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THE FLORA AND FAUNA OF THE SUBLITTORAL PART OF THE ARTIFICIAL ROCKY SHORES IN THE SOUTH-WEST NETHERLANDS

R.J. Leewis* and H.W. Waardenburg**

* Ministry of Transport and Public Works, Tidal Waters Division, Department of Marine Biology, P.O. Box 20904, 2500 Ex Den Haag, The Netherlands.

** Bureau Waardenburg b.v., P.O. Box 365, 4100 AJ Culemborg, The Netherlands.

ABSTRACT

Since 1979 the artificial rocky shores of the Oosterschelde estuary and (salt water) Lake Grevelingen have been investigated by diving biologists. The main aims are: 1) to acquire information about a habitat that was hitherto virtually unknown, and 2) to assess the influence on the flora and fauna of the construction of a storm surge barrier in the mouth of the Oosterschelde estuary. Spatial and temporal patterns of species diversity were studied in both basins, and revealed 6 different characteristic and dominant groups of species in the Oosterschelde, but only two in Lake Grevelingen. In both basins distinct west-east gradients were distinguished. Relationships with environmental variables were also studied, and it was found that species distributions were mainly determined by current velocities, wave impact, light (turbidity), and the nature of the substrate. The influences of texture, hardness and potential toxicity were specifically examined. The materials could be arranged in the order in which they were covered with organisms. Concrete showed the densest covering of all materials. Certain heavy metals were found in increased concentrations in those organisms grown on some substrates, but a toxic effect was only evident on copper slag. On some other materials such an effect was probably obscured by the effects of the physical properties of those materials. The biomass of the sublittoral hard substrate epifauna proved to be much more important than previously thought. Although the surface area of the hard bottom is only a small fraction of the total bottom area in the Oosterschelde, biomass associated with hard bottom

surfaces is about one third of the total benthic biomass of the area. The presence of the storm surge barrier has itself increased the available hard substrate by about 30%. This is probably more important than all indirect effects of the barrier caused by changes in current patterns, turbidity, etc.

INTRODUCTION

Originally, there were no hard underwater substrates in the Netherlands - except for some isolated fossil peat banks. Early in the history of the Low Countries, however, people started to build dikes to protect themselves and their agricultural land and cattle against the numerous inundations that took place. Those dikes became ever higher and bigger, and ever more hard materials were used. At first often wood, but increasingly natural and artificial stones were brought in from elsewhere. Those artificial stones were often waste materials from ore works or other industrial processes, such as copper slag, steel slag, or phosphorus slag.

Nowadays, the Netherlands have several hundred kilometers of artificial rocky shores, sometimes extending down to 30 meters under water. Of course, all those hard substrates quickly got covered with a variety of marine organisms. The intertidal area has been studied, as everywhere, for some time. Emphasis in these studies often lay on the algae, and on zonation (e.g. Den Hartog, 1959; Nienhuis, 1969, 1980). The subtidal zone however, could only be studied when biologists learned to dive.

A few student reports exist from the early 1970's, but the first extensive underwater research project in the Netherlands started in 1979. This was part of the environmental research accompanying the large aquatic engineering works of the so-called "Delta Plan". Adopted as a consequence of the disastrous inundations of 1953, this plan provided for the closing off of several estuaries in the south-west Netherlands. The study presented here took place in two of those: the Oosterschelde, closed off with a storm surge barrier in 1986, and salt water Lake Grevelingen, closed off with a dam (later provided with a sluice) in 1971.

The aims of the work were:

1. To assess the spatial and temporal distribution of species, qualitatively and quantitatively, on the subtidal hard substrates.

2. To assess the influence of the storm surge barrier and other aquatic engineering works on the flora and fauna - and if possible to predict the continuing influence of those works in the years after completion.

METHODS

13 transects were laid out, 9 in the Oosterschelde and 4 in Lake Grevelingen (see Fig. 1). Sampling was done by SCUBA divers, at 7 depths at each transect (1, 2, 3, 5, 7, 9 and 12 meters below mean low water (MLW) level). At each depth, the percentage cover of each species present was estimated in 50 by 50 cm quadrats, and recorded using a slightly simplified Braun-Blanquet scale (Braun-Blanquet, 1964). This was done in early spring, summer and late autumn.

