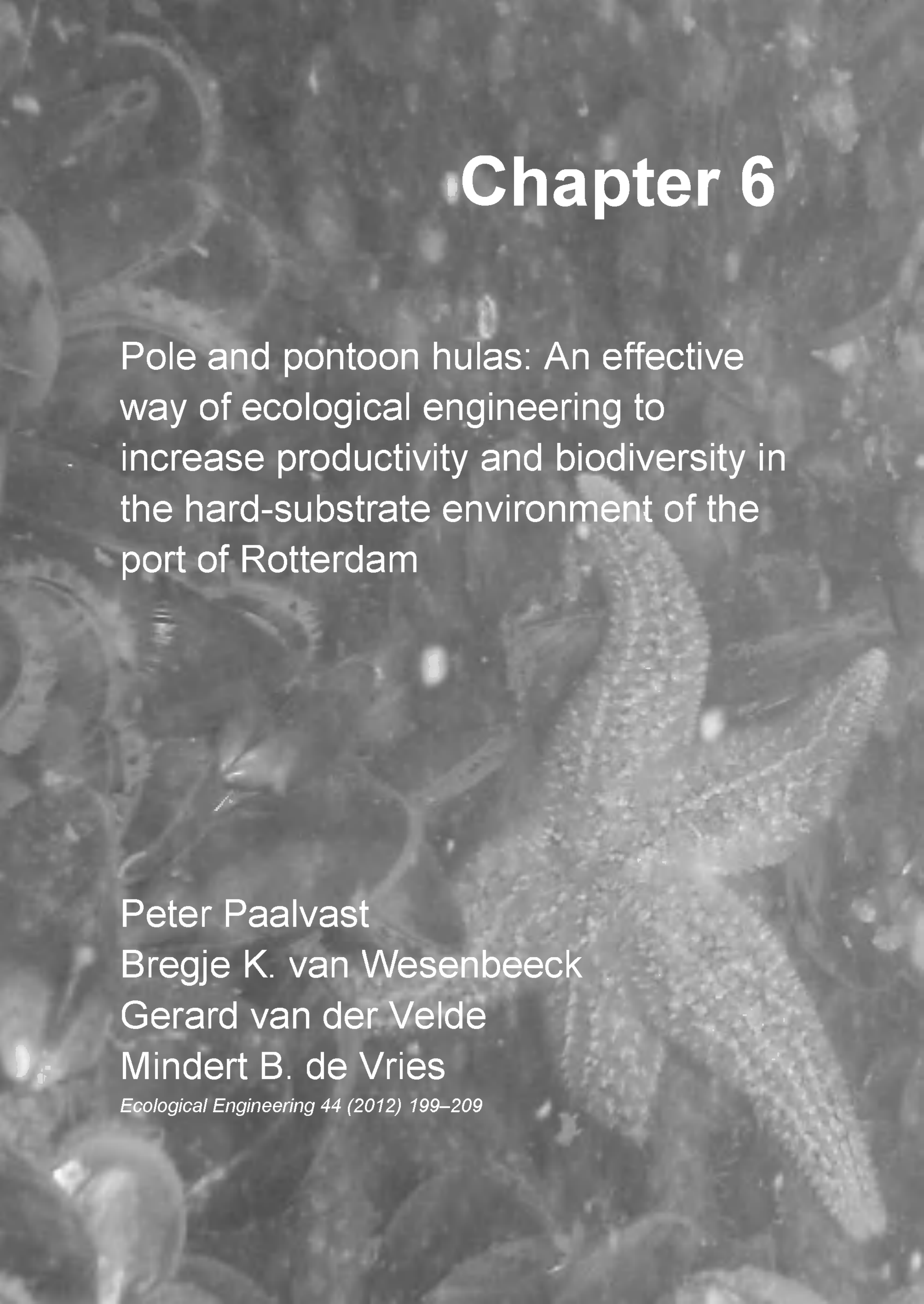

Chapter 6

Pole and pontoon hulas: An effective way of ecological engineering to increase productivity and biodiversity in the hard-substrate environment of the port of Rotterdam

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Abstract

Underwater environments in ports are designed for harbour activities solely. However, by simple and cost-effective measures, suitable habitat for underwater flora and fauna can be created. This is expected to have positive effects on higher trophic levels, such as fish, and improve water quality, by enlarging filter feeder biomass. In this study we developed ‘pole hulas’ and ‘pontoon hulas’, consisting of hanging ropes of different materials. The pole hulas are made up of many 6 mm thick and 55 cm long strings just above and below the mean low water level (MLWL) around poles. The pontoon hulas resemble raft like structures with 12 mm thick and 150 cm long ropes within the open space of mooring pontoons. The first experimentation with these structures was executed in the polyhaline harbours of the port of Rotterdam. The pole hulas were rapidly colonized by a variety of organisms. Above MLWL a seaweed community dominated on the strings. Below MLWL *Mytilus edulis* (the Blue mussel) was found to be the dominating species after a few months. In the dense layer of *M. edulis* on both pole hulas and pontoon hulas many mobile soft-bottom amphipods and young ragworms occurred, which means that colonisation on these structures compensate for biodiversity loss of bottom fauna due to dredging and disturbance by propellers of ships. Settlement of the exotic *Crassostrea gigas* (Pacific or Japanese oyster) did not occur on the strings of the pole hulas, the ropes of the pontoon hulas and not on the poles with hulas.

Wet biomass (including shells) on pole hulas was positively correlated with depth and on average 4.4-11.4 higher compared to biomass on reference poles. Colonization of the pontoon hula ropes was similar to colonization of the pole hulas below MLWL. Biomass production per rope was density dependent and optimal density of ropes was estimated at 4 to 8 ropes m^{-2}. Biomass (mainly *M. edulis*) on the ropes of pontoon hulas decreased to a half from the edge to the heart of the hula demonstrating the limitation of food by competition.

It was concluded that ecological engineering in the port of Rotterdam with simple structures such as pole and pontoon hulas strongly enhances sessile biological production and biodiversity. This is likely to result in a positive impact on local water quality, and, if applied at larger scales, may have positive influences on the remains of Rhine-Meuse estuary.

Introduction

Various large ports all over the world have come to development over centuries and are situated as far land inwards the estuary as ancient ships could sail. Systematic dredging for greater depth of the waterways and canalization started in the 19th century. Together with agriculture, urbanization, industrialization and port development, this exerted a strong influence on the estuarine ecosystem. In estuaries such as the Elbe (Reky, 1992) and the Seine (Lesueur and Lesourd, 1999) most marshes were used for land reclamation and sand and mudflats disappeared due to hydrological changes. Within the Humber estuary some 50% of the original intertidal zone area was sacrificed for human activity (Jones, 1988).

