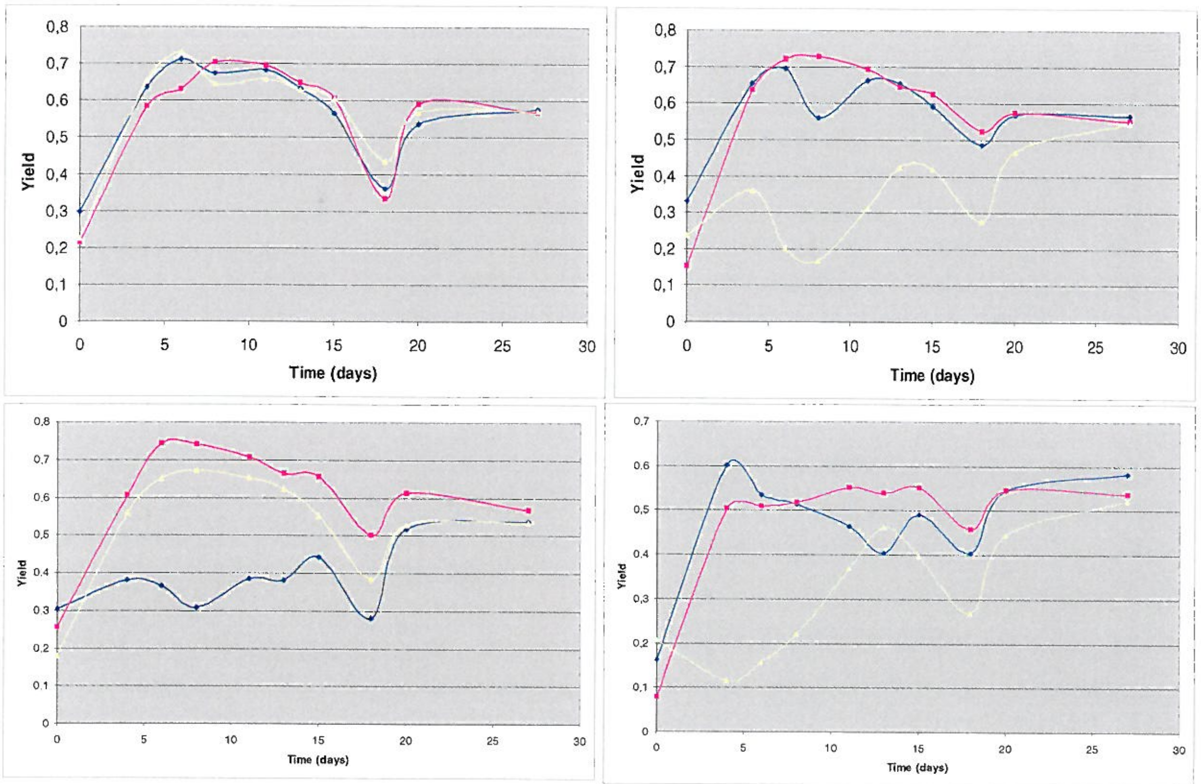
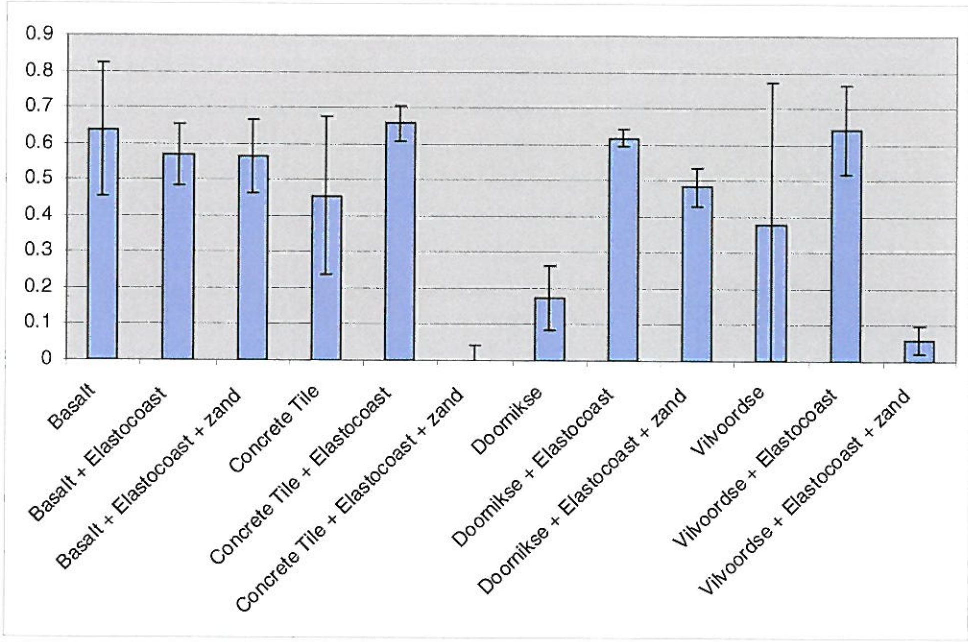
