The recolonization by seaweed on different revetment types on the test site at Sint-Annaland, Tholen

Progress report of the seaweed development in the first five months after placement

Tim van Oijen

HZ University of Applied Sciences, Delta Academy, Research group Building with Nature

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HZ UNIVERSITY OF APPLIED SCIENCES

This report is a progress report for the RAAKPRO-project Building for Nature, subproject Dike revetments. The partners involved in this research are:

-HZ

-Rijkswaterstaat/Projectbureau Zeeweringen

-Haringman Betonwaren

Summary

Dikes are primarily designed to protect the hinterland against storm surges. The aim of the RAAK Building for Nature (BfN) project is to innovate the design and construction of dikes to give them an added value to nature and facilitate their multifunctional use for recreational diving, fishing and aquaculture. As part of this project the biodiversity development on different types of revetments is monitored on a dike section at Sint-Annaland (Tholen, Zeeland). In this progress report the results are reported of the developments in the first six months after placement.

In May 2015 triplicate sections of 10 meters width of different types of hydroblocks were placed on a sheltered NE facing dike at Sint-Annaland: standard blocks; blocks with a lavastone ecotop and BfN blocks with a varying number of pits. In addition, duplicate 5m-sections of standard and porous Hillblocks were placed. Based on pictures that were taken every 6-8 weeks, the coverage rate of the top surface of the blocks by three main seaweed species groups (gutweed, *Fucus* spec. and *Porphyra*) was estimated at two different inundation times: 32,4% and 74,8 %. There were strong differences in the development of seaweed coverage at both levels between the different revetment types. On 21 October 2015, approx. five months after the placement of the revetments, at the high inundation time the % cover was highest (>80%) on the BfN blocks and the Hill blocks, followed by the blocks with ecotop (65%). The standard blocks had the lowest coverage (35%). At the low inundation time the blocks with ecotop had the highest coverage (>80%), followed by the BfN blocks (65%), the Hill blocks (25%) and the standard hydroblocks (<10%). The coverage rate with gutweed was remarkably high on hydroblocks with ecotop. It is suggested that there is a competition for space between the pioneer species gutweed and the *Fucus* spec.. The ecotop seems to stimulate gutweed growth the most, reducing the space available for brown seaweeds to settle during the observation period. There were only minor differences between the four BfN-block types as well as between the two Hill block types. It can be concluded that at sheltered dikes, all revetments tested perform better than the standard hydroblocks in terms of seaweed cover. Since the climax state of the seaweed population on dikes is dominated by brown seaweeds (*Fucus vesiculosis* and *Fucus spiralis*) at the inundation times studied, the contribution of gutweed is expected to strongly decrease in later stages. Therefore, the ecotop appears to delay the development of the seaweed population to this climax state. The monitoring will be continued to test this hypothesis. Future research will also include a GIS-analysis of the coverage of different species groups over the full height range, detailed species composition analysis and biomass (wet weight and dry weight) assessments.

1. Introduction

In the last centuries, parts of the Dutch coast got an artificial rocky shore by the construction of dikes (Baptist et al., 2007). These were and are primarily designed from a civil engineering perspective: the main focus is on flood protection and water management. The Building for Nature (BfN) approach aims at innovating the design of coastal protection structures in order to increase their ecological value. Dikes with this type of design are called rich dikes, or rich revetments (Fig. 1). These revetments can support the multifunctional use of dikes, eg for diving, fishing or aquaculture. Where the nature on dikes has special protection, such as in the Natura2000 area the Eastern Scheldt, bringing back the nature value that existed in the past, may be a requirement during the reinforcement of dikes. In past years at several locations in the Netherlands, including a few dike sections in Zeeland and the pier of IJmuiden first experiments were carried out to promote nature on dikes.

Fig. 1. An artist impression of a 'rich revetment' with a high biodiversity on the revetment, the riprap at the toe and in the foreshore.

In the context of the above-mentioned overarching goals, the RAAK-project Building for Nature has initiated several new experiments to test different designs and materials that can be applied to increase biodiversity on different parts of the dike, including the foreshore, the riprap layer at the toe and the revetment on the slope of the dike. In Spring 2015, a dike section of 100m was built at Sint-Annaland where replicate sections of different types of revetments were placed to test their potential to contribute to a 'rich revetment' in the intertidal zone (Fig. 2). The blocks studied include different types of hydroblocks: standard blocks; blocks with a lavastone ecotop and BfN blocks with a varying number of pits. In addition standard and porous Hillblocks were placed. The major aim of the pits in the BfN blocks was to increase the microfauna on the dike by creating a heterogeneous surface with hiding places for differently sized organisms. However, the holes in the blocks also increase moisture retention capacity thereby facilitating various seaweed species.

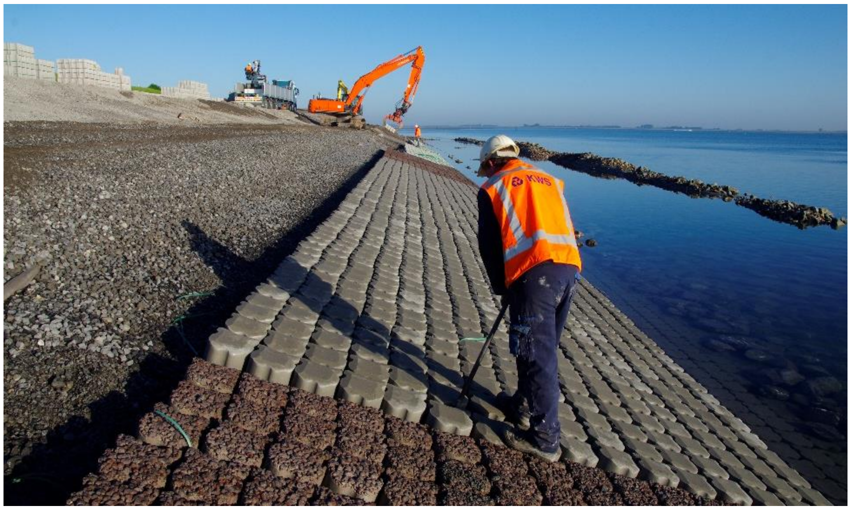


Fig. 2. The placement of the revetment at Sint-Annaland during spring 2015.

As part of the monitoring program the potential of the different blocks for seaweed population development was studied. In this progress report the changes in seaweed coverage in the first five months after placement are reported.

Research questions

Main question:

- What are the changes in seaweed coverage and composition on standard hydroblocks, hydroblocks with a lava stone ecotop, hydroblocks with BfN patterns, and standard and porous Hillblocks on the test dike section at Sint-Annaland, in the first five months after placement?

Subquestions:

- What are the differences in the development of the seaweed coverage and composition between each of the tested block types?
- What are the differences in seaweed coverage and composition between the four BfN- designs (with 1, 2 4 or 9 diamond-shaped pits)?
- What are the differences in seaweed coverage and composition between the standard and porous Hillblock?
- What is the effect of inundation time on the seaweed coverage and composition on the different types of revetments?

Hypotheses

Since the dike section at Sint-Annaland is located at a NE-faced, sheltered place, wave impact is expected to be relatively limited. Settlement of seaweed is expected to be relatively easy, with a low chance of disruption of the growing individuals. Moisture retention rather than attachment possibilities is therefore expected to be a key factor determining which species groups will develop and how fast they will grow. Specifically, gutweed might profit from the moisture retention capacity of the lavastone ecotop, porous Hillblocks and BfN blocks (which retain water in the pits). For the same reason these blocks are hypothesized to facilitate faster growth of the seaweed species present at lower inundation times that the standard blocks. Since this research is covering the first five months only, the seaweed vegetation is expected to be dominated by pioneer species, i.e. gutweed species.

Limits and preconditions

Given the sheltered location of the test dike section, this research only studies the effect of the revetments in sheltered conditions. Furthermore only coverage rates are studied, not the development in biomass. Also, in this report only cover the first five months after placement. The later seaweed development will be reported in other reports.

2. Material and methods

2.1 Research location

The research was done on a dike in Sint-Annaland. Sint-Annaland is a town that is a part of the municipality of Tholen. It lies in the province of Zeeland in the Netherlands (Fig 3). The town is situated along the Krabbenkreek. The location of the test dike section is indicated in Fig. 3b.

Fig 3. a. The location of Sint-Annaland (left); b. the position of the test dike section (right).

2.2 Description of the test dike

In May 2015 triplicate sections of 10 meters width of different types of hydroblocks were placed on a sheltered NE facing dike at Sint-Annaland: standard blocks; blocks with a lavastone ecotop and BfN blocks with a varying number of pits (Fig. 4). The BfN blocks are designed in a way that the number of pits varies, but the total surface of the block is kept the same. In addition to the different hydroblocks, duplicate 4,5/5m-sections of standard and porous Hillblocks were placed.