The port of Rotterdam is situated in the remains of the Rhine-Meuse estuary. Before the Delta Works (Smits et al., 2006) that closed most of the river mouths with dams and barriers (1958–1986), the intertidal zone of the estuary consisted mostly out of beaches, salt and brackish marshes, sand and mud flats, tidal creeks, immense fresh and brackish rush and reed beds and intertidal forests. In the northern part of the Rhine-Meuse estuary many of these soft substrate ecotopes disappeared gradually with the development of the port of Rotterdam between 1870 and 1970 (Paalvast, 2002). At present along the salinity gradient no more than 3 ha of brackish marshes, rush and reed beds are left, and due to canalization the tidal creeks and the natural sand and mud banks have disappeared completely (Paalvast, 2002). Between 1960 and 1970 the pollution of the port of Rotterdam was severely degrading the ecosystem to a low number of pollution tolerant species (Wolff, 1978). However, since the 1970’s the water and sediment quality has been improved. This was due to the lowering of pollutants in the river Rhine in particular as a result of the Rhine Action Plan after the Sandoz accident in 1986 (Admiraal et al., 1993, Huisman et al., 1998, Middelkoop and Van Haselen, 1999, Bij de Vaate et al., 2006). But also the ban of TBT, dredging and removal of the heavily polluted sediment, prevention of oil spills and the change from a bulk harbour to a container harbour contributed to a better water and sediment quality (Anonymous, 1999, Anonymous, 2006).The development of the port of Rotterdam transformed a formerly soft sediment habitat into a habitat that is mainly dominated by hard structures such as retaining walls, rip rap, piers, quays, pontoons, and mooring poles of concrete, hardwood and steel. These structures were quickly colonised by hard substrate communities and it is known that although distinct such ‘artificial reefs’ on the long-term may resemble natural reefs (Burt et al., 2011).

In 1964 the Japanese or Pacific oyster *Crassostrea gigas* was deliberately introduced by oyster farmers in the Eastern Scheldt in the Netherlands

(Duursma et al., 1982) and has since then spread over the brackish and salty waters of the Netherlands and abroad. In the Rotterdam port area *C. gigas* was observed for the first time in 1994 and has expanded since that time greatly over the past 15 years (Paalvast, 1995, 1998, 2008) mainly at the expense of the native Blue mussel *Mytilus edulis*. Nowadays *C. gigas* occupies almost all hard substratum including the pontoons and pier and mooring poles, while *M. edulis* is mainly confined to a narrow zone around the mean low water level (MLWL).
Ecological engineering was defined by Odum and Odum (2003) as the practice of joining the economy of society to the environment symbiotically fitting technological with ecological self design. Ecological engineering is common practice along rivers (Leuven et al., 2006) and was applied in coastal protection of the Netherlands on an experimental scale (Borsje et al., 2011). Such ecological engineering is rarely applied in port development (De Wit et al., 2007).
Considering the position of these large harbour water bodies within the Rhine-Meuse estuary implicating an enormous supply of nutrients and detritus by the river, ecological engineering by the enrichment of the aquatic environment with simple cost-effective under water structures that means surface enlargement and increased structure diversity for settlement, could enhance bioproductivity in particular of filter feeders as well as biodiversity. Fibrous structures are well known (since the 13th century) for their rapid colonisation by a variety of aquatic organisms particularly mussels (Veverica, 1982, Bompais et al., 1991, Pulfrich, 1996). Fibrous structures were chosen to test how far bioproductivity as well as biodiversity could be improved. “Pole hulas” (paalhula’s in Dutch), hula skirt liked rope structures were attached to wooden and steel poles, and “pontoon hulas” (pontonhula’s in Dutch) raft liked structures with ropes were placed in the enclosed space of the floaters of mooring pontoons.
The main goal of the present study is to get an answer on the question if pole and pontoon hulas can serve as tools for ecological engineering in a man-made estuarine environment, the port of Rotterdam. Therefore the following research questions were formulated: (a) How proceeds the colonisation and the succession of the fouling community on pole and pontoon hulas, (b) Can colonisation on pole and pontoon hulas compensate for biodiversity loss of the bottom fauna due to dredging and disturbance by propellers of ships, and reduce the settlement of the exotic Pacific oyster? (c) How does biomass production of the fouling community on pole and pontoon hulas develops in time? (d) Is biomass production on poles with hula’s higher than on those without? (e) Is biomass production on the pole hulas related to their position relative to the MLWL?, (f) Does competition exist between the fouling organisms

on different ropes of the pontoon hulas, and does rope density on pontoon hulas influence the biomass production?

Material and methods

Study area

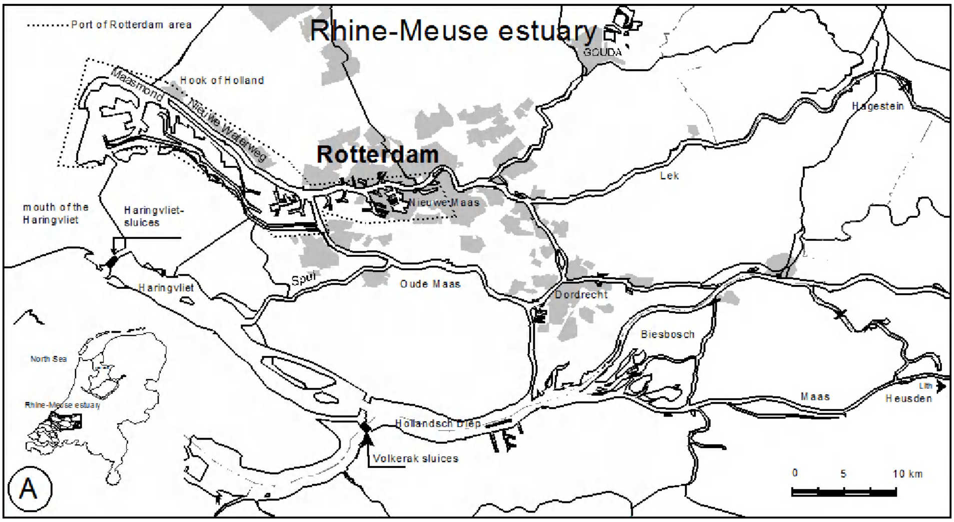
The Beer- and Calandkanaal are two large man-made polyhaline tidal water bodies (>2200 ha) in the westward part of the port of Rotterdam (Fig. 1).

Location

The colonisation experiment with pole and pontoon hulas was carried out in two small harbours, the Scheurhaven and the Pistoolhaven (Fig. 1). The Scheurhaven is a small working harbour with a length of over 300 m and a width of 100 m at the MLWL (mean low water level). The depth of the port is variable and ranges between 3.5 and 9.5 m below MLWL. Due to its location with access to the southeast, the Scheurhaven is a lee port. Waves, even in big storms, and tidal currents are negligible. However, there is 24-h activity of in and outgoing tugs and their propellers produce strong water currents, resulting in sediment resuspension. The average tidal range is 1.94 m. At springtide the tidal cycle exhibits approximately a 4 h period of flood, a 4 h period of ebb and a 4.5 h low water period. The water is often clear with a Secchi depth up to 3 m. The water is always polyhaline and depending on the river discharge there is a more or less clear vertical gradient in salinity with high salinity near the sea floor and a lower salinity at the water surface (Paalvast and Van der Velde, 2011).
The Pistoolhaven is one of the home ports of pilot tenders and has a length of 165 m and a width of 110 m at MLWL. At low tide the harbour is about 6 m deep. The abiotic conditions are similar to those of the Scheurhaven, but with wider salinity fluctuations and due to its entrance to the west waves are slightly higher. There is no significant resuspension of sediment by the tenders.