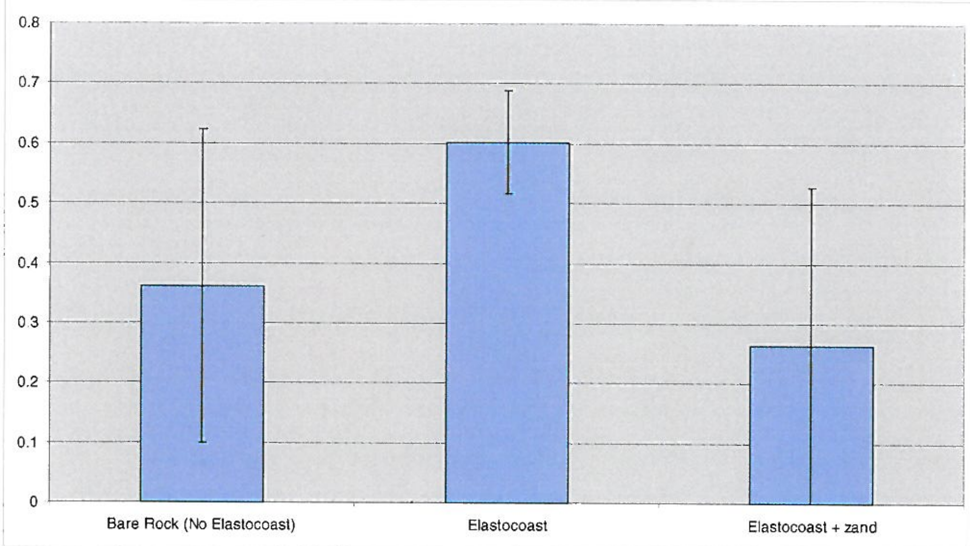