Fig. 4. The four different types of BfN blocks.

Figure 5 shows the order of the sections. The sections are 6 meters from top to bottom an cover a height range between -0.64m NAP and +0,95m NAP.

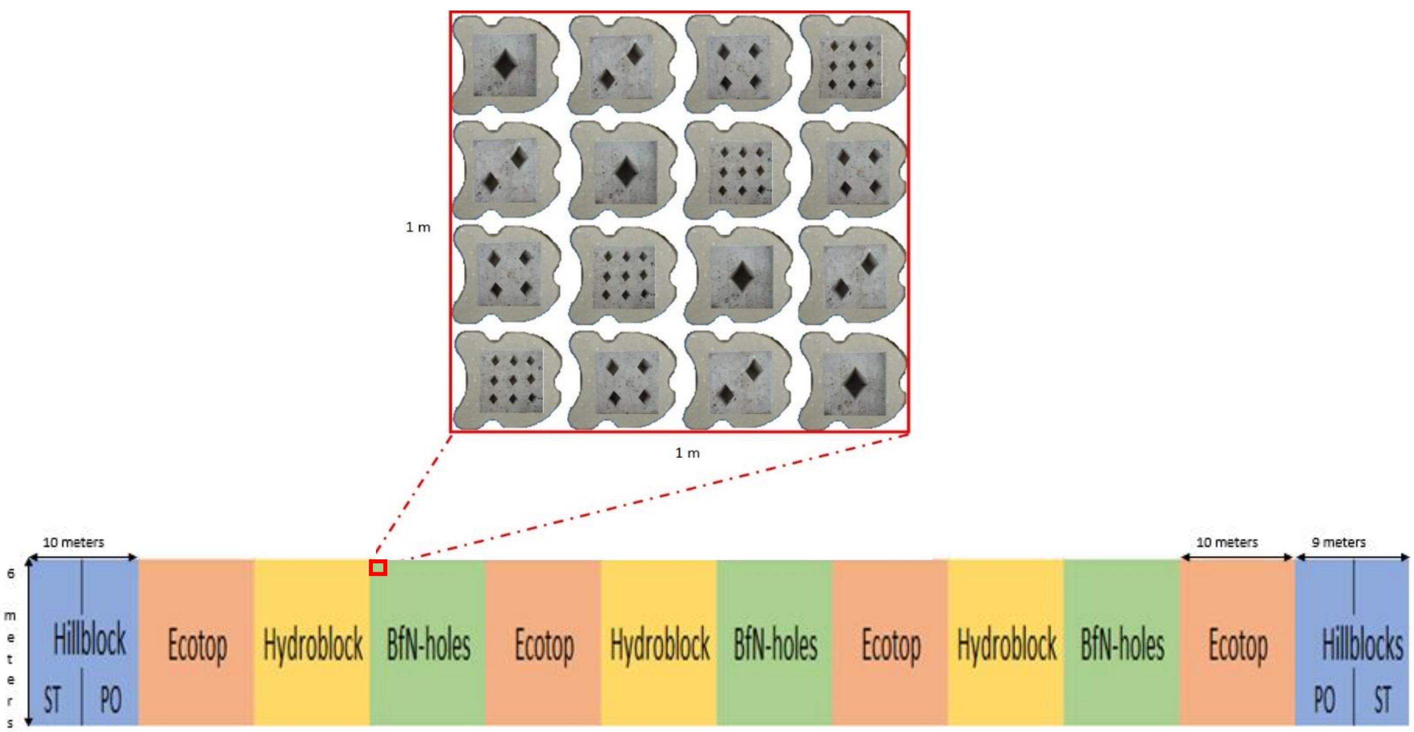


Fig. 5. The order and dimensions of the sections with the different block types as seen facing the dike. Also the way the different types of BfN blocks were places are shown (top). ST= standard; PO=porous.

2.3 Sampling

The location was visited once every six to eight weeks: T1= 2 June 2015; T2= 15 July 2015; T3= 9 September 2015; T4= 21 October 2015. During these visits pictures were taken at two different height levels: +0.68 m NAP and -0.64 m NAP. At the high level there is an inundation time of 32.4 % and at the low level an inundation time of 74.8 %. On each of the sections depicted in Figure 5 a picture was taken of four blocks on each of the two height levels. On the sections with the BfN blocks, pictures were taken of four replicate blocks of each block type (1, 2, 4 or 9 pits) at each height level. Since the two Hill block sections most to the right on the test dike was placed later than the other sections, this section was not included in the analysis. In case an unknown seaweed species was found on the dike, this species was sampled in a bottle and analysed in the lab with a light microscope.

2.4 Picture analysis

The seaweed species found on the blocks could be grouped into three different species groups: gutweed (including *Blidingia minima* and all *Ulva* species), *Fucus* spec. and *Porphyra purpurea* (just one species). The gutweeds were group because they are very difficult to distinguish from each other, especially from pictures. The same goes for the brow seaweeds. Especially the young *Fucus* species are still very hard to identify. Below, the gutweed group is sometimes also called *Ulva spec*.. Based on the pictures, for each of the seaweed species present on a block the % cover was estimated in ArcGis. This was done independently by two persons. For a more accurate estimate a mask layer was added to the picture with lines that divided the surface in four different parts. The average of the two individual estimates was taken.

2.5 Statistical analysis

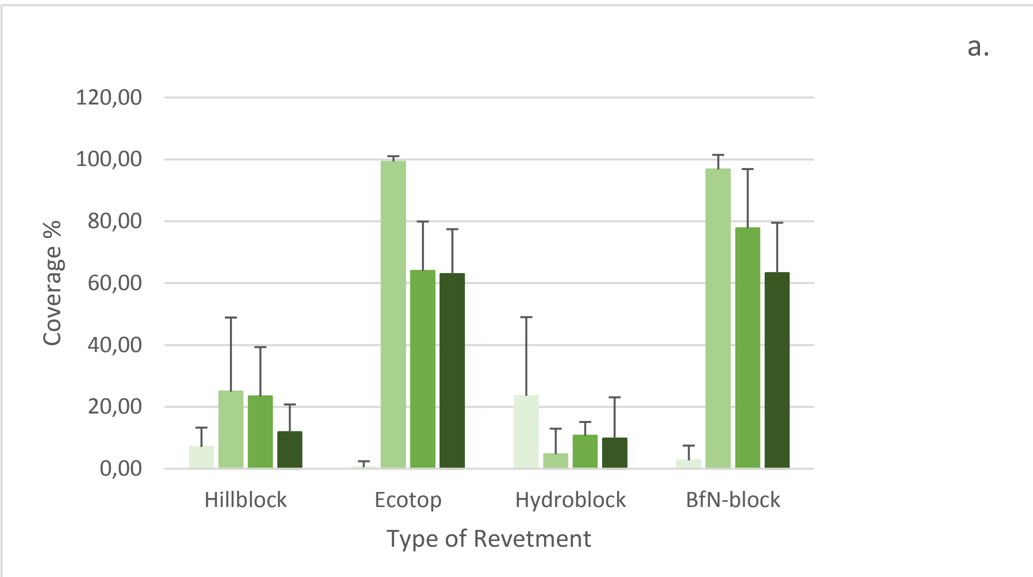
The differences that were observed in the seaweed coverage of the different revetment types on 21 October 2015 (T4) were statistically analyzed by several non-parametric two-way ANOVA's including revetment type and inundation time as factors. Because equal groups were required some results of especially the hydroblocks with ecotop (of which there are four sections instead of three) had to be deleted randomly. This is done with the use of the Microsoft Excel function '=RANDBETWEEN', when the random number chosen by this function is not in the results, the function is run again. If there is a result deleted from one inundation time, the exactly equal dike block at the other inundation time is also deleted.

3. Results

In 4.1 the development in the seaweed coverage is described. Here the different types of Hillblocks were grouped, as well as the different types of BfN blocks, since the differences between the subtypes were only minor. This is later described in more detail in 3.2 and 3.3.

3.1 Seaweed development

In figure 6 the development in the coverage rate of gutweed is shown. After initial low coverage rates a few weeks after the placement of the revetments was finished, the presence of gutweed strongly increased in the second month. Especially on the hydroblocks with ecotop and the BfN hydroblocks the coverage rate was very high, upto almost 100% at -0.64m NAP. Gutweed coverage was lower on standard hydroblocks and Hillblocks on most of the sampling dates. It has to be noted that strong differences were observed in the thickness of the vegetation i.e. the length of the individual plants was much longer on later sampling dates. There was a significant effect of revetment type on gutweed coverage at T4 (two-way non-parametric ANOVA, $H = 68.63$, $df = 3$, $p = 0.00$). The coverage rate was not significantly dependent on the inundation time on this sampling date (two-way non-parametric ANOVA, $H = 1.28$, $df = 1$, $p = 0.26$) although after the analysis of the different BfN designs (see 3.2) a significant effect of inundation time was observed at T4 for this revetment type.