Pole and pontoon hulas

A pole hula is a synthetic free-hanging rope work that can be attached around wooden and steel poles. It consists of a 10 cm high hollow band made of a heavy quality plastic canvas on the top. In the seam of the band strings of 55 cm long with a diameter of 6 mm are sewn (Fig. 2). Per metre band there are 167



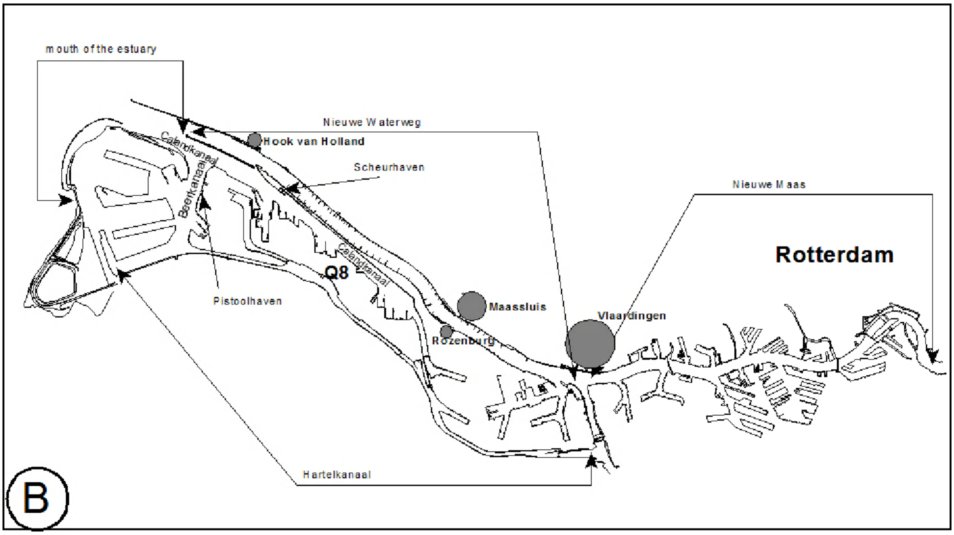


Figure 1 (A) The port of Rotterdam in the Rhine-Meuse Estuary. (B) The location of the Scheurhaven and the Pistoolhaven in the port of Rotterdam. Relevant temperature gauges are located at Hoek van Holland in the Nieuwe Waterweg and Q8 in the Hartelkanaal.

strings with a total length of 92 m. Through the hollow band runs a 25 mm wide nylon strap which at one end has a stainless steel rattle that is fixed on the band. With the rattle the pole hula can be attached tightly around a pole. For monitoring purposes, six counter buckles are stitched to the hollow band at equal distances. To each buckle four strings with a label are fastened. Pole hulas with polyamide strings that float are placed at intertidal levels and pole hulas with nylon strings that sink are attached subtidally (Fig. 2).

Pole hulas were mounted on five wooden poles in the Scheurhaven on the 9th of March 2009. Each pole contained four hulas, one with polyamide strings at 50 cm above MLWL and three with nylon strings with an overlap of approximately 10 cm at 0 cm, 50 cm and 100 cm below MLWL. On two steel poles in the Scheurhaven, three pole hulas were mounted below MLWL, because a hula above MLWL would be scraped off the pole by the pontoon that moves up and down with the tide. Fouling organisms were removed from all poles, including five wooden and two steel reference poles, with a high pressure sprayer (200 bars) between 1 m above and 2 m below MLWL.

A pontoon hula consists of a floating frame which is made of PVC sewer pipe with a diameter of 125 mm. Within this frame a nylon net with a mesh size of 12.5 cm x 12.5 cm is mounted. At the knots of the net nylon ropes with a diameter of 12 mm are attached. By the cross of the frame numbered counter buckles are attached to the knots of the net. Each counter buckle contains a numbered rope for monitoring purposes. The length of the rope and the string density varies per pontoon hula. There are two types (Fig. 3). Type I consists of ropes with a length of around 150 cm, and type II contains varying rope lengths, ranging from 30 cm in the middle to 150 cm at the outside with 20 cm differences between adjacent ropes (bell type). Hulas were placed in both harbour basins on the 16th and 17th of March 2009. In the Scheurhaven a type I and type II pontoon hula measuring 160 cm x 200 cm with both 208 ropes, and in the Pistoolhaven three type I pontoon hulas D16, D32 and D64 (with respectively 16, 32 and 64 ropes m^{-2}) measuring 85 cm x 230 cm were placed in the enclosed space of the floaters of mooring pontoons (Table 1).

Salinity, oxygen and temperature measurements

At two nearby measuring stations water temperature was recorded every ten minutes (Fig. 1). To determine if oxygen was limited, samples of the surface water were taken and oxygen concentration was measured with a HQ20 Hach Portable LDOTM Dissolved Oxygen/pH Meter. Salinity was measured with a WTW-conductivity meter (Cond 3301) with a TetraCon®325 conductivity and temperature sensor. From the data of the measuring stations the mean daily water temperature during the monitoring period was calculated.

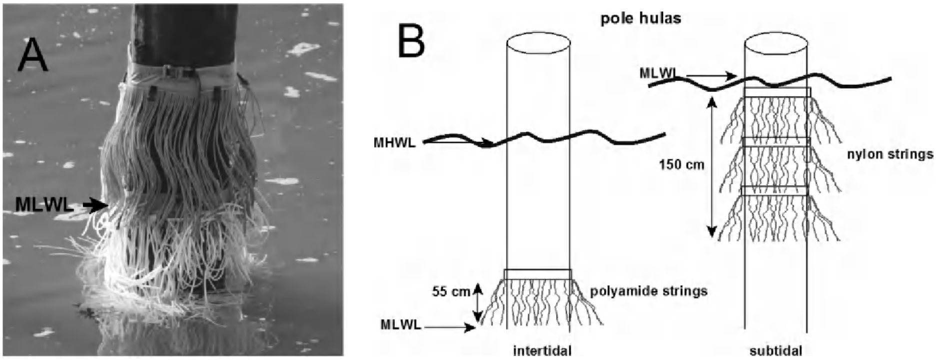


Figure 2 The pole hulas and their position in relation to the mean low water level (MLWL). MHWL = mean high water level.

