The development of fouling communities on an artificial reef off Nienhagen

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Abstract

Under project management by the Institute for Fishery of the State Research Establishment for Agriculture and Fishery of Mecklenburg-Western Pomerania, two artificial reefs were constructed off the coast of Mecklenburg. The development of fauna and flora, particularly their influence on the recruitment of cod, is scientifically accompanied by a compound of various research institutes (see www.riff-nienhagen.de). The results shown here refer to the colonization of the structures by invertebrates and algae on the structures in the artificial reef off Nienhagen and their basis as a food source for the fish population. A summary of the most important results are given for the accompanying fouling monitoring programme, which has been running for seven years.

Keywords

artificial reef, fouling, invertebrates, algae, cod recruitment

Introduction

The Baltic Sea fishery (including the western coastal region of Mecklenburg-Western Pomerania) has shown a decline in stock over recent years, despite numerous measures to promote growth. These measures range from conventional management, such as implementing minimum landing and mesh sizes, to restricting fishing activities during certain time periods and introducing no take zones.

Within the reef project, researchers were looking for alternatives for stabilizing the economic fish stocks. To this end, an extensive artificial underwater habitat was created off the coast of Nienhagen to act as a recruitment, growth and resting zone for the fish species which are found in the region. A survey of the reef will determine whether an increase in the fishery value of this area has been achieved.

The aim of the sub-project “Monitoring of the colonization ecology of various reef materials“ was firstly to describe within an accompanying monitoring programme the colonization and development of fouling communities taking place on the structures in the reef (composition of species, colonization times, growth dynamics). Secondly, it was a matter of understanding this process more exactly by carrying out specific individual tests and drawing conclusions from that for an optimum construction of artificial reefs from a fisheries perspective. These results form the basis of another publication and are not included here.

Material and Methods

The artificial reef is situated on German Baltic coast *ca.* 8 km west of Warnemünde and north of the Baltic seaside resort Nienhagen at a distance of *ca.* 1.5 km from shore at a water depth of 11 to 12 m (Fig.1).

Figure1: Location of the artificial reef Nienhagen.

Construction of the reef was initiated in 2002 with completion of the basic structure by 2003. In the following years, smaller repair work was carried out and the structures were supplemented by special elements for growing algae and mussels. At present the reef at Nienhagen consists of *ca.* 1,400 concrete elements (tetrapods, rings, reef cones, algae tables) and *ca.* 2,500 tonnes of natural stone covering an area of approximately 50,000 m² (Fig.2).

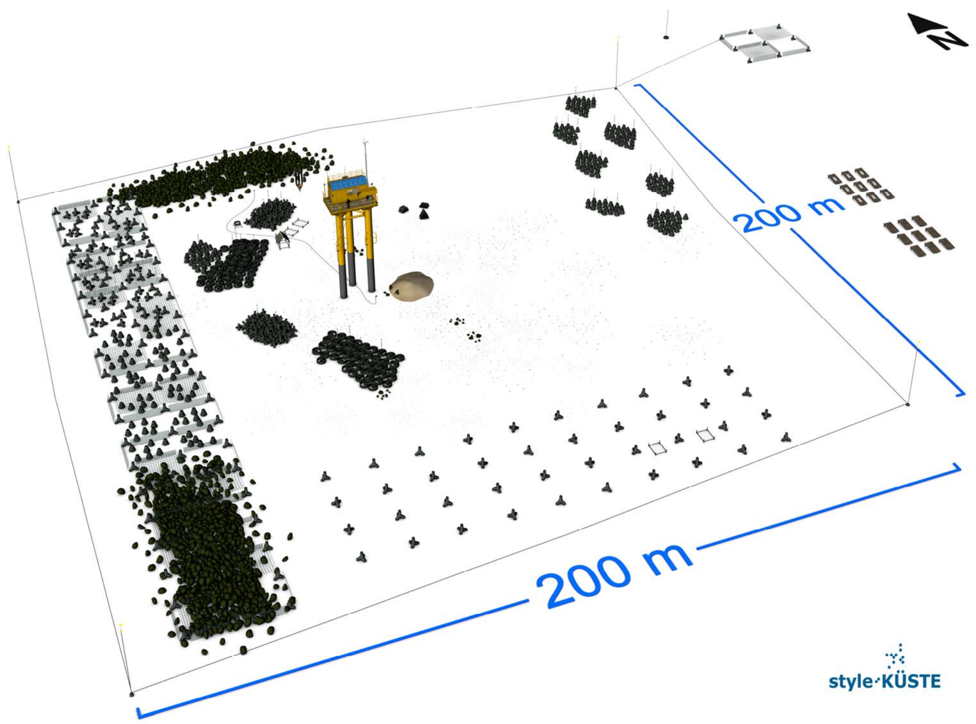

Figure 2: Arrangement of the structural elements on the artificial reef Nienhagen (style Küste).

By integrating the artificial structures *ca.* 18,000 m² of additional hard soil substratum was formed, creating a fouling area. During the period from 2004 until 2006 monitoring activities were carried out at monthly intervals; from 2007 onward, the intervals were extended by three months.

Photography

In order to describe the colonisation of the newly deployed concrete bodies, two representative areas were selected from both the upper and lower third of the reef respectively. Care was taken to include the four typical elemental structures present on the reef (concrete rings, small and large tetrapods and frustums of a cone). The orientation of bolts on the reef provided a reference point from which the diver could accurately place a quadrat (measuring 20 cm × 25 cm), thus allowing images to be taken in exactly the same place every time. Photographs were taken monthly at these locations.

Evaluation of images encompassed species identification and area percentage coverage. For the purpose of this assessment, the following increments were assigned to degrees of coverage: 0 %, 0 – 5 %, 5 – 25 %, 26 – 50 %, 50 – 75 %, and 75 – 100 %.

Larger and subsequently more visible species such as barnacles and starfish could be counted on the screen, thus allowing assessments of abundance (individuals/area unit). Photographic techniques allowed for non-intrusive observation of succession in all eight areas sampled.

Scratch samples

As smaller organisms were not visible on photographs, scratch samples were taken directly beside the quadrats at half-yearly intervals, allowing exact description of the fouling composition. This consisted of removing an area of 225 cm² (15 cm × 15 cm) using a hand pile scraper and transferring the samples into a sealable bag. The mesh size of the net bag attached to the scraper was 0.5 mm so that smaller vagile forms could also be collected. Besides classification of species, evaluation in the laboratory also included the determination of abundance and the biomass of the individual species (wet mass WM, dry mass DM, ash-free dry mass AFDM).

Long-term concrete panels

To quantify fouling on concrete areas, a quadrat composed of seawater-resistant aluminium and containing 120 concrete test panels (9 cm × 24 cm) was placed within the reef area. At monthly intervals, two parallel panels were removed and the development of fouling was assessed.