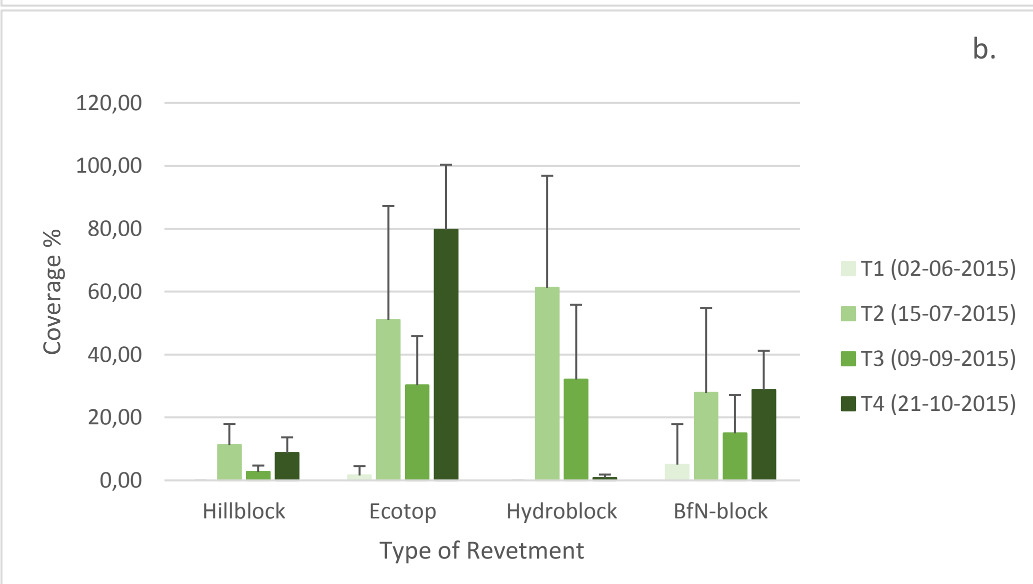


Figure 6. The average coverage rates of gutweed on the four different revetment groups on the four sampling dates. The error bars show the standard deviation between the replicate sections (n=3). a. -0.64m NAP; b. +0.68m NAP.

The coverage with *Fucus sp.* started to increase in a later stage than gutweed (Fig. 7). The first time significant coverage rates were observed was on T3, over three months after placement. at - 0.64 m NAP Hillblocks have the highest coverage rates. Also standard hydroblocks and BfN blocks a have relatively high coverage. On hydroblocks with ecotop almost no *Fucus sp.* is found. At T4 there was a significant effect of revetment type on *Fucus sp.* coverage at T4 (two-way non-parametric ANOVA, H = 46.94, df = 3, p = 0.00). The *Fucus sp.* coverage was not significantly dependent on the inundation time (two-way non-parametric ANOVA, H = 2.18, df = 1, p = 0.14). At T4, at+ 0.68m NAP the coverage rates of Hillblocks and hydroblocks are a lot lower than at -0.64m NAP, but for the BfN-blocks the opposite is observed. Therefore there is an interaction between revetment type and inundation time at this sampling date, which was significant (two-way non-parametric ANOVA, H = 17.10, df = 3, p = 0.001).

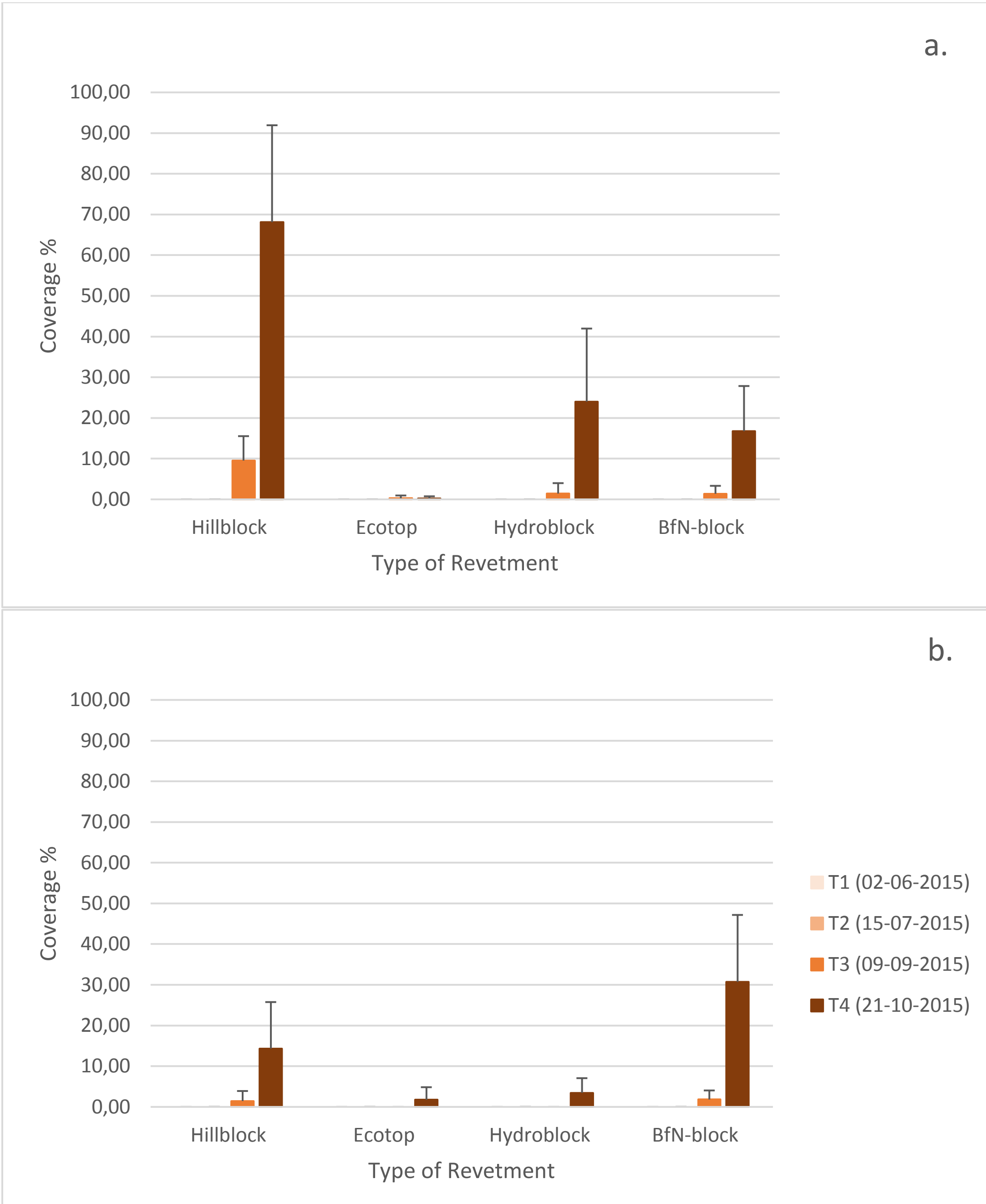


Figure 7. The average coverage rates of *Fucus* spec. on the four different revetment groups on the four sampling dates. The error bars show the standard deviation between the replicate sections (n=3). a. -0.64m NAP; b. +0.68m NAP.

As for *Fucus sp.*, significant coverage rates for *Porphyra purpurea* were only observed starting from T3. The coverage rate was highest on the hydroblock with ecotop but standard deviations were relatively high.At T4 there was a significant effect of revetment type on *Porphyra* coverage (two-way non-parametric ANOVA, H = 10.41, df = 3, p = 0.02). The *Porphyra* coverage was not significantly dependent on the inundation time (two-way non-parametric ANOVA, H = 2.24, df = 1, p = 0.13).