gure 20. The different ıecific Growth Rates (SGR) r the different treatments ıd rocks.

In figure 20, the SGR for all treatments is shown. There are no significant differences in SGR between the different rock types and treatments, apart from Doornikse, for which Elastocoast + sand has a higher SGR then untreated Doornikse. Also the treaetment with sand gives varying results, in the case of Basalt the stones coated with sand have the same SGR as untreated basalt and normal coated basalt ($p > 0.05$). For the Vilvoordse rock and concrete however, the treatment with sand has a lower SGR then the treatment with Elastocoast ($p < 0.05$).



ıure 21. The average ecific Growth Rates (SGR) the three different atments: Bare, ELastocoast d Elastocoast + sand

In figure 21, the average SGR of the three different treatments is shown. 'Bare' is all untreated rocks together, 'Elastocoast' is all coated rocks together, and Elastocoast + zand is all rocks together which are coated with Elastocaost and sand. There is no significant difference between the treatments ($p > 0.05$).

In figure 22 the average SGR of all the Elastocoast coated rock is compared with the SGR of all the used 'bare' rocks. There is no significant difference in SGR between Elastocoast and

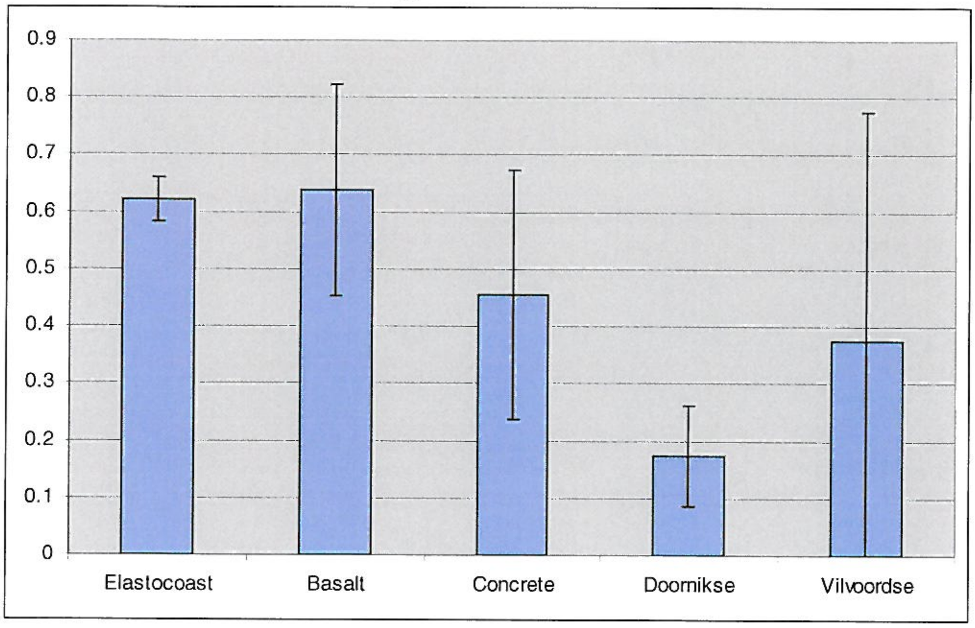


Figure 22. The average Specific Growth Rates (SGR) for the Elastocoast treatments, and the average SGR for all the 'bare' rock types.

Basalt, Concrete and Vilvoordse (p > 0,05). Elastocoast does have a higher SGR then Doornikse (p < 0,05). Doornikse also visually stayed behind in growth, as these rocks looked a lot less occupied then the other stones.

5 Discussion

This study aimed to describe the recovery of biological communities on Elastocoast. Observations of macro-algae coverage in the field and micro-algae in the laboratory experiment indicate that Elastocoast provides a suitable substrate for the development of the biological community.

Elastocoast forms a smooth polyurethane substrate, which may be roughened by the application of sand. The application of sand also could promote algal attachment. However, the results indicate that the application of sand is not necessary for the recovery of the biological community on the substrate. This can also be seen in the field, where areas with very little sand also have full patches of algal vegetation.

Fully grown Fucoids are present on the Elastocoast layer on the Petten revetment but not on the Zuidbout. This indicates that factors other than Elastocoast influence the recovery of Fucoids. In the marine environment, the creation of new unoccupied substrates (which is a form of disturbance) creates colonization opportunities for different marine sessile organisms (14, 20). Organisms secure the new and empty space by overgrowing or spreading over the newly created patch, or disperse propagules. The size, form, tidal regime and location all determine how a new area is being colonized (2, 14, 20, 27). The two pilot sites are both rather large, and it was expected that recolonization could take quite a while. However, even in winter, the first patches of algae coverage appeared on the Elastocoast layers. Recolonization may have been favored by the relatively warm winter. The Zuidbout is located in relatively calm waters with a stable tidal regime (28, 33), which could be a reason why algal attachment on the Zuidbout was earlier then on the dyke near Petten which is located in the much rougher Northsea. The colonization of the Elastocoast layer in wintertime suggests that it forms a substrate to which organisms can adhere even under less favorable conditions (low temperature, winds and storms).

However, it was observed that colonization was not equal on all substrates. Materials such as basalt, concrete and Vilvoordse (which are often used as dyke top layer) have proven to be suitable substrates for a biological community. The results from this study suggest that Elastocoast lies in the range if these materials. Based on these results regarding substrate suitability, the order would be as follows:
unsuitable – Doornikse – basalt – Elastocoast – Concrete - Vilvoordse – suitable
However, more research is necessary. The open-pore structure of Elastocoast, which is not examined here, may improve suitability.