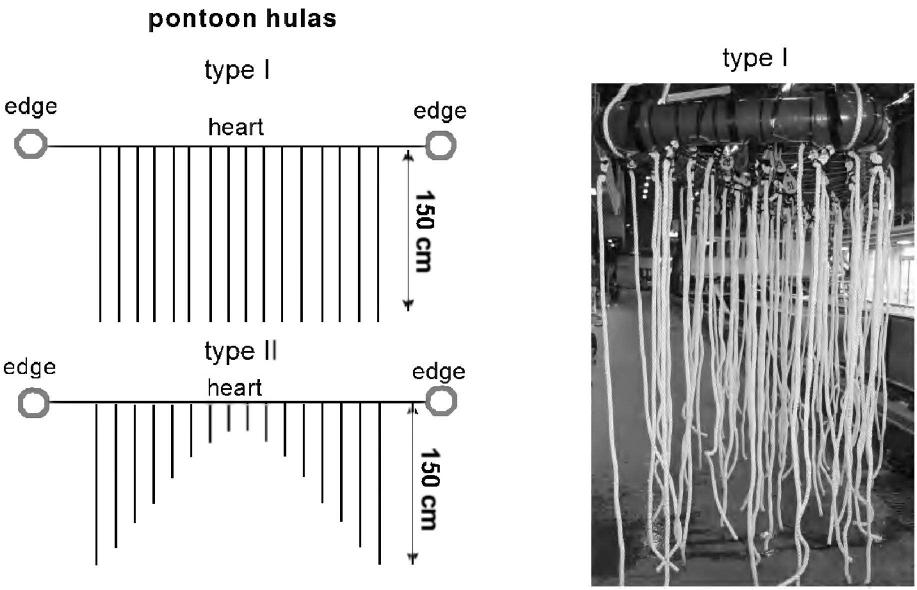


Figure 3 The pole two types of pontoon hulas.

Table 1 Properties of the pontoon hulas placed in the Scheurhaven and Pistoolhaven.

Location	Placing date	Pontoon hula	Number of ropes	n ropes m^{-2}	Length of ropes cm
Scheurhaven	16-03-2009	type I	208	64	150
Scheurhaven	16-03-2009	type II (bell type)	208	64	150–30
Pistoolhaven	17-03-2009	type I D64	168	64	150
Pistoolhaven	17-03-2009	type I D32	80	32	150
Pistoolhaven	17-03-2009	type I D16	40	16	150

Monitoring

The composition of the sessile community on the pole hulas was monitored monthly with the aid of an underwater camera. One set of monitoring strings was removed from each pole hula in June (107 days after placement) and October (231 days after placement) to determine wet biomass and species composition. However, in June strings were only removed from two hulas (out of seven) that were situated 100 cm below MLWL due to dangerous conditions. The strings with the fouling organisms were weighted on a scale with an accuracy of 1 gram after the surplus of water had dropped off. Wet biomass including that of shells (wet biomass = wet tissue plus calcimass) was calculated by extracting the weight of the strings in wet condition. Percentage coverage on the strings of dominant sessile species was estimated, while of other sessile species their numbers were counted. Due to the constant incoming and outgoing tugs it was impossible to sample mobile species on separate monitoring strings in an accurate way. Their abundance was estimated and a simple relative scale ranging from rare (1-10 individuals), common (11-100 individuals) to abundant (>100) was applied. All sessile species were identified to species level. For mobile species this was only done for samples taken in June. In October percentage coverage on reference poles was estimated as well. With the aid of a scrape net some of the fouling on the reference poles was removed and weighted after the surplus of water had dropped off. Wet biomass per m^2 at a 100 % coverage with mussels was calculated from a 100 % coverage of mussels within a frame of 20 cm x 20 cm.

Monitoring ropes on the pontoon hulas in the Scheurhaven were removed to determine wet biomass and species composition on May 19th, June 17th and July 24th 2009, respectively after 64, 93 and 130 days of exposure. The ropes with fouling organisms were weighted on location with a weighing hook with an accuracy of 5 gram hanging in a stable metal frame of 2 m high and 1 m wide. Wet biomass was calculated by extracting the weight of the ropes in wet condition. On July 24th 2009 percentage coverage of sessile species and abundance of mobile species was determined. All organisms were, if possible, identified to the species level. After analysis, ropes with fouling organisms were placed back to their original position. Measurements in the Pistoolhaven were executed on May 18th, June 18th, July 24th and November 6th 2009.

Calculating maximum biomass

Maximum biomass at a given time on each single rope in the absence of competition between ropes can be calculated by considering each individual rope with all the fouling species as one “organism”. For this calculation laws of theoretical crop science are used (De Wit, 1960). This can be done by setting the reciprocal of the biomass per cm^2 pontoon hula (in this case multiplied by 100 for application within SPSS) against the reciprocal of the number of ropes per cm^2 per pontoon hula. The product ($\Omega * \beta$) of the intersection of the regression line with the *x*-axis and *y*-axis gives the maximum wet biomass per rope.

Statistical analysis

Statistical analysis was carried out with SPSS for Windows (Release 15.0). Linear regression was applied to test (a) the relation of wet biomass on the pole hulas and their position relative to the MLWL, (b) the relation of wet biomass production and rope density on the pontoon hulas in the Pistoolhaven, and (c) the relation of wet biomass on a pontoon hula rope in regard to its shortest distance to the edge of the hula

Analysis of covariance (ANCOVA)(covariate=shortest distance to the edge of the hula) was conducted to compare the wet biomass on the ropes on the pontoon hulas type I and in the Scheurhaven.

1-Way analysis of variance (1-way ANOVA) was applied to compare (a) the mean wet biomass on pontoon hulas with different rope densities in the Pistoolhaven and (b) the mean wet biomass on the ropes of the pontoon hula type I in the Scheurhaven with those of the pontoon hulas in the Pistoolhaven

Levene’s test for the homogeneity of variances was applied for both ANCOVA and 1-way ANOVA.

Results

Abiotics

During the experiment oxygen content of the water fluctuated between 7.6 mg l^{-1} and 8.7 mg l^{-1} and salinity between 15 and 23. Water temperature varied from 7 °C at the start of the experiment in March, till 22 °C in mid August and then gradually dropped to 11 °C at the end of the experiment in November.

Succession

After placement in March pole hulas below MLWL were completely covered by diatoms within a month (solitary, stalked and colonial species). Above MLWL no macroscopic sessile organisms were observed. In the period between April and May some individuals of the sessile algae *Ulva lactuca* and *Porphyra umbilicalis* settled on the strings above MLWL, while the strings below MLWL were completely covered with a monoculture of the hydroid *Obelia dichotoma*. At the end of June more species were present (Table 2). Above MLWL the fouling community was dominated by *P. umbilicalis.* Below MLWL *O. dichotoma* was degenerating and was replaced by small individuals of the Blue mussel (*Mytilus edulis*) and the barnacle *Amphibalanus improvisus* (nn) (nn = not native). The number of seaweed species on the strings of pole hulas decreased from the MLWL downwards. In between the sessile organisms on the strings many mobile species were found (Table 3). Chironomidae, juvenile Polychaeta, crab larvae, the amphipod *Monocorophium insidiosum*, and the tanaidacean *Sinelobus stanfordi* (nn) appeared in high numbers. The amphipods *Monocorophium acherusicum, Microdeutopus gryllotalpa, Melita palmata* (nn) and the decapod *Hemigrapsus takanoi* (nn) were commonly found, while the amphipods *Caprella linearis*, *Caprella mutica* (nn), *Monocorophium sextonae* (nn), *Gammarus salinus*, *Hyale prevosti* and the gastropod *Crepidula fornicata* (nn) were only met on occasion.