Short-term panels made of acrylic glass

To determine both successional and seasonal influences on invertebrate and algal settlement, rough acrylic glass panels (9 cm × 24 cm) were placed on the existing framework and were exposed for one month before being replaced by fresh panels. Attached to these panels were miniature (microscope slide-sized) panels of the same material, allowing for viewing under the binocular and microscope. For the majority of cases, the algae and invertebrates were at advanced stages of development, allowing for classification at the species level. The remaining samples at early stages of development were allowed to mature in the aquarium before identification.

Test panels made of different materials

Using the existing framework, panels composed from various materials were exposed for eight-month periods (April – November) in order to determine fouling intensity. During the first year of testing, these materials included different concrete types used in building the reef *i.e.*, glass-fibre reinforced plastics, granite and marble stone material, and oak. Similarly, during the second year, acrylic glass, stainless steel and rubber larch were used; and in the third year, simple flooring plaster was compared with the special concrete types used on the reef.

Net material

In order to increase habitat diversity and determine whether flexible fouling materials would be useful for this experiment, wide mesh nets were deployed at the reef site in November 2003. These nets were stretched vertically and horizontally on 6 t-tetrapods. Sample extraction proceeded by firstly photographing the sample site and then by removing a length of the material (5 cm × 5 cm). Samples were then bagged and examined in the laboratory, with species composition and total biomass (ww/dw) recorded.

Natural stones

In order to describe fouling of hard soil communities, sampling of natural substrata took place at both the reef and a control reference area off Börgerende (both at the same depth). As both regions contained large single stones, fouled stones of roughly the same size were selected from both stations on a monthly basis. These were sealed in sample bags, taken back to the laboratory for scraping and analysed using the previously stated methodology.

Benthos samples

Benthos samples were retrieved from three sandy areas, using a borer (acrylic glass, diameter of 11.5 cm), with samples being placed directly into a sealable bag. Live samples were then analysed (mesh-size of 0.3 mm) in the laboratory. In addition, representative images corresponding to a quadrat measuring 40 cm × 60 cm were taken of both the reference area and the reef area.

From these images, statements on the abundance of starfish from these substrata could be derived.

Video equipment

Cameras were placed on the reef and delivered a continuous live stream between the months of May and December. Due to the erection of the working platform on the reef in 2010, it was possible to stream these images all year round. With the aid of these cameras, and supplemented with photographs taken by divers, crab and shrimp behaviour could be monitored. Another method involved placing bait in front of a “bait camera”. As soon as the diver left fish, starfish, crabs and shrimps were recorded approaching the bait. Video equipment was also used to document the development of the extended reef in 2005. A new pile of stones extending in a north-south direction was marked by a line, with video footage (SONY DCR-HC39E video camera) being recorded along its length during checking dates.

Results

Succession of colonization on the artificial structures

Seasonality of the release of larvae

Almost all fouling organisms have planktonic larvae, the release and maturity of which are subject to a strong seasonality in temperate latitudes. This seasonality is a crucial determining factor in the first colonization phase. The colonization times of the most important fouling organisms, including algae, were established by following a variety of methods. These include underwater photography, scratch sampling, removal of long term experimental slabs and, primarily, the removal of short-term experimental slabs (which underwent monthly changes from 2004-2006). Table 1 contains a compilation of the results from the years 2004-2006. With regards to the colonization of larvae/spurs in this location, the winter months (December-February) largely remained uneventful, with the exception of a few ciliates and first colonizations by hydroid polyps (*Hartlaubella gelantinosa*).
The spring months (March–May) were characterized by the attachment and fast development of the hydroid polyp *Hartlaubella gelantinosa* and its predators, namely the feather gill snail *Facelina bostoniensis*. During the warmer years, first attachments of barnacles (*Balanus improvisus*) and the edible mussels (*Mytilus edulis*) could be observed in May, sometimes earlier. However, the greatest larval abundance of the two species mentioned (and also the attachment of red algae spores) was observed in the summer months until August. Often, a notable second peak in colonisation was seen to occur for both the barnacles and edible mussels in September. In July 2006 a large settlement of starfish larvae (*Asterias rubens,* 4,800 ind./m²) was recorded for the first time. Late autumn until the end of November was characterised by the colonization and development of the two most frequent genera of red algae, *Polysiphonia* and *Calithamnion*.

Table 1: Attachment times of the most important fouling organisms on the basis of the values from 2004-2006.

	Jan	Feb	März	April	Mai	Juni	Juli	Aug	Sept	Okt	Nov	Dez
Ciliaten (Wimperntierchen)	x	x	xxx	xxx	xx	x	x	x				
Rhodophyceae (Rotalgen)												
Polysiphonia nigrescens						x	x	x	x	x	x	
Callithamnion corymbosum			x			xx	x	x	x	xx	x	
Ceramium rubrum						xx			x			
Hydrozoa (Hohltiere)												
Aurelia aurita (Polyp)							x	xx	x			
Bogainvillia ramosa						x				x		
Coryne tubulosa						x				x		
Hartlaubella gelantinosa	x		xx	xxx	xx	x				xx	x	
Mollusca (Weichtiere)												
Facelina bostoniensis				xx	xx							
Mytilus edulis		x	x	x	x	x	xxx	x	xx	x		
Polychaeta (Vielborster)												
Polydora ciliata					x	x	x	x	xx			
Crustacea (Krebse)												
Balanus improvisus					x	xxx	x	xx	xx		x	
Corophium insidiosum (Röhren)					x	xx	x					
Echinodermata (Stachelhäuter)												
Asterias rubens (Larvenansatz)						xx	xx	x				

Ansatzdichte	gering	mittel	stark
	x	xx	xxx

development of the two most frequent genera of red algae, *Polysiphonia* and *Calithamnion*.

Development of fouling on the concrete structures

The structures were first lowered into the water in September 2003 during the "autumn phase" of larval release. After four weeks macroscopic organisms, mainly the starfish (*Asterias rubens*) and sporadically the hydroid polyps (*Bougainvillea ramosa*) could be recognized on the check surfaces. Traces of the small red algae species, *Callithamnion corymbosum*, were first recognised from photographs and were later confirmed during the evaluation of slabs. After an eight week period the surfaces showed a dramatic transformation, with almost a complete covering by a brown detrital layer. Upon closer examination, this layer was shown to predominantly consist of mud tubes made by the small polychaeta, *Polydora ciliate*.

In January 2004 the abundance of *Polydora ciliata* determined by the slab tests was estimated to be 55,000 ind./m². This number decreased during the following months, but remained at more than 10,000 ind./m² for a long time. After two months the first edible mussels, barnacles and the polyp stages of the ear jellyfish, *Aurelia aurita*¸ began to appear. However, due to their small sizes, these were not immediately apparent from photographs.