Samples were taken for further identification in the laboratory and, since 1984, also for biomass determination. The minimal area to be sampled was determined for all locations, by determining the similarity of species composition between each of two squares of 625 cm^2 and multiples of that area, using the qualitative Sorensen similarity index $Is = 2Cpq/Cp + Cq$ in which Cpq = the number of species that occurs in both squares p and q, Cp = the number of species occuring in p, and Cq = the number of species occuring in q (see Weinberg, 1978; Van Soest and Weinberg, 1981). The minimal area is assumed to be reached when $Is = 0.85$, meaning that 75% of the species potentially present are found. The chosen sample area of 2500 cm^2 was, in most cases, sufficient to meet this criterion. Figure 2 shows the resulting curve for one of the locations.

For the determination of the influence of different substrates on the flora and fauna, 11 different types of stone were placed at several depths under water and in the intertidal zone. Development of covering was followed for half a year, and a final sampling took place after 2.5 years. Samples were taken of the organisms to find out if they had taken up any heavy metals from the substrates. After destruction in nitric acid they were analysed by atomic absorption spectrophotometry (AAS).

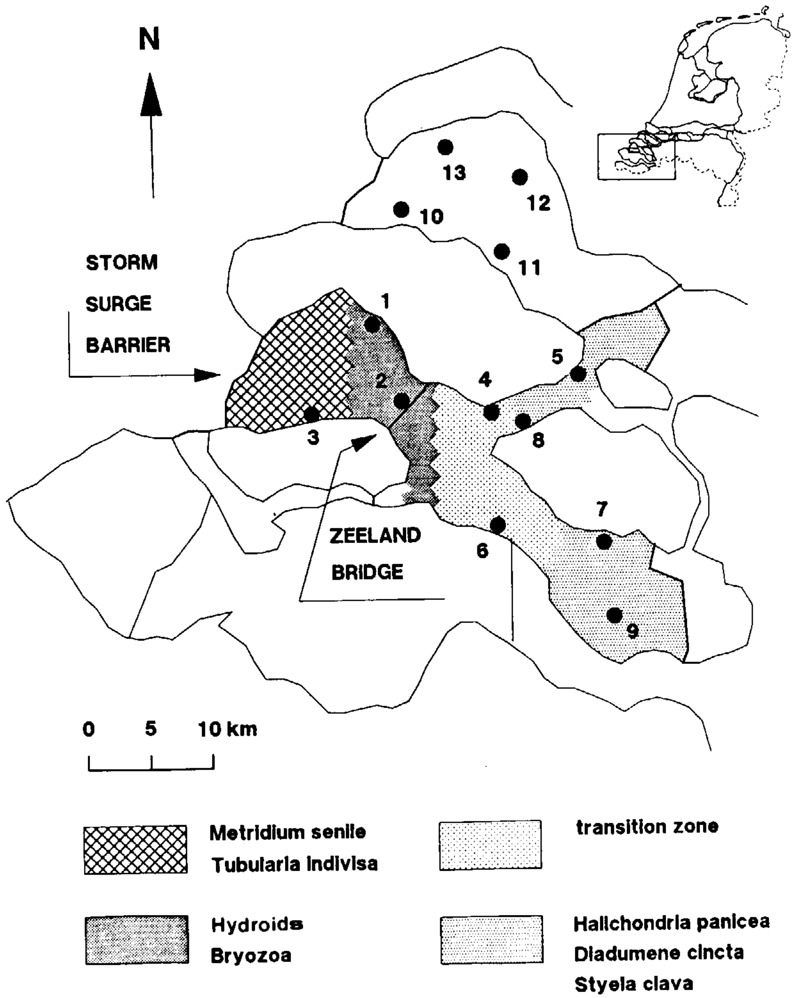

Figure 1. The Oosterschelde and Lake Grevelingen, with the sampling locations.
Oosterschelde:1 = Schelphoek (SH); 2 = Zeeland Bridge Pillar (PYL); 3 = Wissenkerke (later deleted); 4 = Zuidbout (ZB); 5 = Zype (ZYPE); 6 = Wemeldinge (WEM); 7 = Gorishoek (GH); 8 = Stavenisse (STAV); 9 = Boomkil (BK).
Lake Grevelingen:10 = Scharendijke; 11 = Dreischor; 12 = Melissant; 13 = Ouddorp.
The distribution of the four main species assemblages in the zone beneath 3 m depth in the Oosterschelde is also shown, with the characteristic species indicated.

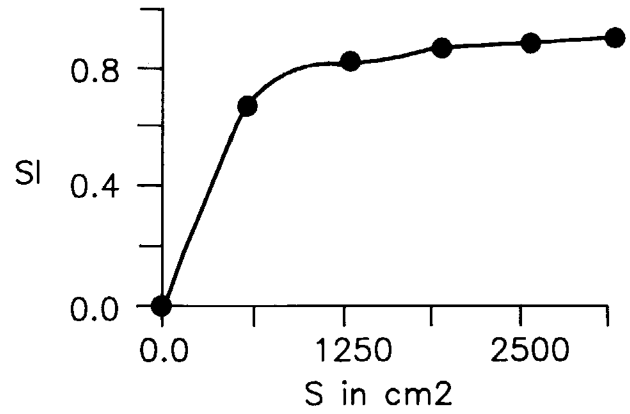

Figure 2. Sorensen similarity index (SI) as a function of sampled area (S). Location: Zuidbout, depth 6m.