At the end of October composition of the fouling community on the strings had changed considerably. Both above and below MLWL *P. umbilicalis* and *Ulva* species disappeared, while the red algae *Callithamnion roseum* and *Ceramium rubrum* increased considerably in abundance. On the whole *M. edulis* became the dominating species with an increasing abundance with depth, thereby outcompeting *A. improvisus*. The Blue mussel grew around the strings and because of the high number of strings were present in multiple layers. On several strings the ascidians *Styela clava* (nn) and *Molgula manhattensis* (nn) and the sponge *Halichondria panicea* were found. Despite a small spot of bryozoans, no fouling was found on the mussels. Mobile species were present between the sessile fauna in higher abundance in October than in June. The sea

Table 2 Coverage by seaweeds and sessile macrofauna of the monitoring strings of the pole hulas in the Scheurhaven on June 24th 2009 and October 26th 2009. >MLWL = above mean low water level. < MLWL = below mean low water level. avg = average. sd = standard deviation. max = maximum. min = minimum. bsw = brown seaweed. gsw = green seaweed. rsw = red seaweed. * non native.

position	sessile species	June 24th 2009						October 26th 2009					
		number of strings	times present	% coverage				number of strings	times present	% coverage			
				avg	sd	max	min			avg	sd	max	min
>MLWL	*Ulva lactuca (gsw)*	5	2	4.2	8.8	20	0	5	0				
	Ulva linza (gsw)	5	4	5.0	5.0	10	0	5	0				
	Porphyra umbilicalis (rsw)	5	5	11.0	10.8	30	5	5	0				
	Callithamnion roseum (rsw)	5	1	0.2	0.4	1	0	5	0				
	Ceramium rubrum (rsw)	5	0					5	1	0.2	0.4	1	0
	Mytilus edulis	5	0					5	5	5.2	3.2	10	1
	*Amphibalanus improvisus**	5	0					5	4	1.4	2.1	5	0
<MLWL	*Ulva lactuca (gsw)*	16	3	0.0	0.0	0.1	0	21	0				
	Ulva linza (gsw)	16	9	3.5	7.4	25	0	21	0				
	Porphyra umbilicalis (rsw)	16	6	8.6	10.3	25	0	21	0				
	Callithamnion roseum (rsw)	16	8	4.3	12.5	50	0	21	12	2.0	4.4	20	0
	Ceramium rubrum (rsw)	16	3	0.3	1.2	5	0	21	5	0.8	1.8	5	0
	Petalonia fascia (bsw)	16	1	0.0	0.0	0.01	0	21	0				
	Conopeum reticulum	16	1	0.0	0.0	0.1	0	21	0				
	Electra pilosa	16	4	0.0	0.1	0.1	0	21	0				
	*Ficopomatus enigmaticus**	16	0					21	1	0.1	0.4	1	0
	Halichondria panicea	16	0					21	9	0.6	1.2	5	0
	Botryllus schlosseri	16	1	0.1	0.4	1	0	21	0				
	*Molgula manhattensis**	16	0					21	2	0.6	1.0	2	0
	Styela clava`	16	0					21	6	1.1	1.9	6	0
	Mytilus edulis	16	13	19.6	25.2	70	0	21	21	59.4	41.3	100	2
	Obelia dichotoma	16	12	13.8	11.9	30	0	21	12	0.4	0.5	1	0
	Sertularia cupressina	16	0					21	1	0.1	0.4	1	0
	*Amphibalanus improvisus**	16	16	13.0	11.5	40	0.01	21	19	2.2	2.3	10	0

star *Asterias rubens* and the prawn *Palaemonetes varians* were observed on many of the pole hulas below the MLWL. Also in October 2009 the Rock gunnel *Pholis gunnellus* was seen in-between the strings. Thicklip grey mullets (*Chelon labrosus*), a common fish in the port of Rotterdam were often foraging on the seaweeds from the pole hulas. On the poles underneath the pole hulas only barnacles with a coverage of 50% and occasionally a Blue mussel settled. Of these barnacles 80% was dead.
From April till October the same type of fouling developed on the reference poles below MLWL. In contrast with the strings *M. edulis* settled as one layer and on average covered the poles in October by some 50%. *A. improvisus* had an average coverage of 14%. A small amount of Pacific oyster spat was observed on the steel reference poles. In the zone of 50 cm above MLWL the reference poles were for 50% covered in codominance by the algae *P. umbilicalis*, *Ulva linza, U. lactuca* and *Blidingia minima*. In October *P. umbilicalis* disappeared and *U. lactuca* became the dominant species. *Fucus vesiculosus* was also found in low densities.
Succession on the pontoon hulas was similar to succession on the pole hulas with the exception that no seaweeds grew on the ropes of the pontoon hulas as a result of shading by the pontoons. In June 2009 composition of mobile species on the pontoon hulas resembled composition on the pole hulas, although Chironomidae and Polychaeta were rare. Young fish was regularly observed between the ropes, and on one occasion a young eel (*Anguilla anguilla*) was found between the mussels on a rope in the Pistoolhaven.

Table 3 Relative abundance of mobile macrofauna on the monitoring strings of the pole hulas in the Scheurhaven on June 24^{th} 2009 and October 26^{th} 2009. >MLWL = above mean low water level. < MLWL = below mean low water level.

position	mobile species	June 24^{th} 2009	October 26^{th} 2009
>MLWL	Amphipoda	common	common
<MLWL	Amphipoda	abundant	abundant
	Decapoda (crabs)	abundant	abundant
	Tanaidacea	abundant	abundant
	Chironomidae	abundant	rare
	Polychaeta	abundant	abundant

Biomass production on pole hulas

The amount of wet biomass (including shells) on the pole hulas increased significantly in regard to their position around MLWL in June and October (Fig. 4, R^2=0.26, p<0.02 and R^2=0.42, p<0.001). On all individual poles with hulas wet biomass was the lowest on the hulas between 0 cm and 50 cm below MLWL. On average wet biomass increased by a factor 2-3 with depth. There was a significant difference between the average wet biomass on the different poles with hulas (F(6, 14)=3.86, p<0.02) due to the fact that on two poles the coverage of the hulas with mussels was low compared with the others.

Total coverage on the reference poles with algae and macrofauna below MLWL varied between 50% and 100 % in October. *M. edulis* was the dominating species. Biomass mussels on pole hulas was estimated to be 4.4-11.4 times higher in regard to position below MLWL compared to mussel biomass on reference poles (Table 4).