In November 2003 the number of starfish was between 40 and 60 ind./m² (depending on the surface type). In the first winter and in early spring of 2004, the degree of coverage by the hydroid polyp, *Hartlaubella gelantinosa*, increased. The barnacles (*Balanus improvisus*) originating from late autumn largely disappeared under the mud tubes of the *Polydora ciliate*. As a result, they were scarcely recognised on photos yet they were still present. During the months April and May 2004 the share of filamentous diatoms (mostly of the genus *Amphipleura*) forming brown hoses increased, whilst hydroid polyps was slowly decreased due to predation from feather gill snails (*Facelina bostoniensis*).

During the course of development, there was a flux between new species arriving and disappearing. As of December 2010, a total of 57 species of invertebrates and 17 species of algae have been cumulatively found on these structures. The long-term development of species diversity and biomass on the artificial substrata was best demonstrated by the results obtained from the concrete slabs exposed in the slab framework. Variation between individual surfaces still reflected the fouling situation as a whole.

Reflected general

Fig.3 details the number of species (subdivided between invertebrates and macroalgae) on the long-term slabs from 2004 until 2010. The mean number of invertebrate species found per slab slightly increased during the first two years, before levelling out between a range of 8 and 15 species in the following years. This pattern is mirrored in the algae, albeit with a slight increase of species still being observed in 2009 and 2010.

Mytilus communities developed everywhere, with accessory species such as the barnacle *Balanus improvises*; the crustacea *Microdeutopus gryllothalpa*, *Gammarus salinus*, *Melita pilosa* and *Corophium insidiosum*; the polychaeta *Polydora ciliata*, *Neanthes succinea* and *Bylgides sarsi*; and the bryozoa *Electra crustulenta* and *Alcynidium gelantinosum* also showing high abundance. The large quantity of mussels supported its main predator, the starfish *Asterias rubens.*

Among the 17 species of algae found on the long-term slabs and from scratch samples in 2010, *Polysiphonia nigrescens* and *P. violacea*, *Delesseria sanuinea*, *Phycodrys rubens, Callithamnion corymbosum* and *Ectocarpus siliculosus* were the most abundant.

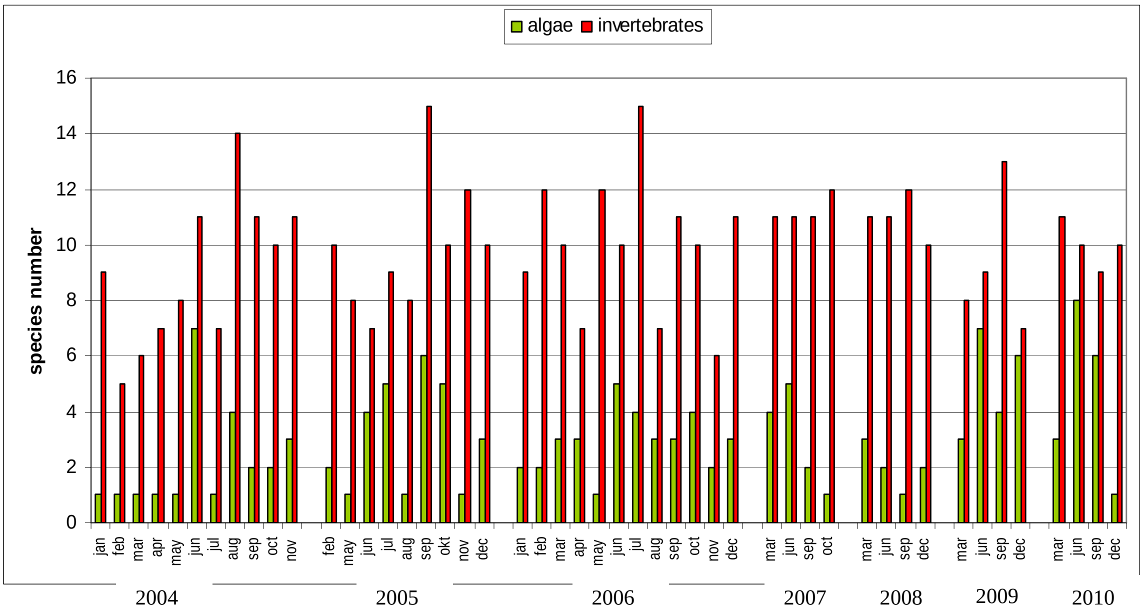

Figure 3: Development of the number of species of invertebrates and macroalgae on the long-term panels since beginning of exposure.

Fig.4 shows the development of the total biomass (dry mass in g/m²) taken from the long-term panels. As expected the values increased with time, but there was always a distinct rhythmicity seen during the course of the year.

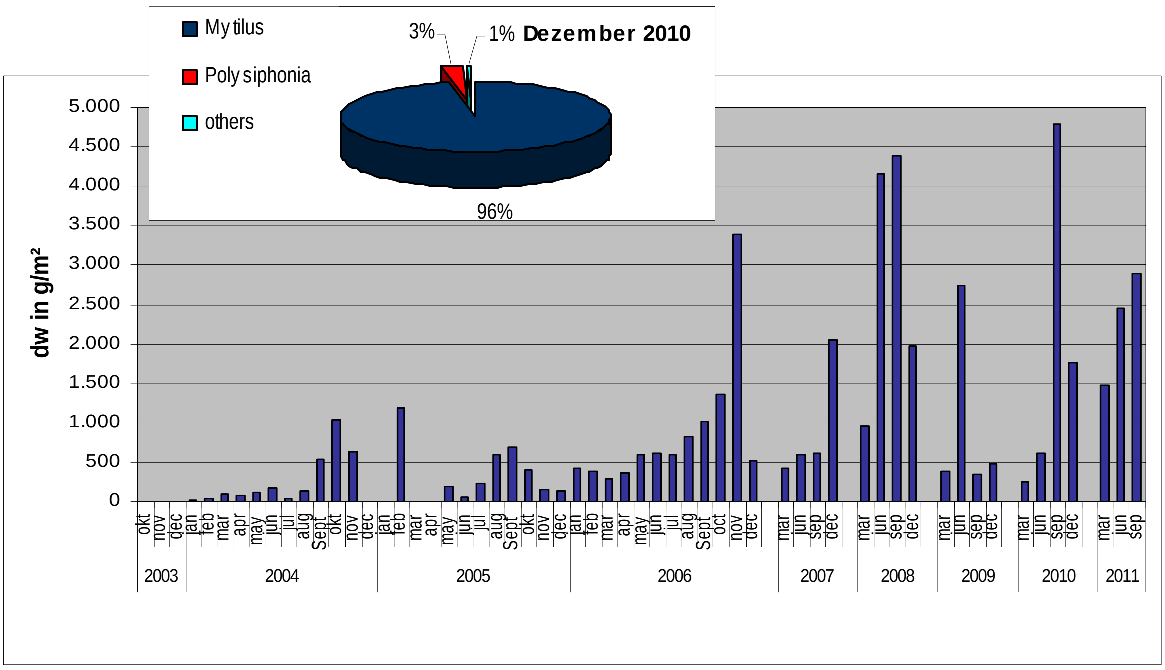

Figure 4: Development of the total biomass on long-term panels and percentage fouling composition in December 2010.