Water quality parameters, current velocities and irradiance were measured routinely by the Tidal Waters Division at a number of locations, although not precisely at the locations of this study, and not very near the bottom. Therefore, we also used "clod-cards" (gipsum blocks, the dissolution of which is proportional to the amount of water movement to which they are exposed; see e.g. Muus, 1968) and small flasks containing stacks of ozalid paper (for light measurement; see Friend, 1961). These could be placed at an exact spot on or between the hard substrate elements, and left there for a few days, so that an integrated measurement was obtained of the amount of water movement and light to which the organisms were really exposed.

Analysis of the data took place with a two-way cluster analysis called TWINSPAN (Hill, 1979), and comparison with abiotic variables was done with correspondence analysis (CANOCO; Ter Braak, 1986).

RESULTS

DISTRIBUTION

During this study, 146 species were found, including a few only identified to genus level. About 30% of these species were algae. The dominant species for 8 locations in the Oosterschelde are given in Table 1. The table is divided into two depth zones; the first from 0 to about 3 m depth, dominated by algae, and the second from 3 m down, dominated by animals.

Table 1. Dominant species at each Oosterschelde location, in two depth zones (0-3 m and 3 m+), from TWINSPAN analysis. The number of plusses indicates the relative measure of dominance at each location.

DEPTH ZONE 0-3 M

Species	Location (see Fig. 1)							
	SH	PYL	ZB	ZYPE	WEM	GH	STAV	BK
Ceramium rubrum	+++		+++	+++	++	+++	+++	+
Ulva spp.	++			+		++	++	+
Codium fragile	++						++	
Polysiphonia nigrescens			++	++		++		
Chondrus crispus					++	++		
Polysiphonia nigra						+		
Hypoglossum woodwardii	+			+	+			+
Laminaria saccharina					+			
Griffithsia devoniensis								+
Enteromorpha spp.	+			+				
Sargassum muticum	+							
Diatoms				+			++	+

DEPTH ZONE 3 M+

Species	Location (see Fig. 1)							
	SH	PYL	ZB	ZYPE	WEM	GH	STAV	BK
Diadumene cincta		++	+++	++	++	++	++	++
Halichondria panicea		++	++	++	++	++	++	++
Metridium senile	+++		++			++		
Barnacles	++	++	+	+	+		++	
Mytilus edulis	+	++	+	+			++	
Crassostrea gigas			++	+		++		
Sagartia troglodytes		+		++	++			
Styela clava		+	++		++	+		++
Electra pilosa	++					++	+	
Bicellariella ciliata	++					++	+	
Tubularia indivisa	++	++		++				
Ophiothrix fragilis		+	++				++	
Actinothoe anguicoma					+			
Campanularidae	++						+	
Halecium halecinum								+
Haliclona oculata					++		+	
Sertularia cupressina				++				
Asterias rubens								+