Table 4 The wet biomass in g m^{-2} on the poles with hulas and the wet biomass in g m^{-2} on the reference (ref) poles without hulas at 100% coverage on the 26th of October 2009 in the Scheurhaven and its ratio.

	ref pole	pole with hulas					
		average (SE)		maximum		minimum	
position MLWL cm	wet biomass g m^{-2}	wet biomass g m^{-2}	ratio	wet biomass g m^{-2}	ratio	wet biomass g m^{-2}	ratio
0	9925	44006 (10266)	4.4	79477	8.0	8730	0.9
-50	9925	95092 (20591)	9.6	164115	16.5	19736	2.0
-100	9925	112996 (27368)	11.4	202677	20.4	16548	1.7

Biomass production on pontoon hulas

After settlement of *M. edulis* on the pontoon hulas in the Scheurhaven in June wet biomass on the ropes increased on average by a factor 16.1 (SD=3.5, max=24.0, min=10.3) for type I and 18.7 (SD=5.5, max=26.9, min=8.67) for type II. In July, a significant negative relation existed between the shortest distance of a rope to the edge of the pontoon hula and the biomass per cm rope (Fig. 5) The wet biomass of the bell type (II) pontoon hula was the highest per cm rope from the outside to the inside compared to the pontoon hula type I (ANCOVA, F(1,45) = 6.16, p < 0.02).

Wet biomass on the ropes of the pontoon hulas increased to a great extent after settlement of *M. edulis* in both harbour basins (Fig. 6). Within the pontoon hulas

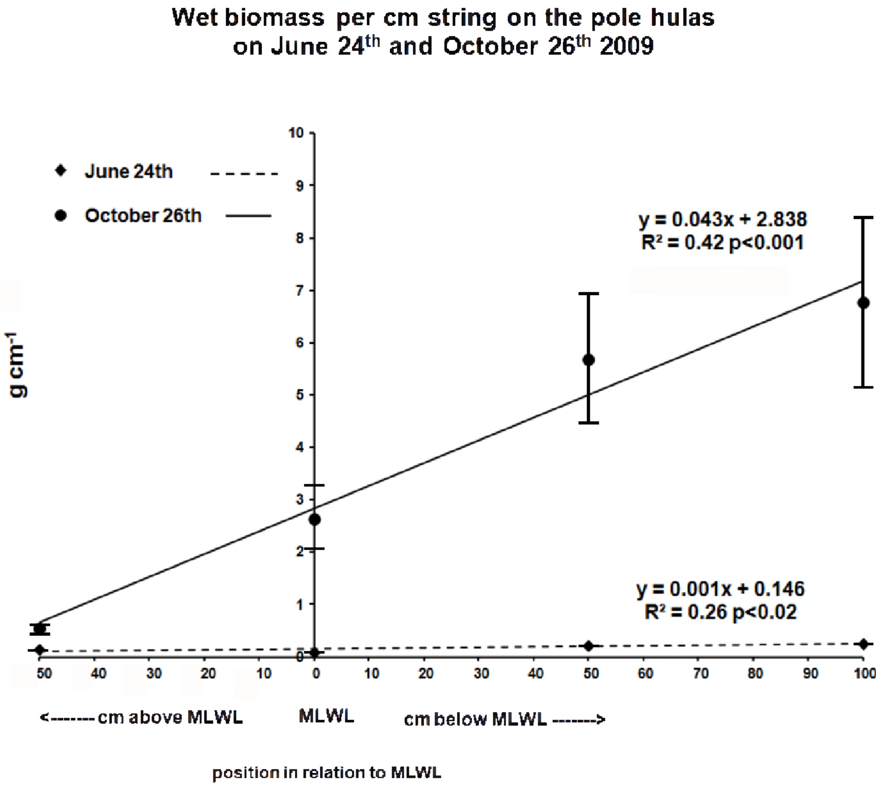


Figure 4 Relation between the average wet biomass cm^{-1} (± S.E.) on the string of the pole hulas in June and October 2009 from the Scheurhaven in relation to their position at the mean low water level (MLWL).

of the Pistoolhaven no relation was found between the position of a rope and the wet biomass per cm rope. However, wet biomass per cm rope was significantly different between the pontoon hulas in July and November (1-way ANOVA, $F(2,74) = 90.1$, $p < 0.001$ and $F(2,74) = 84.69$, $p < 0.001$, respectively) and negatively correlated with the number of ropes per m^2 ($R^2 = 0.60$, $p < 0.001$ and $R^2 = 0.67$, $p < 0.001$, respectively, Fig. 7). In November it was observed that with the hoisting of hulas D64 and D32 lumps of mussels that were attached to other mussels dropped from the ends of the ropes into the water. Furthermore on the ropes the density of mussels increased clearly towards the end of the ropes. On hula D16 the mussels were more evenly distributed over the ropes.

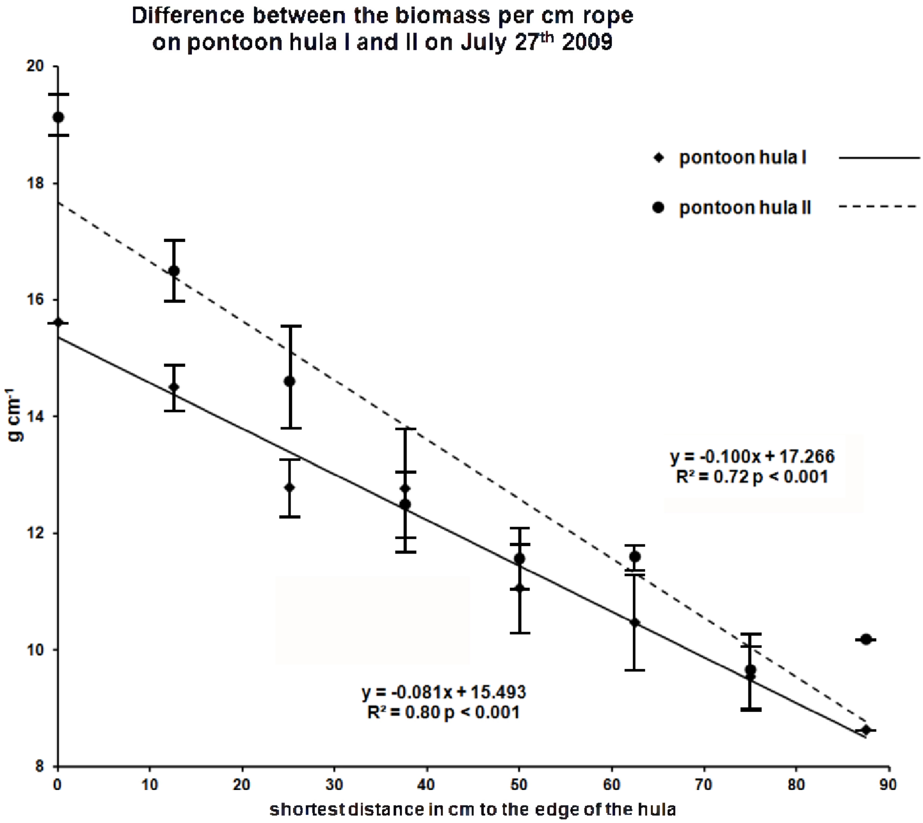


Figure 5 Relation between the average wet biomass cm^{-1} (± S.E.) on the ropes of pontoon hula I and pontoon hula II (bell shaped) from the Scheurhaven and the shortest distance of the ropes to the edge of the pontoon hula on July 24th 2009.