Biomass levels reached their maximum in late autumn, followed by a strong decline during the winter period to levels less than half seen earlier in the autumn. In December 2010 the dry mass was recorded as 1.757 g/m² and consisted of *Mytilus edulis* (96 %) and the red alga *Polysiphonia urceolacea* (3 %), with the remaining 1 % (termed “Others”) distributed among

nine species of invertebrates. Apart from clear seasonal fluctuations, a stationary state regarding the maximum biomass values per unit area has yet to be achieved.
The results of the monitoring investigations showed a clear influence of the shapes of the structural elements (tetrapods, well ring, reef cone) and the spatial position on the structure (close to the bottom, inside, outside) on the quality and quantity of colonization.
The results shown in fig.5 (the evaluation of the scratching samples taken at half-yearly intervals) illustrate the development of total biomass on the eight checking surfaces, as well as giving an impression of the variance range of the colonization intensity found on the reef.
Two groups can be clearly distinguished: on surfaces 2 (well ring, top), 6 (6 t-tetrapod, top) and 8 (stack of tetrapods, top) communities were characterised by dense *Mytilus* growth constituting biomass values above 4,000 g/m², with the remaining groups from five checking surfaces with biomass values below 800 g/m².

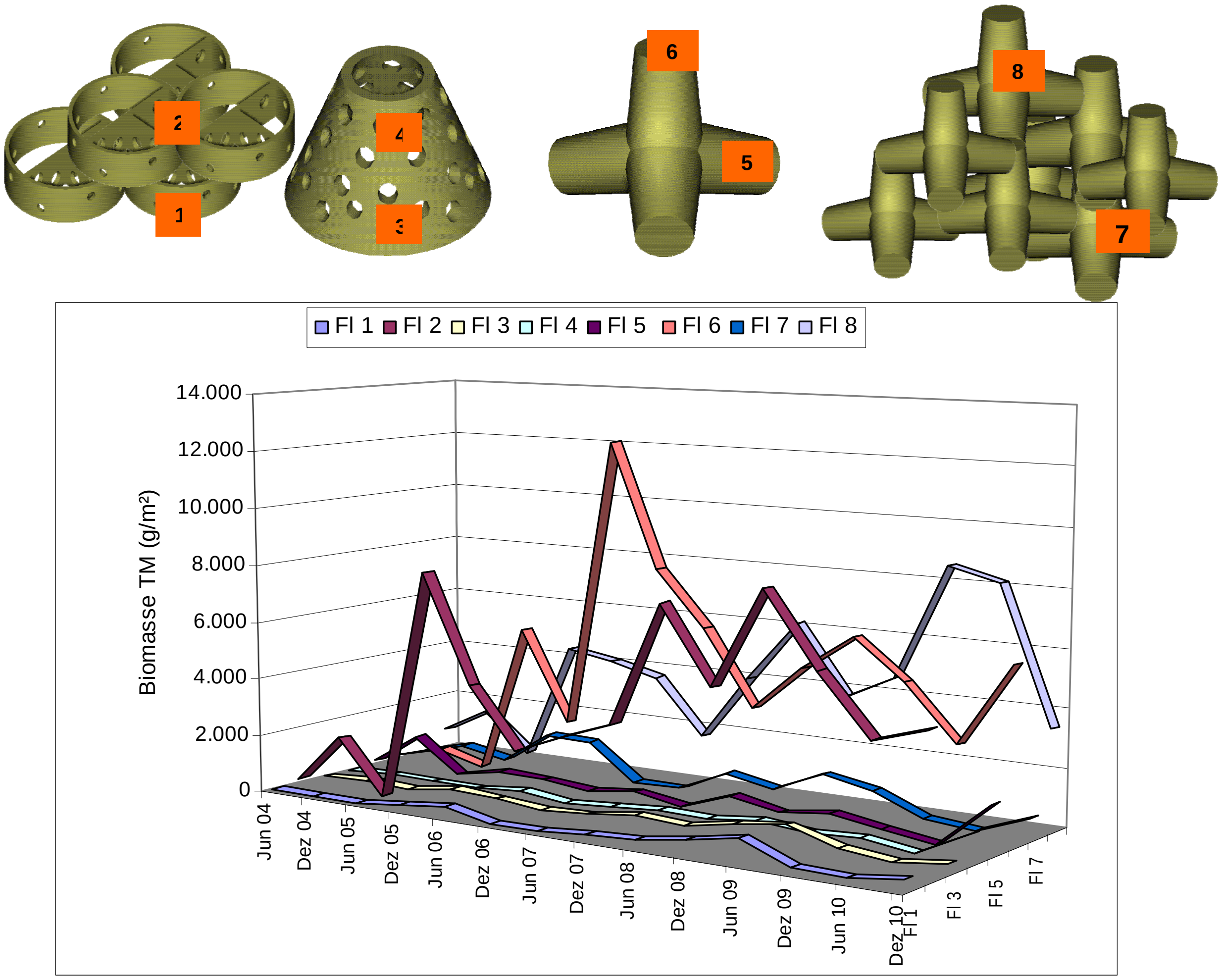

Figure 5: Development of the total biomass at 8 check points since 2004.

Structure form had no influence on colonization. It is notable that surfaces with higher biomasses were situated relatively closer to the surface, away from the sea floor. All surface results showed an oscillation between the low June and higher December values. During the course of the investigation it became apparent that the reason for both the strong seasonal oscillations (which were unexpected due to the predominance of the edible mussel communities) and the clear distinctions regarding the exposure height of the surfaces were most likely due to starfish predation impacting on mussel biomass values.

Fig.6 contains a compilation of the annual abundance mean values of *Asterias rubens* from 2004 until 2010, which were obtained by various investigation methods (photography of surfaces, long-term slabs, analysis of individual stones). Abundance values were highest on natural stones, whereas sandy surfaces were scarcely frequented. On the concrete elements starfish were represented with medium abundances, with typical values above 100 ind./m².