This distribution can be summarized by a gradient from west to east (refer to Fig. 1). In the shallow zone the red alga Ceramium rubrum dominates at nearly all locations. In the west and east it is accompanied by Ulva spp. and Codium fragile, while in the middle part of the Oosterschelde Polysiphonia nigrescens, Chondrus crispus and Hypoglossum woodwardii are the characteristic red algae. Further down, the sea-anemone Metridium senile characterises the biocoenoses of the mouth of the Oosterschelde, together with the hydroid Tubularia indivisa. Further eastwards a community is found where several hydroids, like Halecium halecinum, and bryozoa, like Bicellariella ciliata and Electra pilosa are conspicuous members. In the middle of the Oosterschelde all these species are still important, but the sponge Halichondria panicea becomes more prevalent, sometimes accompanied by Haliclona oculata, and often by the sea-anemone Diadumene cincta. The ascidian Styela clava also becomes conspicuous here, although its numbers do not often surpass $100/m^2$. The most eastern locations are strongly dominated by Halichondria, Diadumene and Styela.

In Lake Grevelingen the situation is somewhat simpler. There is an algal zone, down to about 6 meters depth, dominated by species like Codium fragile, Bryopsis hypnoides and Callithamnion sp., while at some locations Sargassum muticum is strongly dominant. Several sponge species, barnacles and the ascidians Ciona intestinalis, Ascidiella aspersa and Botryllus schlosseri characterise the deeper communities. Several of those species also occur in the algal zone. The benthic (strobilation) stage of the jelly fish Aurelia aurita is characteristic of very sheltered and rather dark places such as the underside of stones and the inside of empty oyster shells.

Of course, many mobile animals, like crustacea, nudibranchs, starfish, grazing molluscs and fish complete the picture of the communities described here on the basis of the attached organisms only. Their distributions are partly determined by abiotic conditions, and partly by the distributions of their particular food organisms.

This picture seems rather consistent. Nevertheless, year to year differences can be large, both in the density of a particular species, and also in the number of species found. The trend in the number of species was analysed for each transect. At the north side of the Oosterschelde, the number of species has increased or not changed at all since 1979. In the middle and at the south side it has decreased, while the two most eastern transects show a decrease only in the algal zone. Although changing current patterns due to building activities, and perhaps some recent cold winters with ice formation particularly in the east of the Oosterschelde may have caused these differences, this remains un-proven.

Vertical distribution of the number of species was also studied. Figure 3 shows this distribution for the Oosterschelde - including the intertidal area -, Lake Grevelingen, and one unusual transect in the Oosterschelde: the Zeeland Bridge pillar. The graph is based on more than 7000 observations made over a period of 8 years.