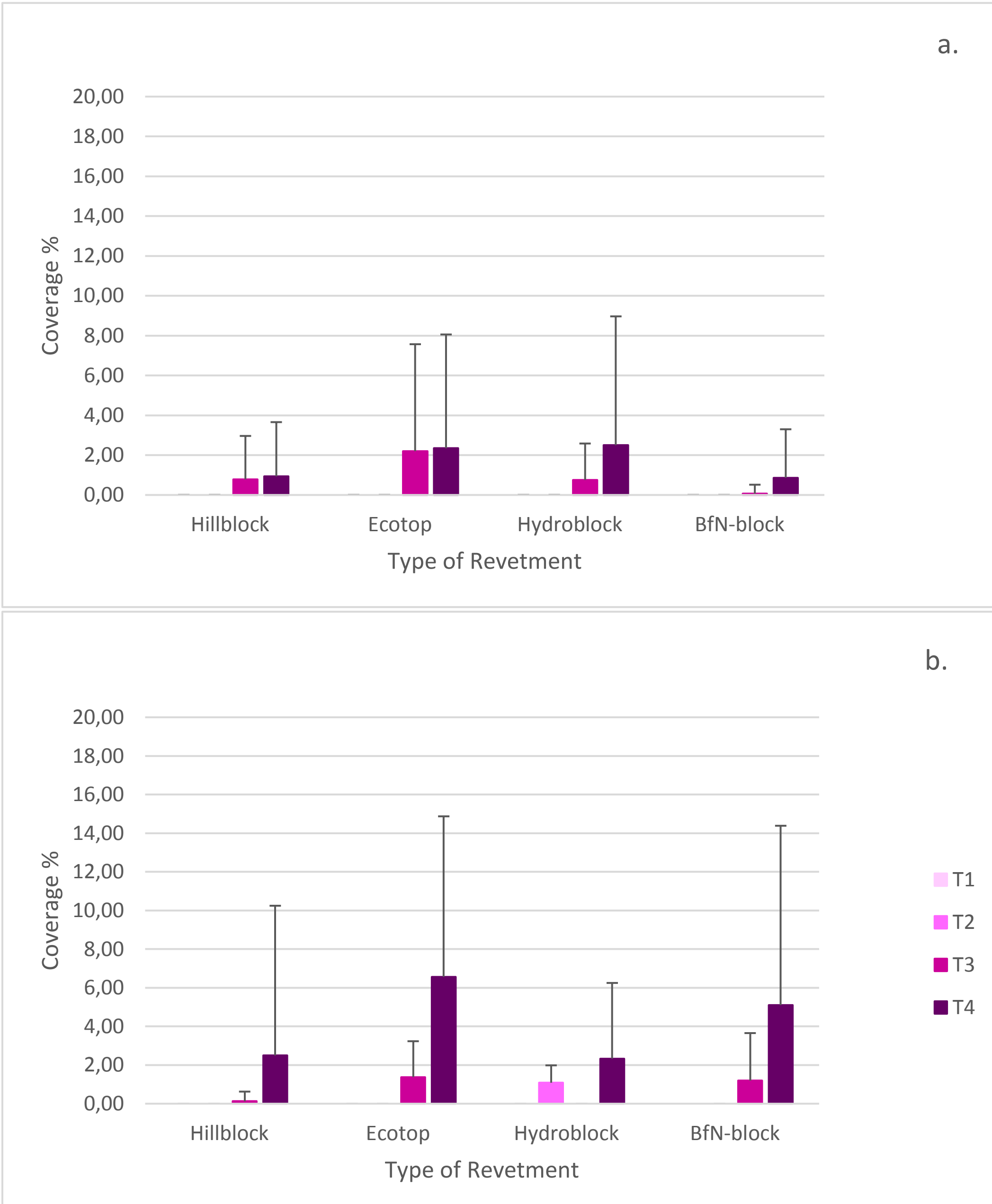


Figure 8. The average coverage rates of *Porphyra purpurea* on the four different revetment groups on the four sampling dates. The error bars show the standard deviation between the replicate sections (n=3). a. -0.64m NAP; b. +0.68m NAP.

Figure 9 provides a synthesis of the results presented above for the last sampling date, T4 (21 October 2015). At - 0.64 m NAP the total coverage rates of Hillblocks, hydroblocks with ecotop and BfN blocks are a lot higher of standard hydroblocks. The diversity of hydroblocks with ecotop is much less than on the other blocks since they are almost completely covered with gutweed whereas the other types of revetments are also covered with *Fucus spec*.. This difference in diversity was also observed at +0.68m NAP. The most remarkable difference between this height and the lower level is that at this level the coverage rate of Fucus spec. is higher for the BfN blocks, while it is considerably lower for the Hillblocks and the standard hydroblocks (as also shown in Fig. 7).

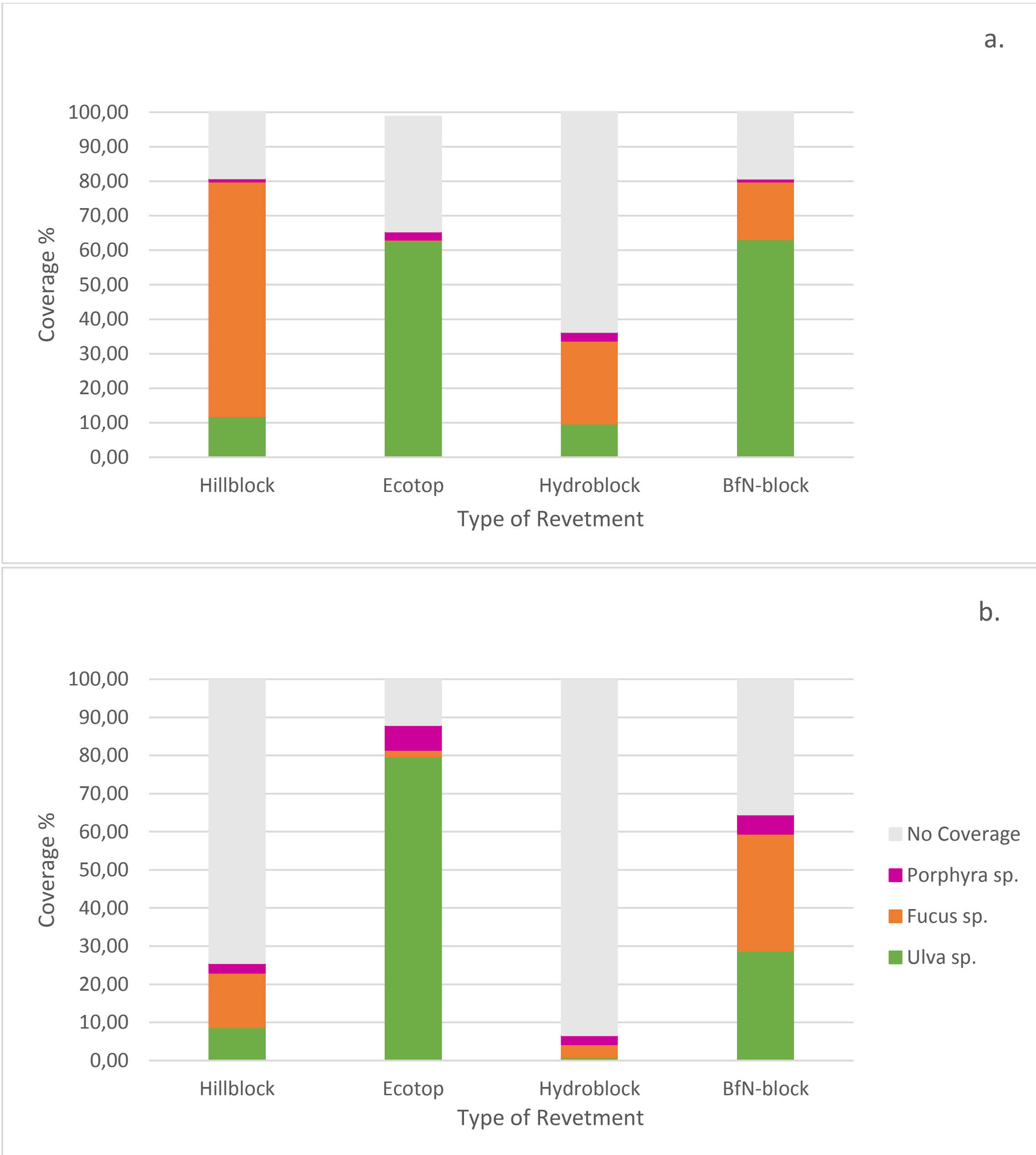


Figure 9. The average coverage rates of all seaweed species groups on the four different revetment groups on T4, 21 October 2015. a. -0.64m NAP; b. +0.68m NAP.

3.2 The seaweed coverage rates on the four BfN designs

The differences between the four different BfN designs are studied for T4 (Figure 10). In appendix 1, the results are shown for all sampling dates (not for *Porphyra*).

For gutweed, the overall pattern at T4 is that there is a significant effect of inundation time on coverage rate (two-way non-parametric ANOVA, H = 59.92, df = 1, p = 0.00) with higher coverage at -0.64m NAP). There is no effect of the different pit sizes and numbers on the gutweed coverage (two-way non-parametric ANOVA, H = 0.47, df = 3, p = 0,93). At the lowest inundation time (at + 0.68m NAP) some differences were discernable in gutweed coverage where coverage rate was highest on the design with one pit/hole. This pattern was consistent from T1 through T4.

The *Fucus* spec. coverage on the BfN designs was also significantly dependent on inundation time (two-way non-parametric ANOVA, H = 22.01, df = 1, p = 0.00) with higher coverage at +0.68m NAP. Again the coverage rate was very similar for the four designs (two-way non-parametric ANOVA, H = 1.68, df = 3, p = 0.64).