But also within one substrate it was observed that colonization by algae was not homogenous on the entire area. On the Zuidbout, a sharp boundary between higher areas with algal colonization and lower parts of which didn't have any vegetation was clearly visible. An explanation for this boundary might be that this is a typical zonation phenomenon observed on many dykes along the Dutch coast, caused by tide. The species *Blidingia minima* will not grow under the level of average high tide (9, 24, 32). This sharp band of algae colonization is called the 'splash zone' or supralittoral (20). This effect can be enhanced by wave action (20, 27, 29), minor differences in substrate (difference in stones and coating as observed in this study), currents and moisture availability. Apparently, Fucoid species also will not grow there, or need more time to colonize these areas. *Fucus spiralis* has been colonizing areas above average high water level. Mollusks, such as *Littorina sp.* and *Patella vulgata* do seem to visit the area below average high water level, they probably migrate upwards (32).

Revetments may get cluttered with sand and smashed shells and other kinds of (organic) debris, water doesn't run off at low tide but is kept inside these shallow tidal pools. This of course, is a major contributor to algae growth, because water is calmer in these pools and light conditions are optimal (29). Because water stays in these tidal pools at low tide, it is quite possible that different microhabitats are present when compared to 'dryer' parts. This results in a higher biodiversity. For example, the green algae *Cladophora sp.* favors being under water all the time (28), and might have a chance to settle in such a tidal pool. However, because these tidal pools are very shallow, they might prove to be an unstable habitat. After early colonization, it is quite possible that algae migrate from these biodiversity hotspots to the surrounding areas. The migration of algae to surrounding areas was indeed observed in the field.

Zonation and patchiness in algal attachment on the two pilot sites may be a result of such physical/chemical factors, but may also be caused by grazing. The mollusks *Littorina sp.* and *Patella vulgata* graze on the early colonizing algae. Especially this early stage of algal development is vulnerable to grazing. This may cause patchiness in the distribution of algae later on during the development of algal communities (38) From earlier studies however, it seems that grazing doesn't seem to have an effect on the early colonizing Fucoid species (30). The effect of grazing might be interesting for further research, since snails became visibly more numerous during the monitoring period. A higher number of snails results in more grazing, which may inhibit further development of the biological community over time.

The differences in the colonization of new substrates observed in this study were pronounced in the beginning and became less during time. It therefore may be quite possible that the barren zones still seen on the Zuidbout and the dyke near Petten will become overgrown with algae during the course of time. This study monitored the development of the biological community for 25 weeks in winter time, therefore it is likely that changes in the current state of development will occur. Fucoid species play a key role in the marine littoral environment, they are the most dominant but also very vulnerable for change (14). The formation of a dense Fucoid canopy (such as seen in the original vegetation on the Zuidbout) can be a good indicator of a stable community (31). When this is not the case it may indicate that full community recovery may take longer. This study mainly focused on algae but also snails and other animals were found. They can provide a food source for larger animals (27, 34, 37), making full community recovery possible (3, 18, 26). For the complete recovery of the biological community ten years or longer may be required (28). A longer time span for monitoring can give more solid results regarding suitability.

6 Conclusions

6.1 CONCLUSIONS

Based on colonization patterns in the field and growth experiments in the laboratory it is concluded that Elastocoast is a suitable material for algal attachment.

There is no need for sand to aid algal recovery, but can be applied for esthetic reasons if desired since it doesn't influence algal growth in a negative way. Placement of Vilvoordse rock on the layer can promote colonization.

Colonization and succession of alga communities under relevant field conditions follow predictable patterns in space and time under the influence of physical and chemical conditions