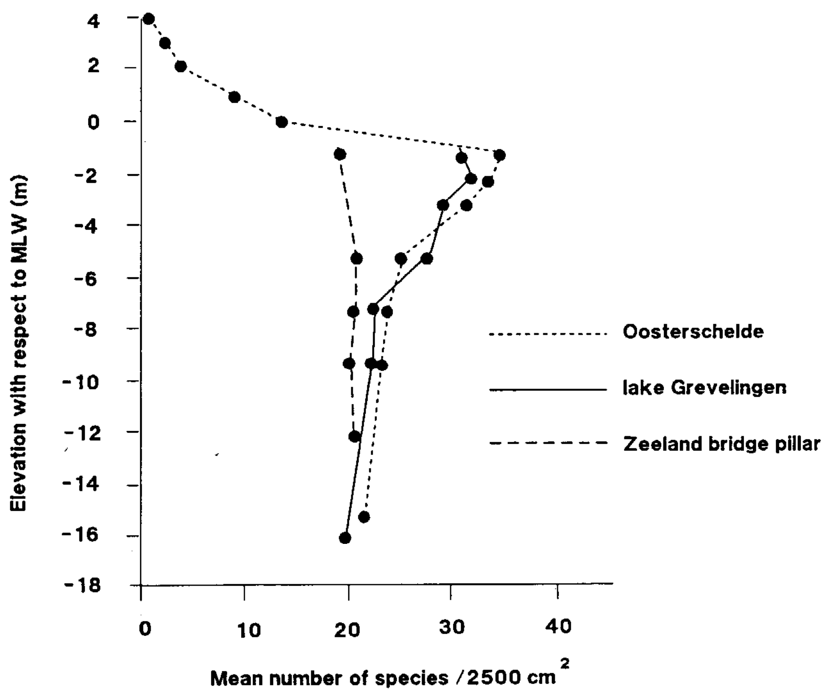

Figure 3. Vertical distribution of species density in The Oosterschelde, Lake Grevelingen, and on the Zeeland Bridge.

The high number of species in the 0 to 3 meter zone is a consequence of the presence of algae. There is then a zone of decreasing species density until, about 5 meters depth in the Oosterschelde and 7 meters in Lake Grevelingen, below which

the density stays about the same. The numbers in stagnant Lake Grevelingen are nearly the same as in the Oosterschelde, where considerable tidal current velocities occur. At the Zeeland Bridge pillar the number of species is smaller than the rest of the Oosterschelde, probably because of the rather smooth surface of the round pillars, combined with the scouring activity of the current, preventing settlement of larvae. In addition, the lower light levels caused by the shadow of the bridge itself may cause the relative absence of algae.

BIOMASS

Hard substrates cover only a small fraction of the total bottom surface along the edges of the basins concerned. Therefore, it was expected that the benthic biomass would also be a small fraction of the total. This is important information for another research project in the Oosterschelde, aiming at the construction of a carbon budget. Therefore, the biomass on hard substrates has been measured since 1984. Biomass density appeared to be much higher than on/in soft substrates, the mean density in the whole basin being 327 ± 141 g/m^2 ash free dry weight (AFDW). Using available surface as a multiplication factor, total hard surface biomass in the whole basin could be compared with those for soft substrates. Table 2 shows this comparison with the mussels and cockles, which account for about 90% of the total soft bottom biomass (figures after Coosen and Smaal, 1985).

Table 2. Biomass of the main groups of soft and hard bottom benthic animals in the Oosterschelde.

		Tons	% of Total Biomass
Soft substrates:	mussels	3647	30.0
	cockles	3685	30.4
	other groups	815	6.7
Hard substrates:	sponges	963	7.9
	ascidians	555	4.6
	hydroids	397	3.2
	oysters	397	3.2
	mussels/limpets	397	3.2
	sea-anemones + rest	1281	10.6

Table 2 indicates that attached hard bottom animals stand for 32.7% of total benthic biomass in the Oosterschelde. This includes the storm surge barrier, which provides about one-third of all available hard substrates. Mobile hard bottom animals were not assessed.

ENVIRONMENTAL FACTORS

CANOCO analysis shows that some natural water quality parameters like salinity, nutrients and oxygen do not have a significant relationship with the distribution of hard substrate species in the Oosterschelde. Important factors, however, were water movement (exposure to currents, vertical tide movements and wave impact); plankton (as nutrition for suspension feeders) and silt and detritus (being able to cover organisms as well as hard substrate, thereby impairing settlement and growth, and in addition providing food for deposit feeders - although these occur only in limited numbers on hard substrates); light (determining in particular the lower depth of the algal zone); and the nature of the substrate. The exposure to water movement is particularly important, shown by the differences in the communities in the west and on the north side of the basin (more often exposed to high current velocities and the prevailing south-westerly winds) and those in the more sheltered eastern area and on the south side.