As for gutweed and *Fucus* spec. the coverage rate of *Porphyra purpurea* at T4 was significantly dependent on inundation time (two-way non-parametric ANOVA, H = 5.26, df = 1, p = 0.02) with a higher coverage at +0.68m NAP. The coverage rate of the designs was not significantly different (two-way non-parametric ANOVA, H = 7.47, df = 3, p = 0.058).

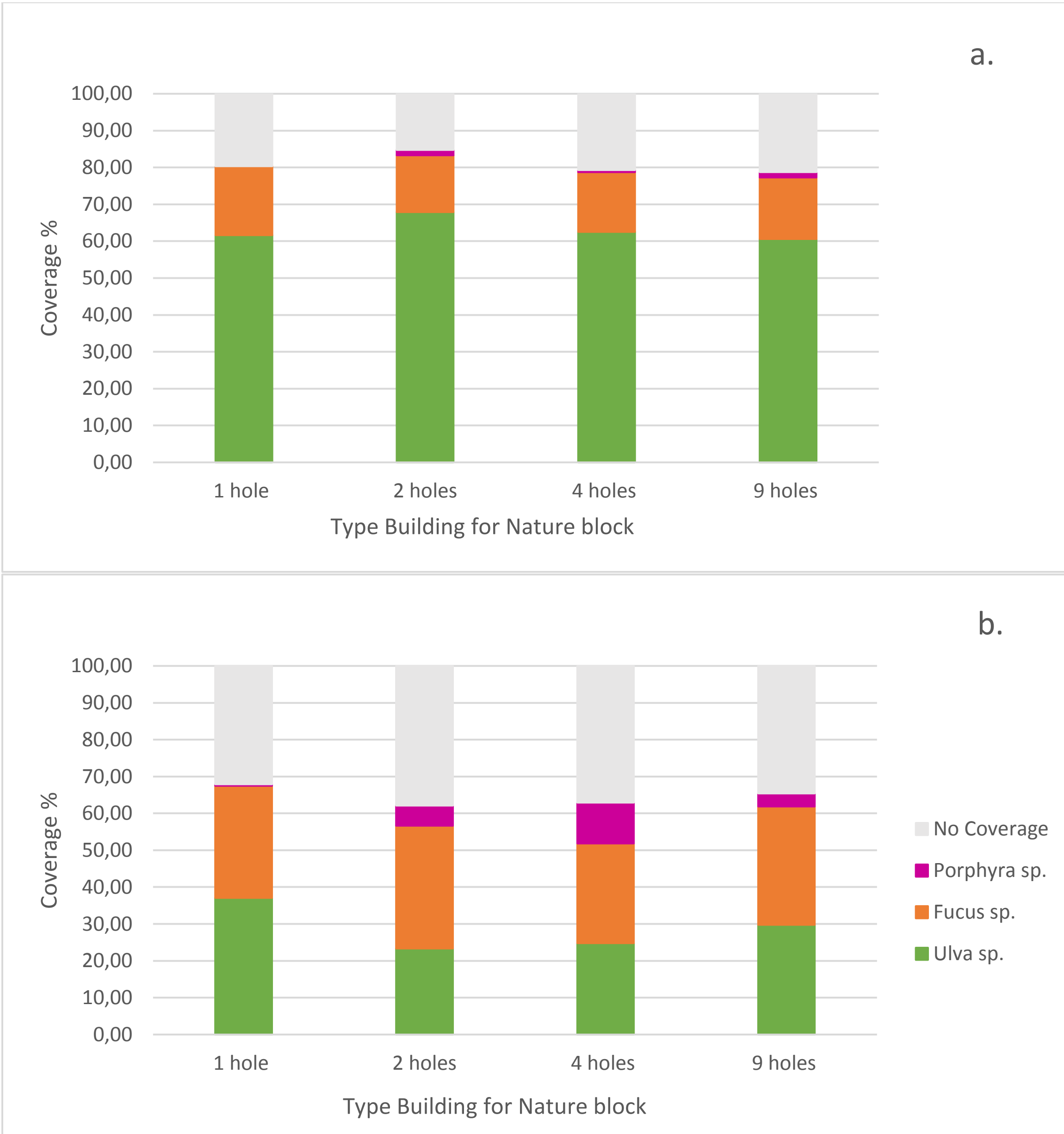
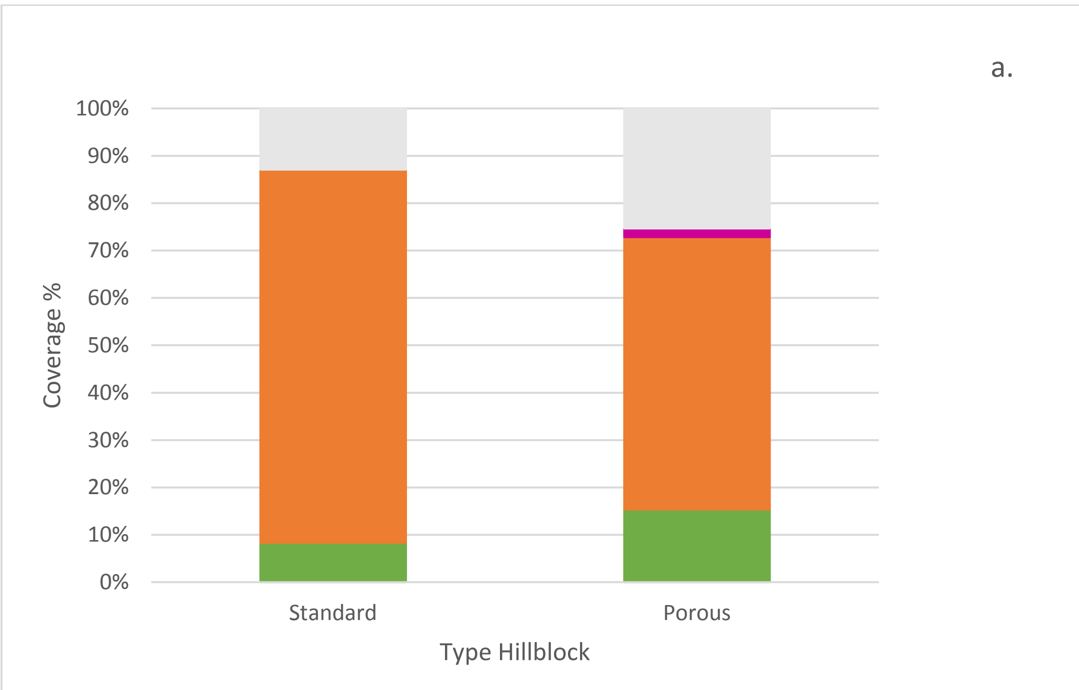


Figure 10. The average coverage rates of all seaweed species groups on the four BfN designs on T4, 21 October 2015. a. -0.64m NAP; b. +0.68m NAP.

3.3 The development of seaweed coverage on standard and porous Hillblocks

As for the BfN designs, the differences between the standard and porous Hillblocks are studied for T4 (Figure 11). In appendix 2, the results are shown for all sampling dates (not for *Porphyra*).

The gutweed coverage at T4 was not significantly dependent on the inundation time (two-way non-parametric ANOVA, H = 0.13, df = 1, p = 0.72). There was a minor yet significant effect of the different Hillblock-types on gutweed coverage (two-way non-parametric ANOVA, H = 5.51, df = 1, p = 0.02) with higher coverage rates on the porous type. The *Fucus* spec. coverage was significantly dependent on the inundation time (two-way non-parametric ANOVA, H = 19.91, df = 1, p = 0.00) with much higher coverage at -0.64m NAP. Coverage rate was not significantly different between Hillblock type (two-way non-parametric ANOVA, H = 1.60, df = 1, p = 0.21). The *Porphyra purpurea* coverage was also not significantly dependent on the inundation time (two-way non parametric ANOVA, H = 0.01, df = 1, p = 0.92). Also, there was no significant effect of the different Hillblock types (two-way non-parametric ANOVA, H = 0.90, df = 1, p = 0.34).