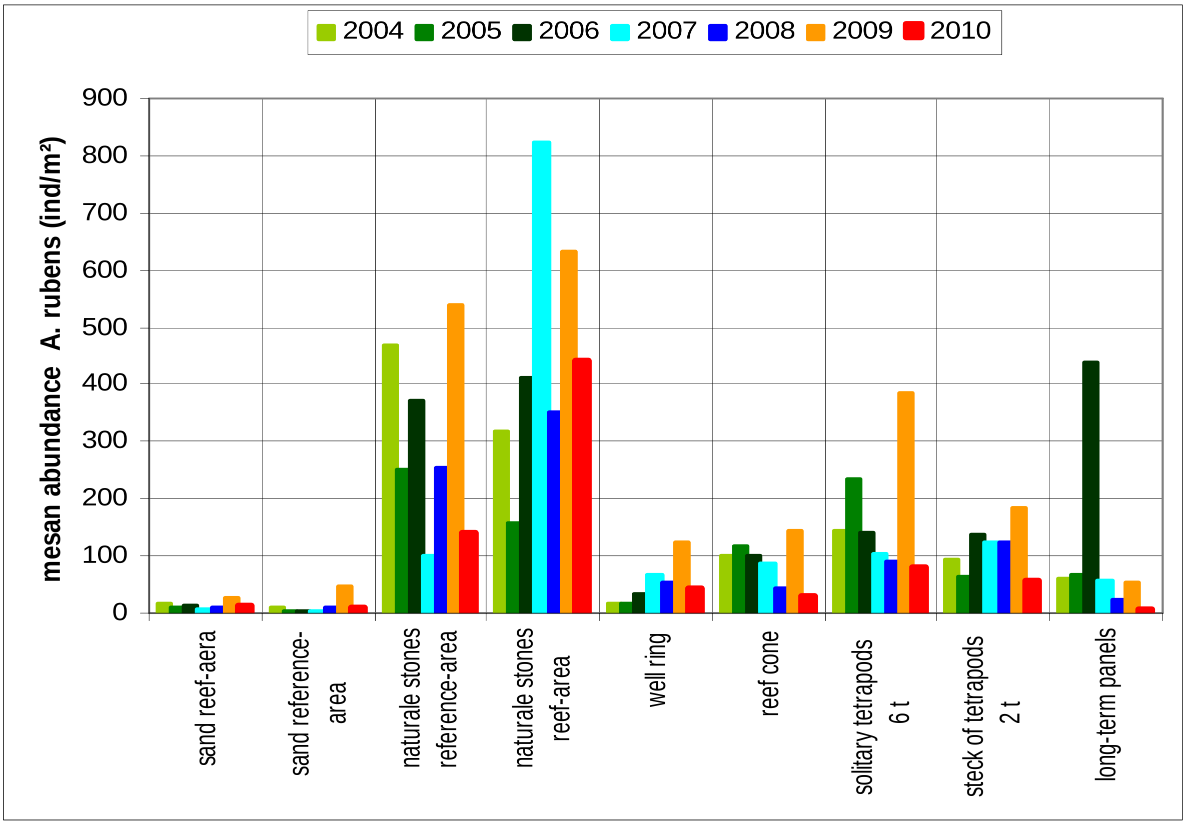

Figure 6: Mean abundance of starfish (ind./m²) on sand, natural stones and various structural elements from 2004 until 2010

Comparisons between the years (Fig.7) infer no general pattern. There were years with both high (2006 and 2009) and relatively low starfish abundances. In summer 2010 the starfish population totally collapsed both on the artificial reef and at the reference station situated *ca.* 3 km to the west. It was not until December that an individual little starfish was found again on a stone from the reference area. From the diagram on the top in fig. 6 the abrupt collapse of the starfish population in summer 2010 can be clearly seen (see also the diagram on top in fig.7).

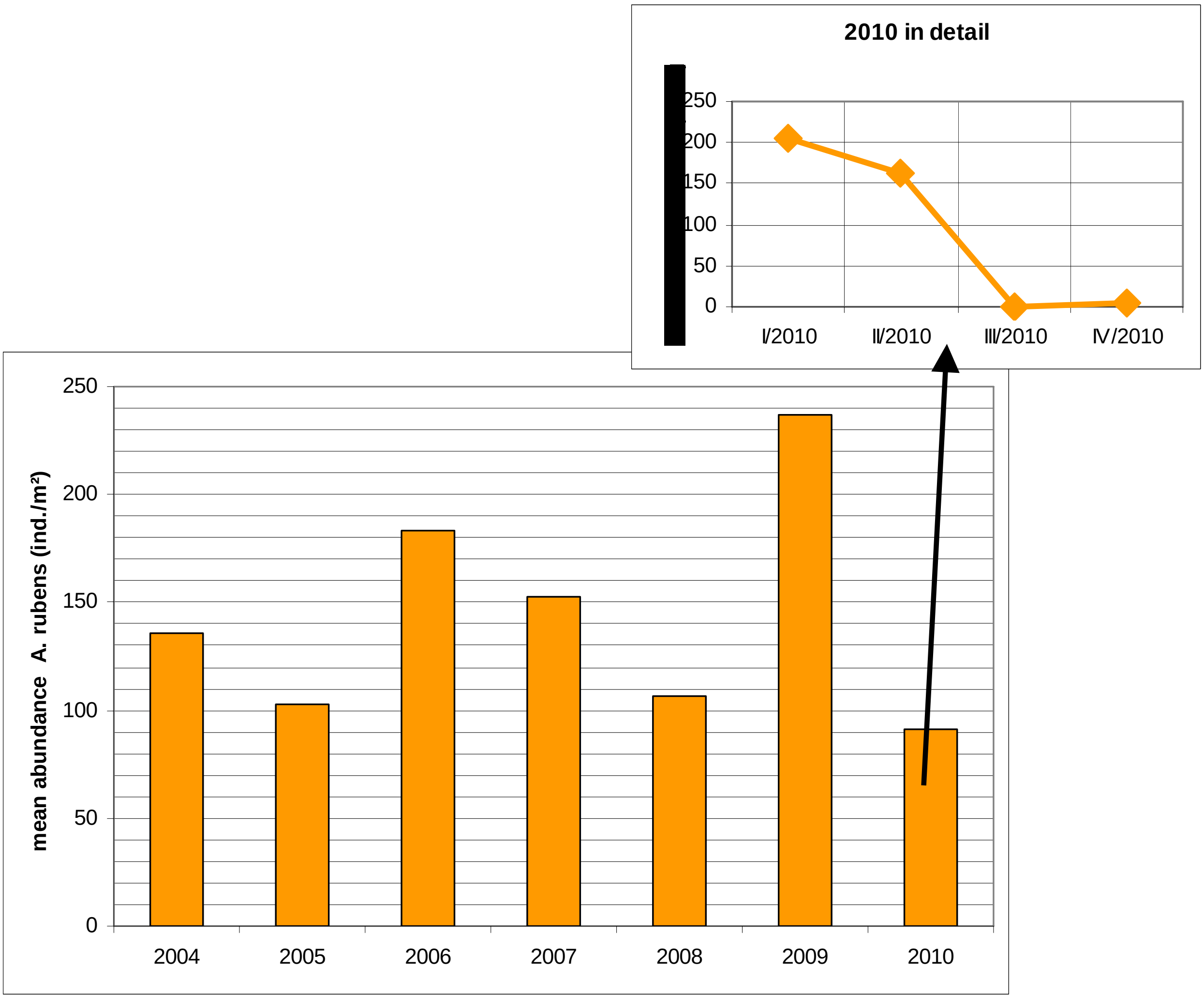

Figure 7: Mean abundances of starfish determined from all single values, making a comparison between the years.