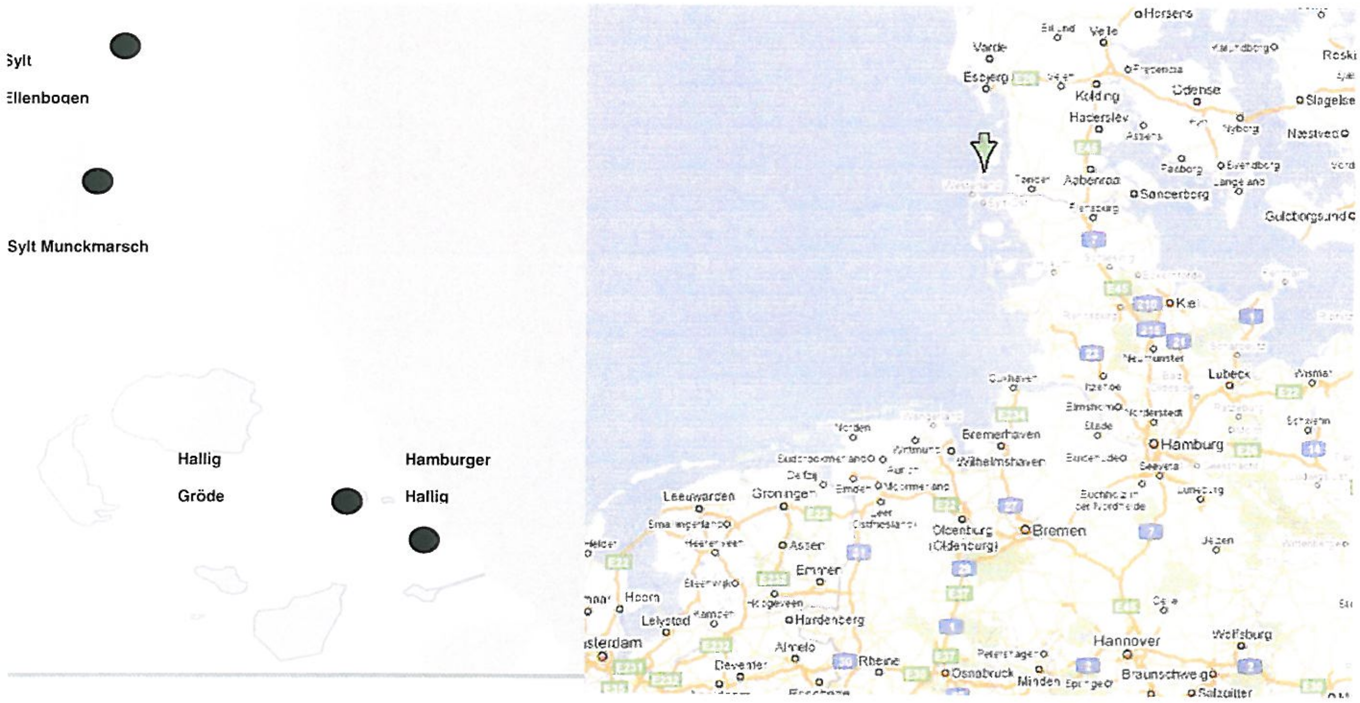
This study monitored the Elastocoast pilots in the field for 25 weeks. Further and longer research is necessary to give results about the development of the biological community as changes are likely to occur.

6.2 IDEAS FOR FURTHER RESEARCH

- Keep monitoring the Elastocaost locations. Every two months for the Dutch pilot locations. For the German locations it might be interesting to keep monitoring Sylt Munckmarsch, Sylt Ellenbogen and Hallig Gröde 1. Twice a year (beginning and end of growth season) will suffice. Hallig Gröde 2, and Hamburger Hallig showed no growth, and might therefore not be interesting to keep monitoring.
- See if monitored areas change over time regarding species composition and abundance.
- Research whether the areas with little growth are still recovering.
- Research Petten tidal pools, and if these create different habitats with different communities compared to drier areas.
- Test the 3D structure of Elastocoast for suitability.

7 Visit to the German Elastocoast Pilot Sites

7.1 THE GERMAN ELASTOCOAST SITES



ure 23. On the left a map ich indicates the German stocoast locations. Insert: ation of Sylt (indicated by en arrow) to the inland.

Elastogran also has Elastocoast projects in Germany, which have been realized before the Dutch projects. To gain a better understanding of how recovery and growth of species on the Dutch Elastocoast sites could develop, a visit to these German Elastocoast sites was made. All these sites are near the border with Denmark, in the German province of Nord-Friesland. These sites are:

- 2004 Hamburger Hallig (first pilot)
- Sept. 2005 Sylt Ellenbogen
- July 2006 Hallig Gröde, first site
- May 2007 Hallig Gröde second site
- Sept. 2007 Sylt Munckmarsch

See figure 28 for the locations of these sites. These sites are described in the order of visitation.