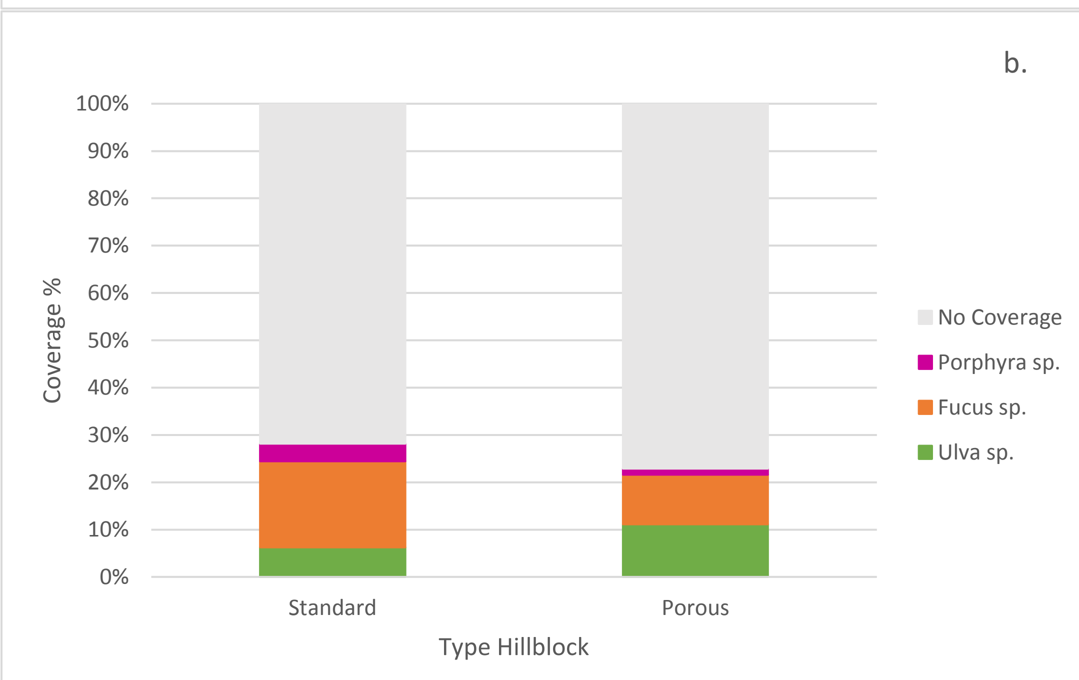


Figure 11. The average coverage rates of all seaweed species groups on standard and porous Hillblocks on T4, 21 October 2015. a. -0.64m NAP; b. +0.68m NAP.

4. Discussion

There is a major challenge to civil engineers in the coming decades to find new ways for the execution of dike reinforcements that conserve the ecological value. In this study the recolonization by seaweed of several innovative revetment types was studied and compared to more traditional types. In the intertidal zone seaweed coverage is key to the restoration of the ecosystem since it provides a habitat for many of the other species groups present including seasnails and crustaceans.

There were strong differences in the development of seaweed coverage at both 32,4% and 74,8 % inundation time between the different revetment types. Five months after the placement of the revetments, at the high inundation time the coverage rate was highest (>80%) on the BfN blocks and the Hill blocks, followed by the blocks with ecotop (65%). The standard blocks had the lowest coverage (35%). At the low inundation time the blocks with ecotop had the highest coverage (>80%), followed by the BfN blocks (65%), the Hill blocks (25%) and the standard hydroblocks (<10%). The coverage rate with gutweed was remarkably high on hydroblocks with ecotop. It is suggested that there is a competition for space between the pioneer species gutweed and the *Fucus* spec.. The ecotop seems to stimulate gutweed growth the most, possibly by their relatively high moisture retention capacity, reducing the space available for brown seaweeds to settle during the observation period. Since the climax state of the seaweed population on dikes is dominated by brown seaweeds (*Fucus vesiculosis* and *Fucus spiralis*) at the inundation times studied, the contribution of gutweed is expected to strongly decrease in later stages. Therefore, the ecotop appears to delay the development of the seaweed population to this climax state. The monitoring will be continued to test this hypothesis.

There were only minor differences between the four BfN-block designs. The total top surface area is exactly the same for each block so any effects of the holes on seaweed attachment can be attributed to the shape and not simply to an increase in surface area. In a study on these block designs on another site (NIOZ-Yerseke) the pits clearly affected seaweed growth on the blocks. Especially only the edges of the pits more growth of *Ulva spec.* was observed. In this study we also see a clear stimulating effect of the pits on the total coverage rate of the whole block as compared with standard blocks. The porous Hill block design was concluded to strongly stimulate seaweed growth in a study on a test site near Burghsluis, Schouwen-Duiveland (Didderen & Meijer, 2015). Here, we do not see pronounced effects of the porous blocks.

For *Porphyra purpurea*, another sampling design is needed since the individuals are distributed on the dike with relatively large spaces in between them so a larger area needs to be sampled. This could be done by the analysis of 1x1m pictures that were taken at the same time as the pictures of the blocks that were analysed in this report.

Year-to-year variation in abiotic factors like temperature and storminess/wave impact might significantly impact on species settlement and growth. Therefore, the results of the experiment might in part be the result of natural year-to-year variations. Still, the major differences that were observed between the revetment types studied are expected to relatively constant over the years, especially on sheltered locations. Another factor that might in part determine the outcome of the study is the timing of the construction of the dike, meaning that a dike that is constructed in early summer might have a considerable different evolution in seaweed coverage in the first years than one that is placed by for instance the end of summer when most settlement has already taken place.

In conclusion, at sheltered dikes, all revetments tested perform better than the standard hydroblocks in terms of seaweed cover. The results show that modifications of concrete block revetments can lead to significant changes in seaweed species abundance and recolonisation in the short-term. Alternative block designs could increase the pace at which a climax-state is reached which could be of pivotal importance to bird species which are dependent on this habitat for foraging.

Ongoing research includes a GIS-analysis of the coverage of different species groups over the full height range of the test dike, a detailed species composition analysis and biomass (wet weight and dry weight) assessments. These results will be published in later progress reports and the final report of the RAAKPRO Building for Nature project.

Acknowledgements

Next to the above-mentioned partners of the RAAK-PRO Building for Nature project many persons contributed to research presented in this progress report. HZ Water management students Dennis Dekker and Ger de Rooij performed a major part of the fieldwork and analysis. Samara Hutting (HZ) contributed to the processing of the results.