The average wet biomass (N=26, M=1796,8 g $rope^{-1}$, SE=67.2) on the ropes of pontoon hula type I from July in the Scheurhaven is compared with the average wet biomass on the ropes of the pontoon hulas D64 (N=27, M=607,2 g $rope^{-1}$, SE=33.0), D32 (N=24, M=842,1 g $rope^{-1}$, SE=42.6) and D16 (N=26, M=1382,1 g $rope^{-1}$, SE=50.3) from July in the Pistoolhaven. The average biomass on the ropes of pontoon hula I in the Scheurhaven was significantly higher (1-way ANOVA, $F(3,99)=116.79$, $p<0.001$).
For the sampling on November 6, 2009 in the Pistoolhaven using the laws of theoretical crop science (de Wit, 1960) the maximum biomass on one rope in the absence of competition between ropes would give a wet biomass of 3030 g $rope^{-1}$ (Fig. 8). This could be achieved at a density between 4 to 8 ropes per m^{-2}.

Figure 6 Pontoon hula type I D16 on July 24th 2009 in the Pistoolhaven.

Discussion

Species that settled on the pole hulas are commonly found in the Netherlands. A number of them are non-native. *M. manhattensis* (18th century) and *Amphibalanus improvisus* (19th century) invaded the Netherlands long ago as hull fouling, while others like *C. fornicata* (1926), *M. sextonae* (1952), *S. clava* (1974), *C. mutica* (1994) appeared in the course of the 20th century (Wolff, 2005, Cook et al., 2007). *H. takanoi* (2000)(Wolff, 2005) and *S. stanfordi* (2006)(van Haaren and Soors, 2009) were introduced recently in the first decade of this century.

The hydroid *O. dichotoma* was the first macroinvertebrate species that occupied the ropes of the pole (below MLWL) and pontoon hulas massively in early spring. This creates a great advantage for mussels as the larvae preferentially

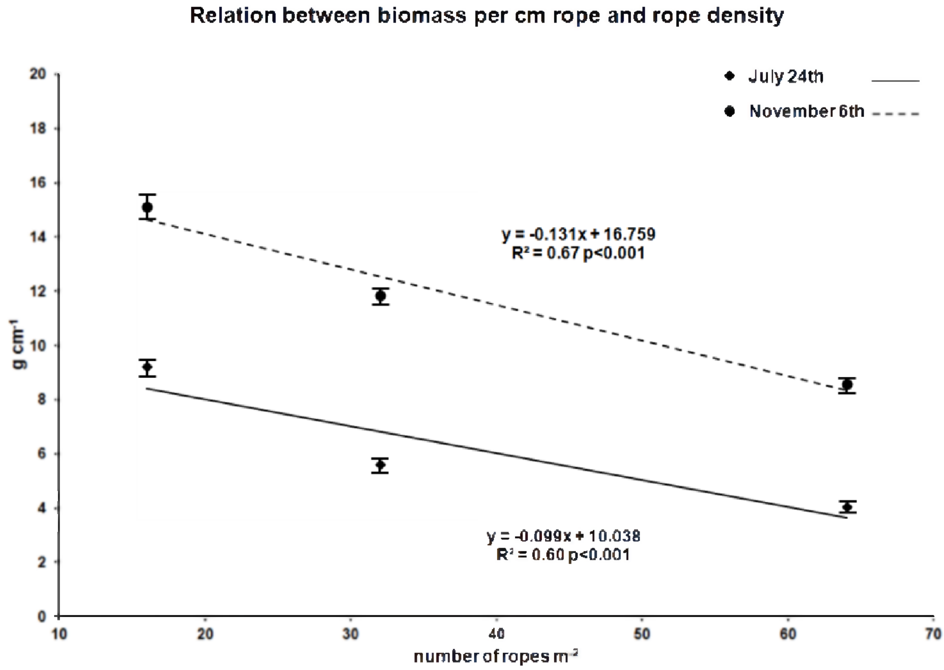


Figure 7 Relation between rope density and the average wet biomass cm^{-1} (± S.E.) on the ropes of the pontoon hulas from the Pistoolhaven on July 24th 2009 and November 6th 2009.

attach to filamentous substrates in particularly hydroids (Brienne, 1960, Pulfrich, 1996, Genzano et al., 2003).

Within the dense layer of *M. edulis* that developed in short time many mobile soft-bottom amphipods and young ragworms occurred in the interstices, which indicates sediment trapping. This phenomenon has been observed both in mussel culture on ropes (Loo and Rosenberg, 1983, Lopez-Jamar et al., 1984) and on suspended oyster cultures (Mazouni et al., 2001), but also in mussel beds (Dittmann, 1990, Crooks, 1998, Thiel and Ulrich, 2002, Koivisto and Westerbom, 2010). Within a harbour system where the top layer of the sea floor is continuously disturbed by the propellers of the ships, and where dredging is common practice, hula systems potentially offer a refugium for animals that normally inhabit soft sediments on the sea floor. From hanging mussel cultures it is known that if the infaunal macrobenthos community beneath rafts is depauperated the diet of fish is composed primarily of raft epifauna (López-Jamar et al., 1984). Furthermore, Iglesias (1981) found density and biomass of gobies to be higher in raft areas than in non-raft areas. The gobies were not supposed to take much advantages of the rope epifauna, but from the cover of the episubstrate of the shell deposits under the rafts (Chesney and Iglesias, 1979). Also crab density can be much higher in raft- areas compared to non-raft areas (Romero et al., 1982). Different bird species might well profit from an