7.2 HALLIG GRÖDE

On the 13th of November Hallig Gröde was visited. On Hallig Gröde, there are two Elastocoast sites, the first one was realized in July 2006, and has a surface of 500m2. This site is referred to as HG1. The second one, realized May 2007, has a surface of 2500m2. This site will be called HG2.

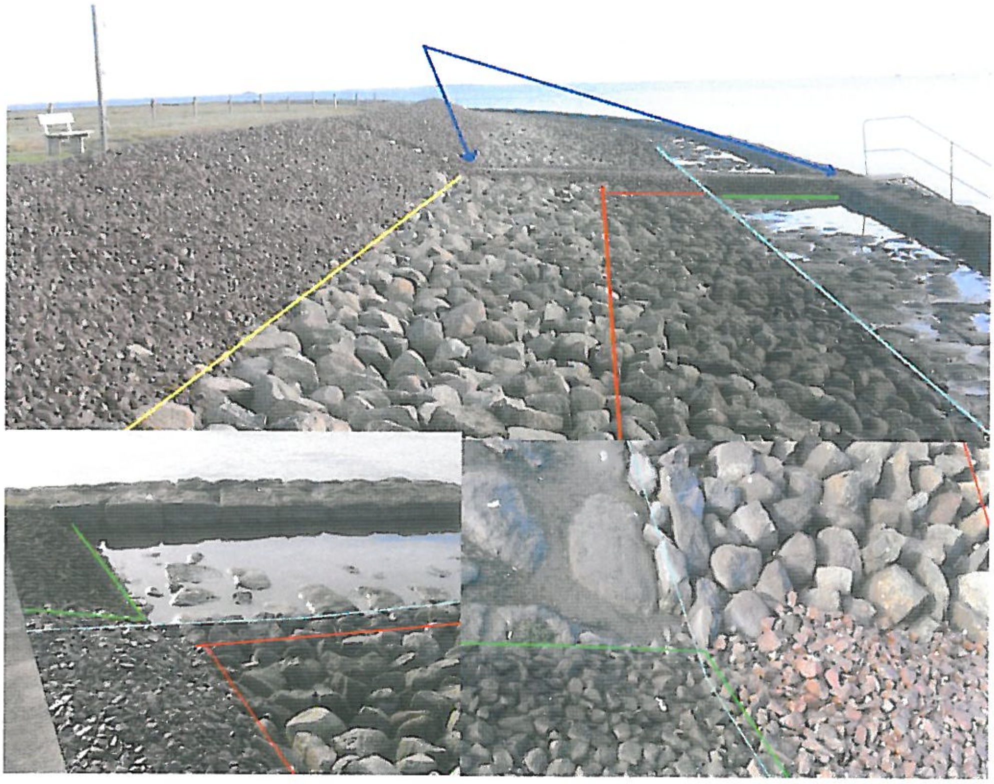


Figure 24. An overview of the first Elastocoast pilot on Hallig Grode. The green line denotes the area where green algae can be found, the light blue line indicates from where water is held in a basin. The red line indicates from where black crustose algae

HG1, shown in figure 24, is constructed above high water level. Under normal conditions, the main part, underlined by yellow, never is underwater. However, Elastocoast has also been applied in a small area towards the stairs (indicated by the blue arrows). A part of this area is underwater during high tide.

On the large area of HG1 which never gets underwater, there is no vegetation, and there are no animals. Also, samples taken from the surface contained very few cells. However, on the small area from the main part to the stairs there was an area which did have life (underlined by green). On the right side of the light blue line, water which has poured in during high water is held by the basalt ledge, forming a basin. Between the light blue and the red line is a dark, almost black formation of algae, which according to Robert Jentink (Rijkswaterstaat, NL) are cyanobacteria. In the basin there are small patches of weed, which are *Blidingia minima*). Also, samples taken from the Elastocoast area with growth (underlined by green) showed cells from a green weed (probably *Blidingia minima*), and a brown weed and some diatoms.