Development of fouling on flexible artificial structures (net material)

Development of fouling communities on the nets followed a similar oscillating pattern as seen on solid structures. Until 2006 there was a clear, upwards trend in the development of biomass, which then started to decline (Fig.8). These biomass values consisted mainly of the edible mussels (*Mytilus edulis*). However, on occasions, red algae, particularly *Polysiphonia nigrescens* and *Delesseria sanguine*, had a greater impact on biomass. The growth of red algae was strongly limited by the occurrence of larvae of the edible mussels and their later development on the thalli. When the algae are densely occupied with mussels, it is only a matter of time until they are torn the surface beneath. This often found on the vertically stretched nets.

A similar event probably occurred during the first years of colonisation by edible mussels, which grew to a length of 60-65 mm. Annual mussel settlement caused crowding and a decline of the total biomass. As a whole it was found that the mussels actually caused a considerable increase of weight of the nets, but the net holes were at no time fully covered and closed by mussels.

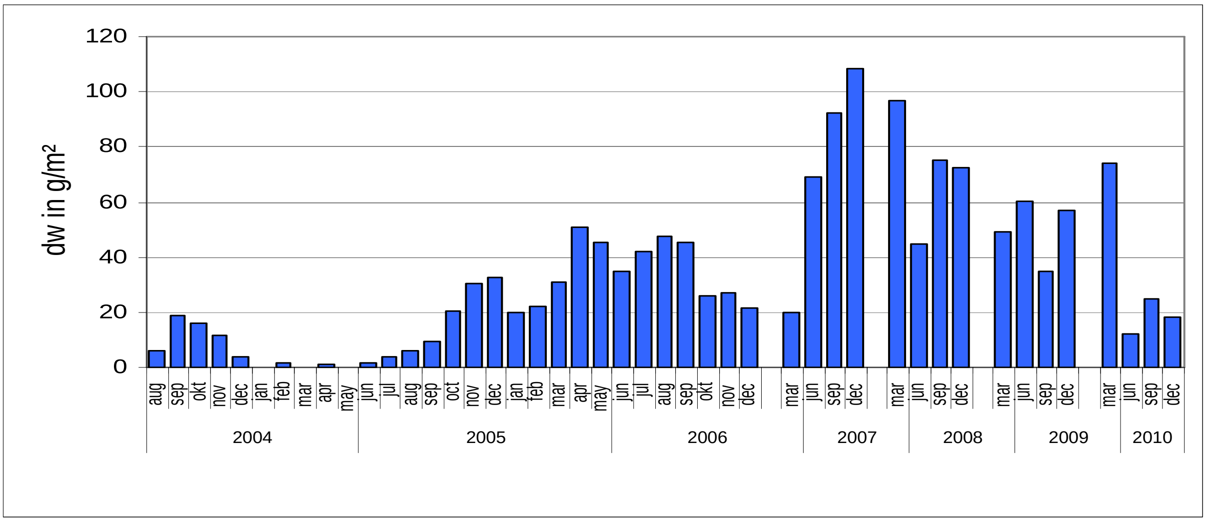

Figure 8: Development of the dry mass of fouling taken from net knots of 5 cm × 5 cm between the years 2004 and 2010.

Comparison of artificial hard substrata with natural stones

Comparisons between fouling communities on pre-existing stones from the area and newly submerged concrete elements, irrespective of the construction of the artificial reef, still show differences after a seven year period. The four diagrams in fig.9 show a comparison between the results from 2005 and 2010.

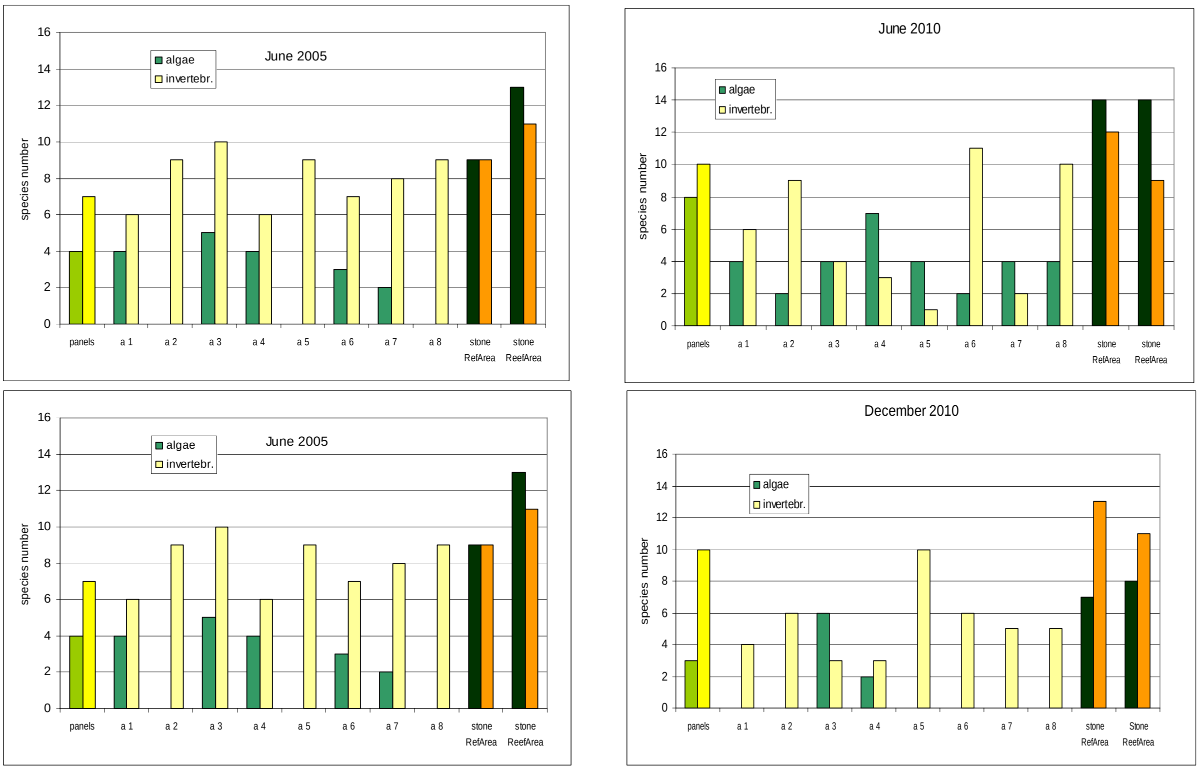

Figure 9: Development of the number of species of invertebrates and algae on artificial and natural (stone) substrata in comparison between the years 2005 and 2010, in each case in June and December

The diagrams at the top show the summer values with the diagrams at the bottom showing winter values. In each case, the species abundance on long-term panels slabs and on the natural stones taken from the reef and reference area are compared with one another.