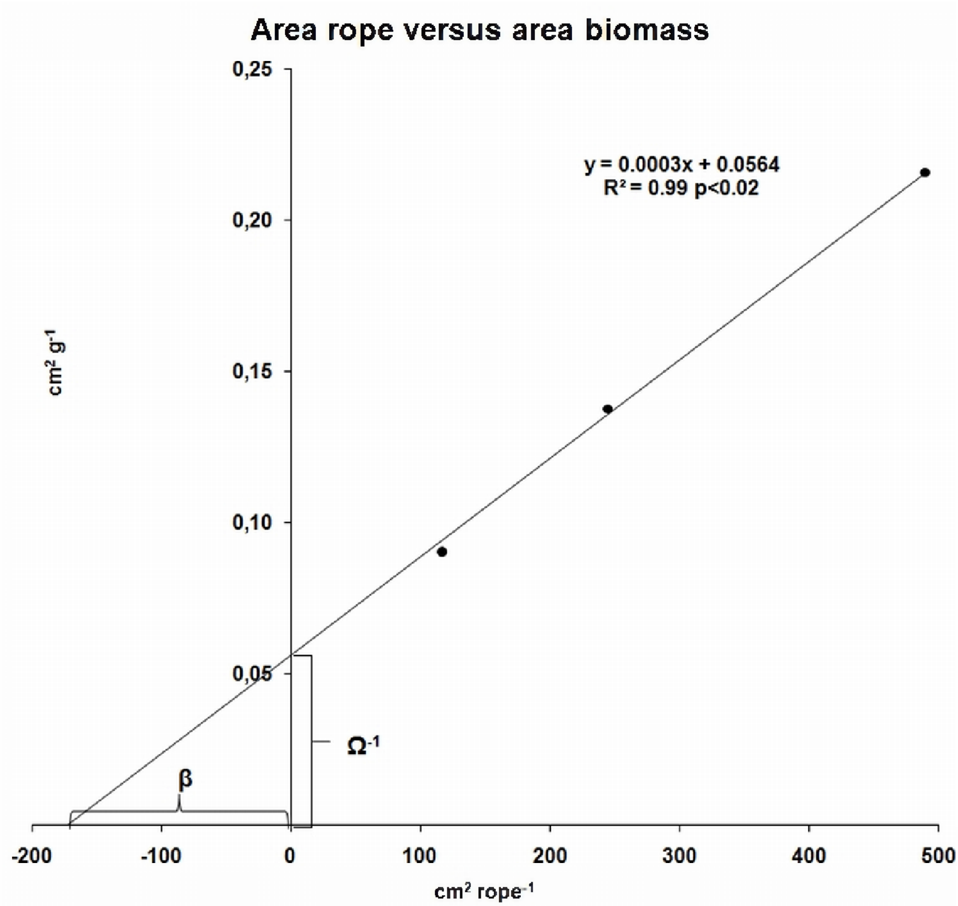


Figure 8 Relation between the area per gram wet biomass and the area per rope.

increase in density and biomass of the mussel. As clumps of mussels are released from the ropes due to heavy turbulence caused by propellers from time to time, these mussels may serve as the start of a mussel bed on the sea floor beneath piers and pontoons where pole and pontoon hulas are located and so creating new habitat.

The pole hulas above MLWL were mainly covered by large green and red seaweeds. No large brown seaweeds were found after one season. In the polyhaline harbours of the port of Rotterdam *F. vesiculosus* grows on anchor ropes and ropes that hold old car tires that serve as fenders. Applying pole hulas with thicker strings or ropes above the MLWL increases the biomass of large seaweeds from which not only the herbivorous Thicklip grey mullets will profit but many other fish species as well due to the presence of high numbers of amphipods.

The value of the pole hula to strengthen the biodiversity of the port seems (after one year) still limited, but they do increase the biodiversity on smooth concrete and steel poles by providing a more structure rich habitat enabling animals to creep in and between. An important phenomenon was the absence of the exotic *C. gigas* both on and on the pole under the strings of the pole hulas. Because of the inability of *C. gigas* to attach to relatively thin rope structures which prevented also direct settlement of *C. gigas* on the poles, the presence of pole hulas may strengthen the weakened position of *M. edulis* in the Rotterdam port area. In particular when pole hulas are introduced in March/April before spawning of *M. edulis* and *C. gigas,* because first spatfall in the Netherlands of *M. edulis* takes place in May/June (Tydeman, 1996) and *C. gigas* in July/August (Dankers et al., 2004), when water temperatures rises above 16 – 18 ºC.

The biomass on the pole hulas increased with increasing depth. Chaves and Chew (1975) have found that mussel spat settled less at the top metre of a rope and suggest that light intensity plays a role for settlement of spat. In the case of pole hulas the inundation duration as their position was around MLWL might have been important too. Due to the tidal movement more individuals could settle on the lower pole hulas and had more time to feed than on the higher ones. As the biomass (mainly *M. edulis*) per m^2 pole hula below MLWL was found to exceed the biomass per m^2 on a reference pole as much as 20 times, pole hulas are efficient tools in ecological engineering for strengthening the estuarine biomass production in harbours.

On both types of pontoon hulas in the Scheurhaven the biomass (mainly *M. edulis*) in July on the ropes decreased to a half from the edge to the heart of the hula demonstrating the limitation of food by competition. The competition on the bell shaped hula was slightly less because the individuals on the shorter ropes underwent less competition compared to those at the same location and on the same height within the hula with all ropes of the same length. This means that the horizontal food supply played a more important role in the competition than the vertical one. Also at the end of the ropes there is slightly more space to settle and less competition and this works in favour for the average biomass on shorter ropes.

No competition for food due to the location of the ropes within the pontoon hulas by means of the biomass on the ropes could be demonstrated in the Pistoolhaven. This is probably due to the size of the pontoon hulas in which the ropes on the inside still had a short distance to the edge of the pontoon hula. By varying the number of ropes a density dependent biomass production was shown. This means that the amount of food in the water column was limited. An additional aspect is that by the violent turbulence of the water by the propellers of ships the risk of rubbing against each other of the ropes increases at higher rope densities which cause the release of blue mussels and thus further limits the increase in biomass.

The higher biomass on the ropes of the pontoon hulas in the Scheurhaven in July compared with the biomass on the ropes of the pontoon hulas in the Pistoolhaven, could be the result of lower and stronger fluctuating salinity in the Pistoolhaven. Also the higher activity of ships near the pontoon hulas in the Scheurhaven will have caused more flow of water and hence provided a greater food supply.

Considering one rope on a pontoon hula as a single individual the maximum biomass on a rope in the absence of competition with other ropes at a certain moment has been calculated for the month November 2009, from the figure the optimal density for biomass production was estimated at 4 to 8 ropes m^{-2}. This is consistent with the findings of Brienne (1960) who found the best growth of mussels at a density of approximately 9 ropes m^{-2}.

Blue mussels filter their food together with inorganic silt out of the water column and excrete the remains as pseudofaeces. This has a positive impact on the transparency, which benefits algal growth and thus the oxygen concentration of the water. By the ingestion of large quantities of organic material from the water column the Blue mussel contributes to a rapid recirculation of nutrients and these are again used in the production of phytoplankton and benthic macroalgae (see Newell, 2004 for a comprehensive overview). Brzowowska et al. (2012) also showed that it is possible to improve seawater quality and attain high efficiency of removal of some heavy metals from raw seawater using the filtering activity of *Mytilus* sp. This would make easily moveable pontoon hulas suitable for quickly reducing the concentration of toxic substances in case of emergencies within a harbour before further distribution takes place.

Taking the above into account, ecological engineering in the port of Rotterdam with simple structures like pole hulas and pontoon hulas on a much larger scale could strongly enhance biological production and biodiversity and the water quality in the remains of the Rhine-Meuse estuary. This might have a positive impact on both the ecology of the rivers Rhine and Meuse and the North Sea. Furthermore it contributes to the ambition of the Rotterdam Port Authority to enhance the ecological value of the port wherever possible (Stuurgroep Regie Buitenruimte, 2004, De Wit et al., 2007).
In conclusion, succession on pole hulas above MLWL leads to a seaweed dominated community. Succession on pole hulas below MLWL and on pontoon hulas leads to a Blue mussel dominated community. Both pole hulas and pontoon hulas contribute to the bioproductivity and biodiversity of the polyhaline harbours of the port of Rotterdam. Pole hulas prevent settlement of the exotic Pacific oyster and this may strengthen the weakened position of the Blue mussel in the Rotterdam port area. Pole and pontoon hulas are successful tools for ecological engineering within harbours in the estuarine and marine environment.

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