It is worth noticing that there was no growth of vegetation on Elastocoast till the red line. Growth on Elastocoast seems to stop when, seen from the left, the basin ends and rocks start. It is possible that the presence of water near Elastocoast enables growth on Elastocoast, and when a much more dryer surface is next to Elastocoast, growth is not favored. Also, there was little growth on the basalt rocks, just *Blidingia minima*.

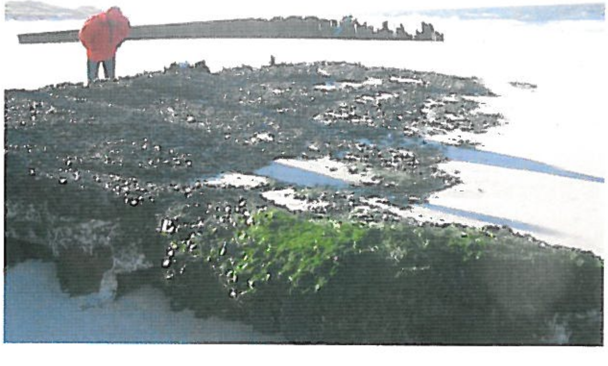
On HG2, which has been placed May 2007, there was no growth at all (see figure 25). Although this site has been there during a part of spring and summer, there is no vegetation 'e 25. The top left 're shows an iew of the second | Grode pilot. There vegetation on the)coast layer)m right), times there is 'gia minima) on the t below (bottom The only animals nt on HG2 are

on Elastocoast. The grass on top of the dyke in figure 25 has been put there by wind and extreme high tide during a storm prior to the visit. On the basalt below the Elastocoast top layer there is no vegetation as well, apart from the areas which act as a basin. The shoreline, which consists of basalt rocks, hardly has any vegetation. At some point, as shown in figure 29, water kept in the basin came to where Elastocoast was started. *Blidingia minima* which has been growing in that basin area has grown all the way up to Elastocoast. There was no sign of *Blidingia* growing on Elastocoast itself yet, but maybe when given some time *Blidingia* will also grow on Elastocoast.
The shoreline of Hallig Gröde consists of basalt rocks, on which there is no vegetation. There are animals; a species of snail (probably *Littorina sp.*) and *Semibalanus balanoides*, (common barnacle). The shoreline is often attacked by winds and strong tidal currents. This probably causes the limited growth of weeds observed. Green algae are mostly found in the basin, where they are protected from winds are waves, and growth on Elastocoast or any other substrate seem to be favored by calm conditions in this case.

7.3 SYLT ELLENBOGEN

On the 14th of November the island Sylt was visited. Sylt is a part of the Nordfriesische Isles, and suffers a lot of wave-action from the North sea. Without proper coastal protection, the

ure 26. The Elastocoast site ;ylt Ellenbogen. On the parts ront, *Blidingia minima* is wing.



island would erode quite quickly. However, Sylt's coast has protection, and the rough waves and the potential erosion make Sylt a perfect test site for Elastocoast.
The Elastocoast site of Sylt Ellenbogen is situated on the beach of the most-northern part of Sylt. The site was build in September 2005 and has a surface of 270 m2. When we visited Sylt, a large part of the site was covered with sand, leaving a site of about 40 m2 (figure 26). From figure 31, it is obvious green algae are growing on this site. This is *Blidingia minima* and covered about 5 % of the visible surface. There were no other visible species of algae, and no animals. The rough waves, the wind and sand winds are likely to slow growth and migration of species.