The influence of the nature of the substrate was studied separately. After determining the normal colonization pattern on a well-known location, colonization was followed on different substrates placed in the intertidal and subtidal area, and in aquaria provided with running sea water. It is beyond the scope of this paper to present the full results of these experiments, but results can be summarized by arranging the substrate types in the order in which they were covered with organisms. This is done in Table 3.

Table 3. "Coverability" of different substrate types.

SUBTIDAL (location: Kisternol)

Well Covered	Moderately Covered	Scarcely Covered
Lime stone (Vilvoordse)	Finnish stone	Asphalt
Concrete	LD slag	Copper slag
Manganese slag	Basalt	
	Phosphorus slag	
	Mine Stone	

Table 3. "Coverability" of different substrate types. Cont.

INTERTIDAL (location: Harbour Jetty Zierikzee)

Well Covered	Moderately Covered	Scarcely Covered
LD slag	Lime stone (Vilvoordse)	Basalt
Concrete	Phosphorus slag	Mine Stone
	Manganese slag	Copper slag
	Asphalt Concrete	Asphalt
	Finnish stone	

AQUARIA (location: Laboratory Sophiahaven)

Well Covered	Moderately Covered	Scarcely Covered
Concrete	Phosphorus slag	Copper slag
Mine Stone	Asphalt Concrete	
Manganese slag	LD slag	
Asphalt		

SHOWING DIP AND SUBSEQUENT RECOVERY IN COVERAGE

Finnish stone
Basalt
Lime stone

Table 3 demonstrates that concrete is a very good substrate, in contrast to copper slag. A number of moderately covered substrates have been studied further. Leaching experiments, reported by Dijkzeul (1979) showed important amounts of heavy metals leaching into the surrounding water from copper and lead slags, but not from other slags. Most of these experiments were done in fresh water. Leewis, Misdorp, Al and De Haan (1984) suggested another possible influence on organisms: an animal or plant settling and growing on a substrate mostly uses mechanical or chemical processes for the attachment. Doing this, it causes a very local weathering of the substrate, namely directly under itself, and thereby a temporarily increased leaching of the material from the substrate. In this way, toxic material such as heavy metals might penetrate directly into the tissues of the growing organism. In our experiments, a number of species appeared to have taken up heavy metals from the substrates, but toxic effects were only evident on copper slag. Algae from the intertidal area were particularly sensitive to heavy metals from the substrates, while barnacles, hydroids and bryozoa were the least sensitive. Ascidians even showed a preference for steel slag. Full results of these experiments are published elsewhere (Leewis and Ter Kuile, 1985; Ter Kuile and Waardenburg, 1986; Leewis, Ter Kuile, Jonkers and Waardenburg, 1989).

THE EFFECTS OF THE STORM SURGE BARRIER

The storm surge barrier and accompanying dams have changed the hydrographical regime within the Oosterschelde in several ways. The tidal amplitude has been reduced by about 10%. This, of course, affects the zonation in the intertidal area, and the extent of this influence is currently being measured. The exchange of water with the North Sea, and with it, of larvae and adult organisms, has been reduced by about 25%. Current velocities in the basin have been reduced (sometimes even by 60%), except very near the barrier, where they have been increased strongly. Also, the changed volume of water entering and leaving the basin during each tidal cycle causes a change in the pattern of currents, the course of tidal gullies and the place and size of sand and mud flats. This causes two important effects: at certain places sedimentation is increasing enormously, totally covering whole stretches of hard substrate communities, and at other places currents are uncovering hard substrates previously covered with silt or even sand. At the same time the average visibility has increased, which may cause phytoplankton growth to increase, and the algal zone on the hard substrates to stretch a little deeper.

Lastly, as previously stated, the presence of the storm surge barrier itself and the other engineering works have increased the amount of available hard substrate by about 30%. Although copper and other slags have been used in some situations, most of this new substrate is concrete. Even at places with tidal current velocities of 6 m/sec new hard substrate communities are now developing. This effect may well surpass any of the other mentioned effects of importance for the hard substrate communities in the Oosterschelde and the study is continuing in order to assess the changes that, undoubtedly, will still take place in the coming years.

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