The results reveal a disparity between the level of development amongst artificial substrata and the natural stones (which had pre-existed in the area for a long time), the latter showing a higher biomass. The number of species of invertebrates has actually largely approximated, but for the algae, now as before, there are strong deficiencies on the artificial structures.

Fouling on different materials

Qualitative differences concerning the structural composition of the fouling community on the different hard substrata tested did not occur within a year. All materials were accepted as a place of colonization. There were differentiations with regard to the quantitative aspects, which were reflected by the total biomass on the slabs. Among the materials compared with each other in 2004, glass-fibre reinforced plastics, granite, marble and oak were colonized equally well. When comparing the concrete types used on the reef, the washed concrete rich in natural stone, of which the reef cones are made, supported less biomass. This was reaffirmed by a repeated test in 2006. The test series of 2005 showed that under static exposure conditions even Teflon (though less than the other materials) is colonized, and stainless steel is colonized more heavily than rubber, acrylic glass or wood. The results of the year 2006 indicate that even though flooring plaster concrete, despite slightly increased pH values at the surface at the beginning of the trial, is colonized to the same degree as pH-neutral special concrete in the course of a fouling season.

Investigations on influencing neighbouring substrata by artificial reef structures

Fouling on natural hard soil in the reef and in the reference area

There is no difference in the colonization of medium-sized natural individual stones from both the reef and control areas; these data include both the adhering fouling organisms and the vagile fauna inhabiting the stones. For example, the study measuring invertebrate biodiversity in 2010 from the control area identified seven species in March and September, 12 in June and eight in December, compared with seven species in March and September, nine in June and 12 in December for the reef area. The greatest diversity of algae from both stations was found in June, with 14 different species recorded. In the other months the total number of species was lower, with no differences between the locations. Thus it can be assumed that the reef structure does not have an effect on the composition of species found on natural hard substratum in the surrounding area.

The influence of the artificial reef on the sand-benthos communities of the surrounding area

Flow conditions directly above the sea bed were changed by the artificial reef. Furthermore the increase in the organic content of the water, which was possibly due to the metabolic products of the many edible mussels in the immediate surrounding area, raises the possibility that this will also cause changes in abundance and composition of other species, such as benthos communities of the sandy sea floor in the area immediately surrounding the structures.

Due to this possibility, the benthos of the sandy soils in the reef area was compared with that in the reference area off Börgerende for the years 2004-2006. The diagram in fig.10 shows the monthly biomass values in the reference and reef area from 2004-2006.

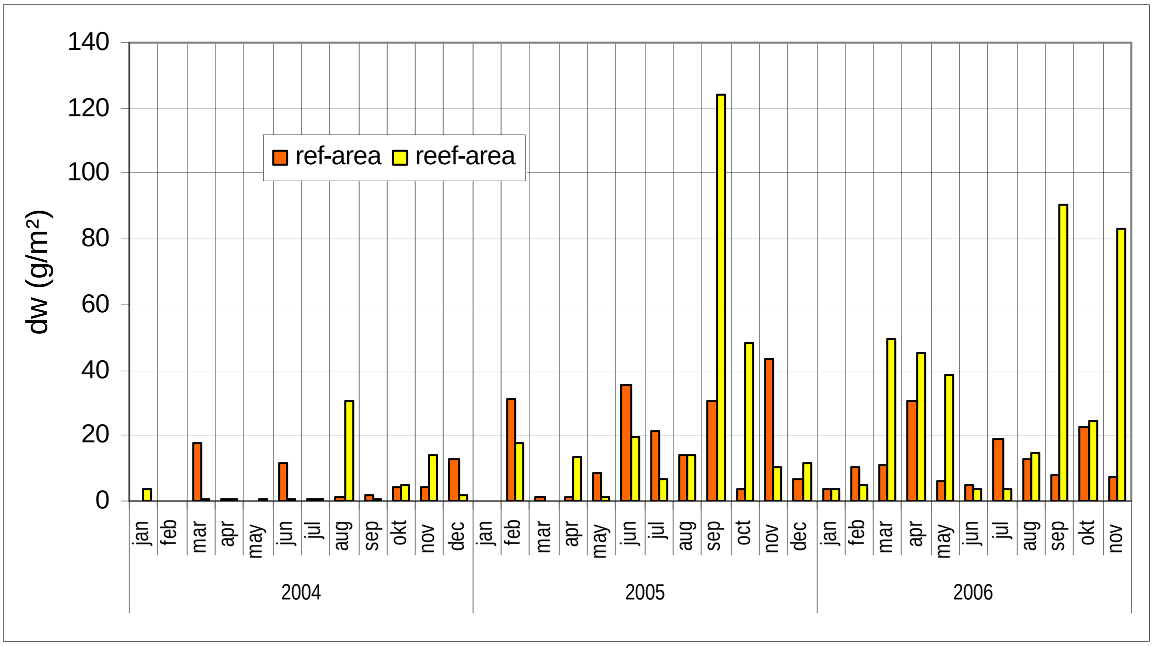

Figure 10: Comparison of the biomass values benthos/sandy bottom in the reference and reef-area from 2004 until 2006

The mean biomass values were typically between 10 and 50 g dw/m² in both locations. Conspicuous "runaways" always arose when a larger mussel was found in the tube samples. This became more commonplace in subsequent years in the sand samples from the reef area, as the fine sand was increasingly washed away by changed flow conditions and *Mytilus* could establish itself on small stones. As a result, higher biomasses in the benthos of the sandy bed in the reef area were achieved.

A similar development was observed in respect of diversity. Particularly among the polychaeta and crustaceans the number of species in the sandy soil on the reef was clearly above that in the reference area (Tab.2). The total number of species found in the sand of the reef area in 2006 increased to 33 species from 28 species in the preceding year; in the reference area, species number increased from 21 to 24 species over the same time period. In both areas the most abundant species were the oligochaete *Tubificoides benedii*, the polychaeta *Pygospio elegans, Eteone longa, Scoloplos arminger* and *Nephtys caeca*, the molluscans *Macoma baltica* and *Hydrobia ulvae*, and the crayfish *Microdeutopus gryllotalpa.*

The difference in species diversity may be explained by the fact that the sand-bearing surface has decreased due to sediment transport processes, and relatively more stones are to be found than in the reference area. This leads to the fact that more hard soil representatives are to be found in the samples, with the edible mussel making up the highest share in weight of them.