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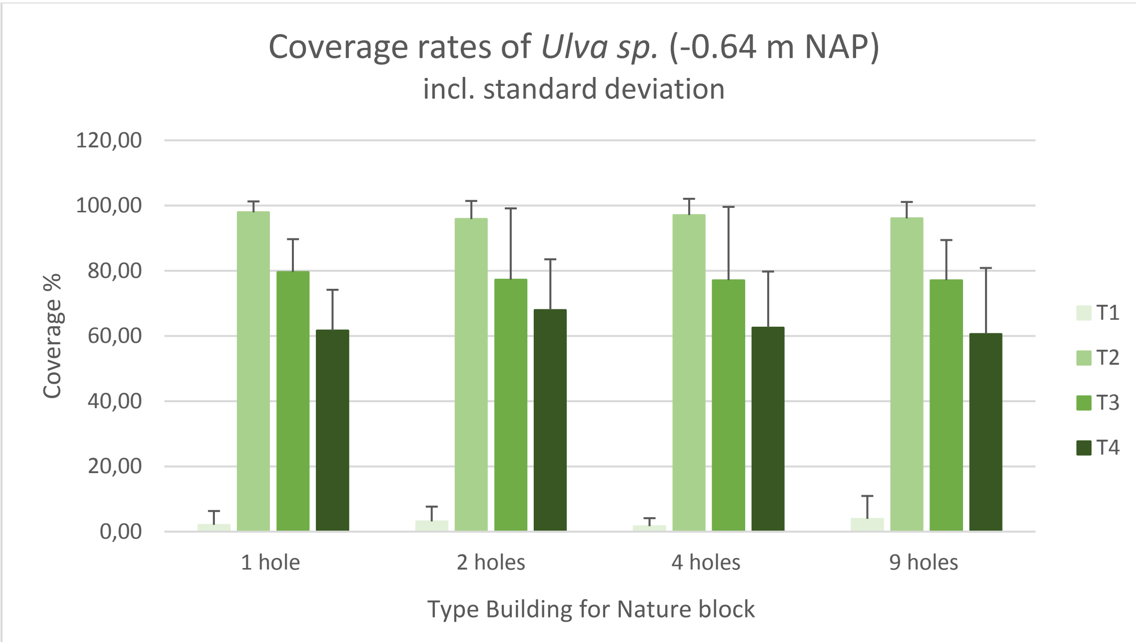
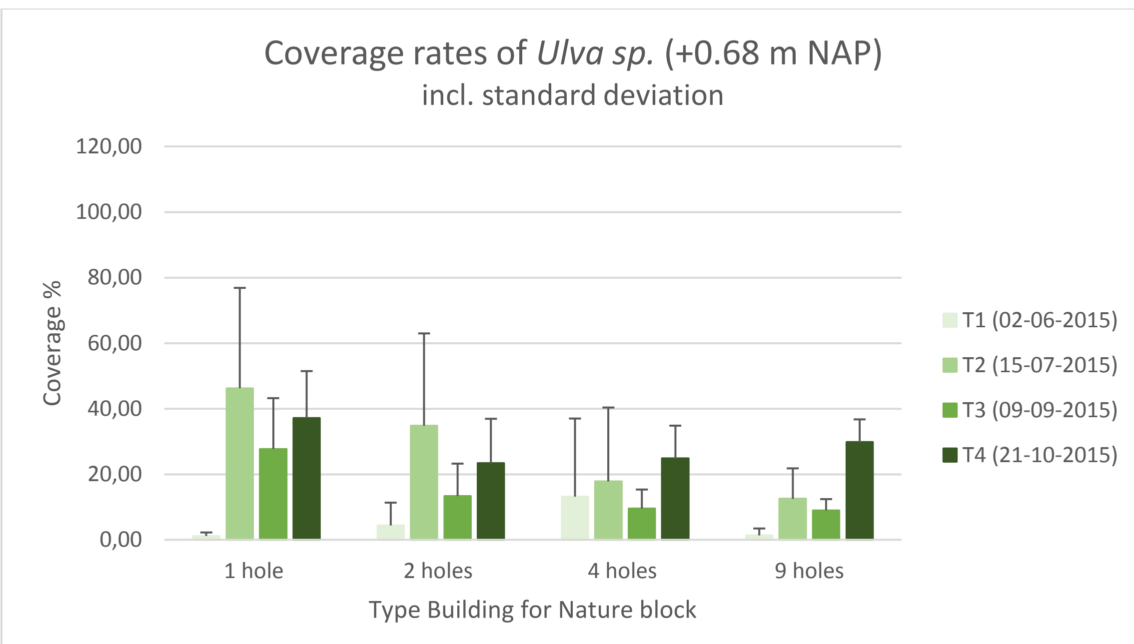
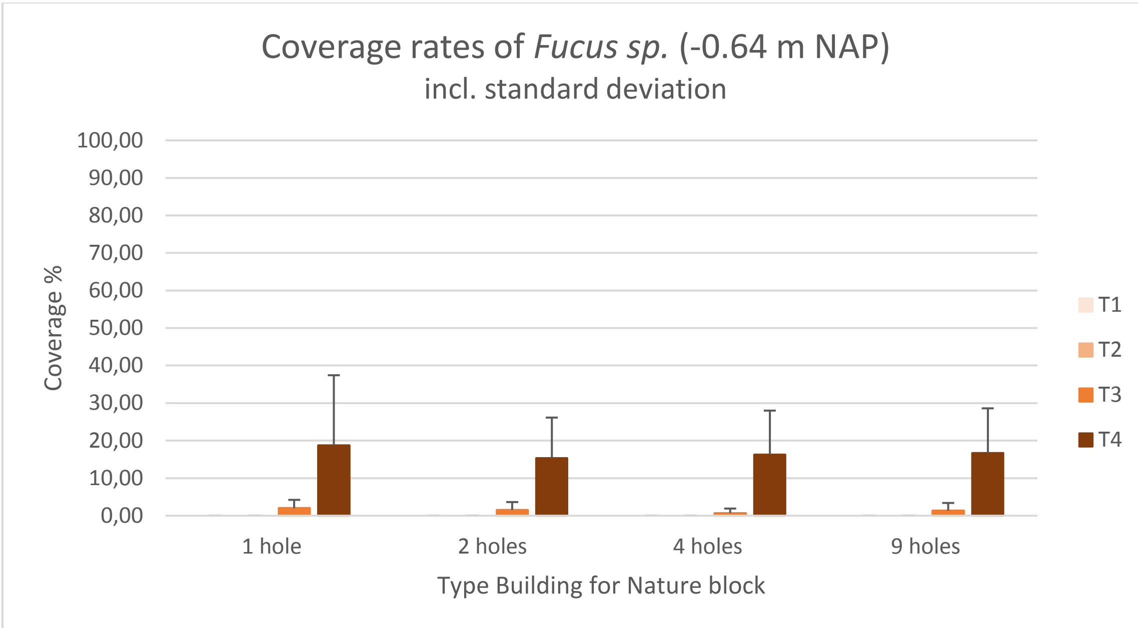
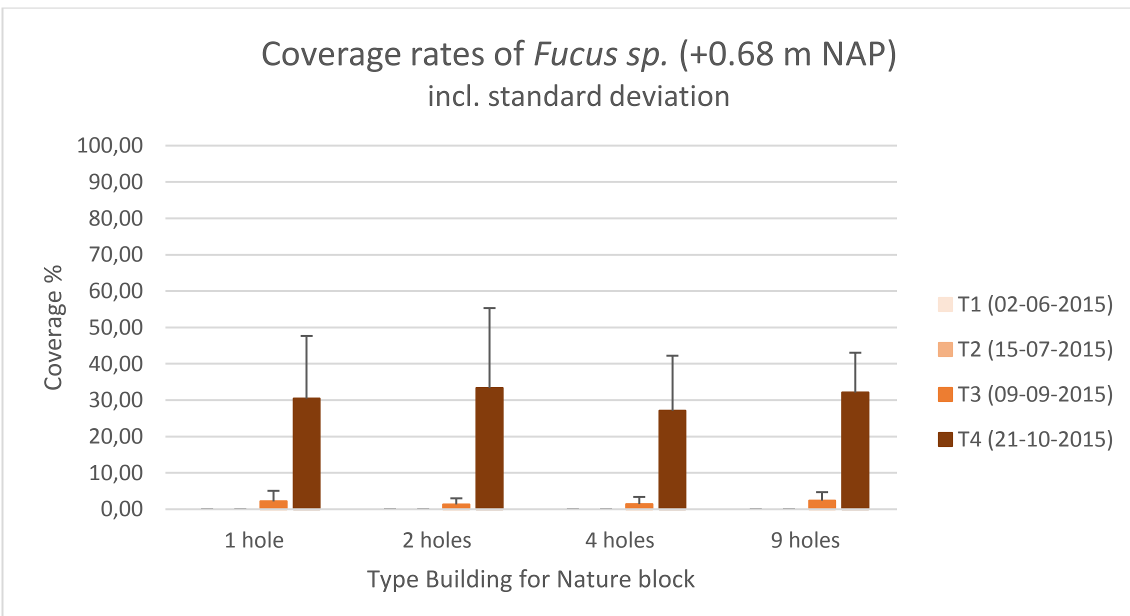
Appendix 1. Seaweed coverage rate development on the four different types of BfN blocks