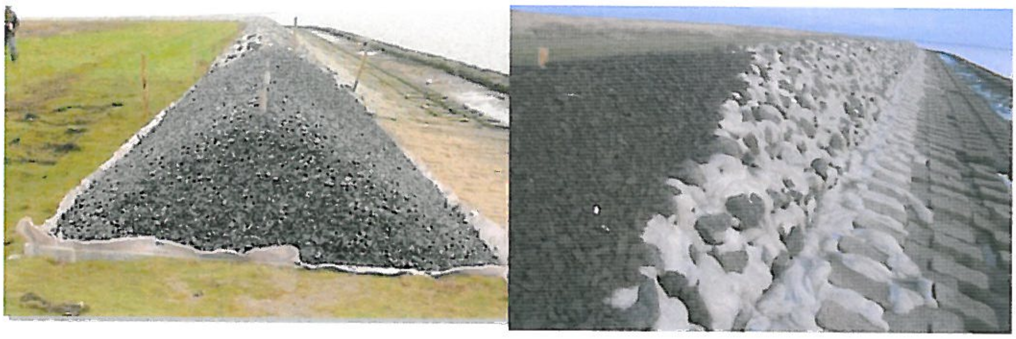
7.4 SYLT MUNCKMARSCH

ıure 27. The Elastocoast etment of Sylt Munckmarsh. tice the algae on the sand. hough there are no algae yet the revetment, the green ae from the sand might ȷrate upwards.

The Elastocoast site of Sylt Munckmarsch is a commercial site, not a pilot site. It has been placed there as a renovation of an existing dyke which was damaged. This site has been build September 2007 and has a surface of 1500 m2 (figure 27).
There was no algae growth on this revetment. The site is very new, so algae may not have been able to grow substantially on the revetment. However, there is a good possibility for algae growth on this revetment, since algae are present on the stones below Elastocoast, and in the sand. The lower part of the Elastocoast is submerged at high tide, which may aid in moving algae upwards on the revetment. This presence of a 'swash zone' of water submersion seems to be an important factor for algae attachment. That is probably why there is algae formation on the Hallig Gröde site in the vicinity of water (20).

7.5 HAMBURGER HALLIG

ꟸigure 28. Left: ›verview of the evetment when it was ȷst realized. Right a ›icture from the visit. here is no vegetation ›n the Elastocoast or on he mixture of concrete



On the 14th of November Hamburger Hallig was also visited. The Elastocoast revetment on this location is a second barrier for the Northsea (figure 28), and has been placed there in

2004. The Elastocoast layer lays on top of a dyke which already existed, and where Elastocoast ends, and the mixture of concrete andbasalt continues. The Elastocoast layer has no vegetation, but neither does the part of which the top layer is basalt. The top layer has no contact with water under normal condition, and in the surrounding areas there is very little rockweed vegetation. Therefore, this site probably will remain without vegetation.

8 Visit to the pilot locations: June 17th, 2008

8.1 ZUIDBOUT

Algal amount has decreased, the sharp boundary below which there is no algal coverage has moved upwards, leaving more of the revetment without algae. This also occurred on the natural (N) areas, but a more typical zonation (like before any Elastocoast application) is beginning to form on these areas. On the Elastocoast layer the main species is *Blidingia minima*, but on some rocks *Enteromorpha compressa* has settled. Full-grown *Fucus spiralis* shoots have also occupied some patches. Snails were found in large amounts, especially just below the vegetation zone. They are probably feeding on the algae, which may have caused the boundary to move upwards (snails mostly inhabit the lower areas of a dyke (26, 29).

Figure 34. Top left: Snails just below the vegetation. Top right: *Enteromorpha compressa* on a Elastocoast rock. Bottom left: Vegetation on the head of the Zuidbout. Note the difference with figure 7 (bottom left). Bottom right: An overview of the original vegetation, the N area and the Elastocoast layer. Note how the underboundary of vegetation has moved upwards compared with figure 7 (middle).

8.2 PETTEN

The dyke near Petten is completely overgrown with algae. *Blidingia minima* and a brown-algae (probably a Fucoid) are the main species found here. There is no difference in coverage percentages anymore, but it seems that some areas are mainly covered with the brown algae, and other areas more with *Blidingia minima*. Birds, such as the common oystercatcher (*Haematopus Ostralegus*) and the seagull (*Larus spp.*) forage on the revetment. Small tidal pools are still present at low tide.

jure 35. Top left: A coid algae. Top right: lal pools filled with iter at low tide. Bottom t: The Elastocoast layer is vered with algae. ttom right: an overview the Petten revetment. te the birds on the layer.

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EARLY COLONIZATION OF LITTORAL COMMUNITIES ON POLYURETHANE COATED SUBSTRATES: A FIELD AND LABORATORY STUDY

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