Table 2: Number of species per taxonomic group in the sand-benthos samples in 2006 as comparison between reference and reef area

Taxonomic unit	**Reef**	**Ref. area**
Nemertini	1	0
Mollusca	6	7
Oligochaeta	1	2
Polychaeta	14	8
Crustacea	9	6
Insecta	1	0
Echinodermata	1	1
Total number of species	**33**	**24**

Discussion

The seven year documentation of Baltic Sea fouling communities on the artificial reef structures off Nienhagen has produced an abundance of high value data, from which well substantiated conclusions can be drawn. Due to the success of this programme, an artificial reef has been installed at Rosenort (6 m below sea-level). Using a newly installed working platform, it is possible to collect continuous water data, essential for the explanation of unusual phenomena such as the starfish mortality observed in 2010.

As mentioned in the results section, a stable fouling community dominated by *Mytilus* has developed on the reef in Nienhagen. The predominance of *Mytilus* in hard soil communities of temperate and subtropical latitudes is generally well documented and has been observed on the Adriatic coast (TURSI *et al.*, 1984; IGIC, 1988), Delaware Bay in the USA (DEAN & HURD, 1980), and the Scottish coast (von PICKEN, 1986). This is thought to represent the only stable climax stage on hard soils of the temperate latitudes (SUTHERLAND and KARLSON (1977).

The formation of *Mytilus* communities on the coast of Mecklenburg with reliable details about the species inventory and the biomass development has been described by SUBKLEW (1970), BÖTTCHER (1990), SANDROCK (1990) and most recently by ZETTLER (2010).

Observations on the colonisation of the artificial reef in Nienhagen show that a blanket-like covering of edible mussels, complete with accessory fauna, fully develops after a period of just two years. In this period the ecologically basic functions of the mussels, such as filtering capacity, structure/niches and excretion of faeces/pseudofaeces, are almost completely developed.

However in the subsequent years the population grows apart *i.e.*, older mussels continue to grow. At the same time new mussels attach themselves, leading to spatial competition. However, biomass initially increases, and it is predation by starfish rather than spatial competition that acts as the major limiting factor on the reef. That was especially obvious during winter, as no new edible mussels were colonising the area, with the starfish gradually decimating the existing population. This was first revealed by observations from divers, with numerous open and empty mussel shells still hanging on the byssus filaments in the structures each spring. These observations were then tested experimentally by inserting a copper ring, which prevented the starfish from reaching the upper areas of the tetrapod.

In December 2010 with 5.923 g/m² (dw) a biomass value increased by a factor of 3.5 was recorded (reference area directly beneath). It is likely that differences in fouling community development is a direct result of starfish predation and the varying degrees of accessibility of certain structures therein. It was noticeable that all checking surfaces close to the bottom and on the underside of the structures had sparse mussel coverage; however, the surfaces lying furthest from the bottom were densely covered. An exception was surface four, which was situated on the upper edge of a reef cone and was shaped similarly to the surfaces lying further below. A reason for this deviation could have been that the outer walls of the cones have relatively little structure and were accessible to the starfish. Indeed, on a newly constructed reef off Rosenort no starfish exist due to the lower salt concentration, the same structures were more overgrown by edible mussels on the bottom than on the top.

Due to increasing starfish mortality in summer 2010, edible mussel numbers in this region should rebound. Indications of this trend were observed from samples collected in December 2010.

Further predation pressure on the edible mussels came from the arrival of diving ducks - European eider ducks and ice ducks were observed, which decimate mussel populations, even removing the shells from this region.

However, even disregarding annual oscillation, the assumption that the *Mytilus* community is already stably developed after two years with regard to its structure and function has been reached from a purely faunistic standpoint. As the investigations off Nienhagen have clearly shown, algae need a longer period for the colonization of artificial substrata. Even after a seven year period, more microalgae (biomass and species diversity) generally grew on the natural stones originally existing on the reef than on the concrete structures.

The shape of the stones seemed to impart a certain advantage – round shapes reduce sedimentation. However, the variety of shapes available for colonization should have provided areas which would allow optimal algal growth.

Having evaluated the exposures of slabs in 2005, the type of material itself (comparison of various concrete types with natural stone/granite) can be excluded as a reason. In addition, the surface quality is unlikely to be important.

What remains as an explanation is the assumption that developing algae are often torn off the surface beneath, and the remainder continue to grow again with improving conditions. Consequently, the intensity of colonization by algae is determined by the presence of a long-established hard substratum with the necessary colonization potential. Further evidence for this hypothesis is the observation that “old” structures have more algal growth than newly exposed ones, irrespective of whether natural stone or concrete is concerned. A similar phenomenon was also described for the northern Baltic Sea (southern Finnish coast). Floating reef structures, by which dissolved nutrients should be removed from the water body, were very quickly inhabited by mussels. However, filamentous green algae, which typically abound in areas of high nutrition, were still low in numbers after a year (LAIHONEN et al., 1996).

Direct covering up by structures

The increase in the number of species observed on the reef at Nienhagen (and also to a lesser extent that of the biomass of the benthos of the sandy soil) can be principally attributed to the immigration of typical “hard soil species”. This in turn is connected to the fact that fine sandy component parts were washed away as a result of changes in current, and the share of small to medium-sized stones increased.

The most important result of the investigation on the artificial reef is the enhancement of the fishery value in this area - which was proved by parallel fishery-biological investigations, and can be explained by the additional food abundance provided to the fish by the fouling community and accessory fauna that developed.

The target species of this project was the cod. At the time of writing, the appearance rate of the juvenile cod in the reef area is nearly twice as high as in a reference area lying 4 km away. Also for the economically usable fish sizes the catch at the reef has increased by up to 47 %, withan increase in the total number of fish. Of the 42 species found in this region 39 species were found at the reef, compared with 31 species in the reference area. The two spot goby (*Gobius flavescens*) was frequently observed in the flow shadow of the overgrown structural elements. During the first two years, cod mainly feed on the vagile growth fauna, which develops in connection with the *Mytilus*-community. Stomach examinations of cod caught at the reef have revealed that the one-year-old animals mainly feed on amphipods, mysidacea and shrimps. Cod in their second year of development supplemented their diet with fish larvae; from a length of 31 cm, the young cod additionally took shrimps and fish as food. Moreover, comparisons between fish from the reef and fish from the reference area revealed that the animals resident to the reef had a higher proportion of shrimp, crustacea and polychaeta in their diet (DUMKE, 2008).

The potential increase in food available to the cod within the artificial structures is considerable. Scratch samples revealed a mean biomass of 1,887 g/m² (dw) in December 2010.

Installing these reef structures created an additional colonization area of 18,000 m², resulting in a total fouling weight of 33.7 t (dw). Crustacea and polychaeta use the existing niche system and according to our observations, they also cover a considerable part of their energy demand by the intake of faeces/pseudofaeces of the edible mussels so that at this point there is a very direct connection between the fouling and fish community.

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