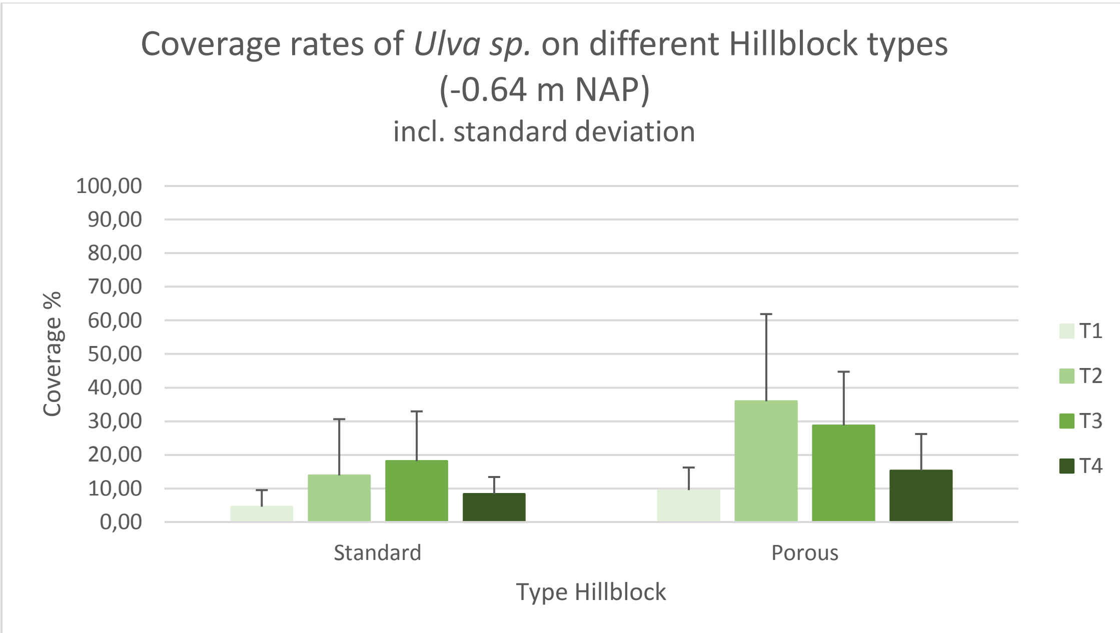


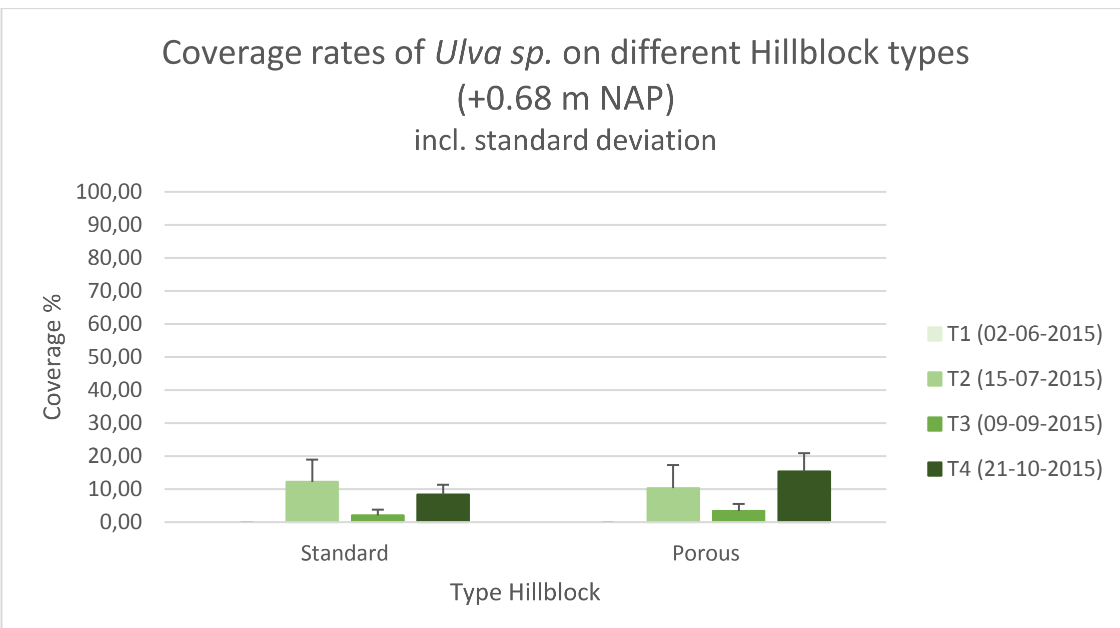
Coverage rates of *Fucus sp.* (-0.64 m NAP)
incl. standard deviation
100,00
90,00
80,00
70,00
60,00
50,00
40,00
30,00
20,00
10,00
0,00
Coverage %
1 hole
2 holes
4 holes
9 holes
Type Building for Nature block
T1
T2
T3
T4

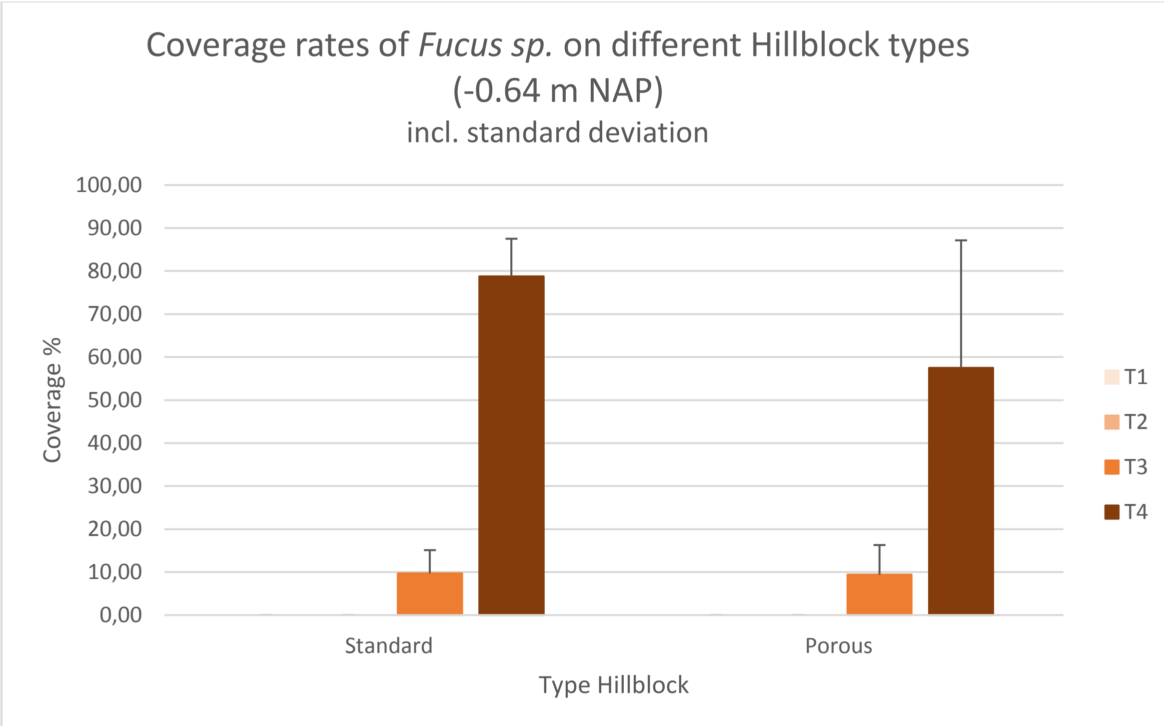


Coverage rates of *Fucus sp.* (+0.68 m NAP)
incl. standard deviation
100,00
90,00
80,00
70,00
60,00
50,00
40,00
30,00
20,00
10,00
0,00
Coverage %
1 hole
2 holes
4 holes
9 holes
Type Building for Nature block
T1 (02-06-2015)
T2 (15-07-2015)
T3 (09-09-2015)
T4 (21-10-2015)

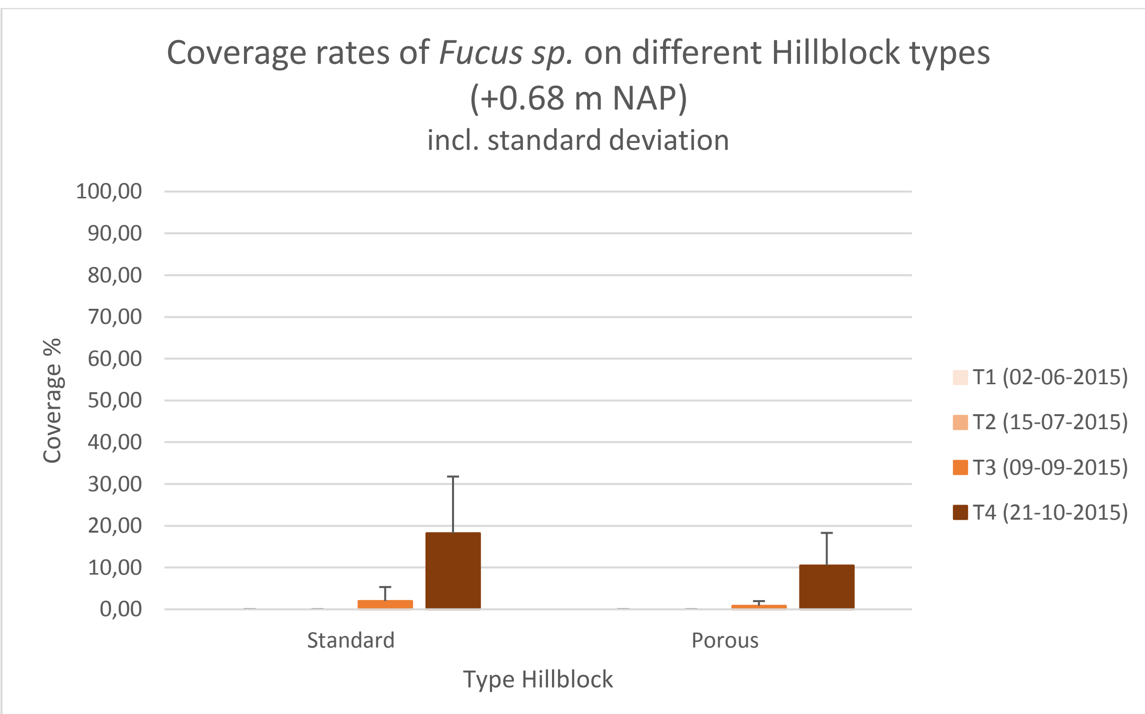
Appendix 2. Seaweed coverage rate development on standard and porous Hillblocks.







Coverage rates of *Fucus sp.* on different Hillblock types
(-0.64 m NAP)
incl. standard deviation
100,00
90,00
80,00
70,00
60,00
50,00
40,00
30,00
20,00
10,00
0,00
Coverage %
Standard
Porous
Type Hillblock
T1
T2
T3
T4



Coverage rates of *Fucus sp.* on different Hillblock types
(+0.68 m NAP)
incl. standard deviation
100,00
90,00
80,00
70,00
60,00
50,00
40,00
30,00
20,00
10,00
0,00
Coverage %
Standard
Porous
Type Hillblock
T1 (02-06-2015)
T2 (15-07-2015)
T3 (09-09-2015)
T4 (21-10-2015)