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THE FOULING OF PLOMIN HARBOUR

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The fouling settlement has been investigated in the inner and middle part of the Bay of Plomin at 2.5 month intervals during a year period. The inner shallow part of the bay was characterized by fouling organisms typical for polluted harbour waters (dominant species *Cryptosula pallasiana* and barnacles). In the middle clearer part of the bay the mussel was the dominant fouling species at the surface and 1.5 m depth, while hydroids and eurybathic species *Anomia ephippium, Pomatoceros triqueter* at 10 m depth.

INTRODUCTION

Marine fouling processes are very good environmental indicators, because they can be easily initiated anywhere as many times as required. In addition, fouling organisms are very suitable for environmental investigations because of their sessile way of life (D o l l a r , 1979) on hard substratum (M c N u l t y , 1970) and mostly in shallow waters where organisms are more exposed to pollution. Fouling organisms are also favourable heavy metal "sentinel organisms" (W a l d i c h u k , 1985).

Since fouling organisms can be used as environmental bioindicators, such studies were applied in complex investigations of the Plomin harbour, which also included toxicological, radiological, biocoenological studies and physical oceanography. The aim of these investigations was monitoring of the impact of the Boljunčica River, activities of the "Raša" coal mines and steam power plant Plomin on marine ecosystem in relation to high geomorphological differences in the study area; especially the lack of hard bottom.

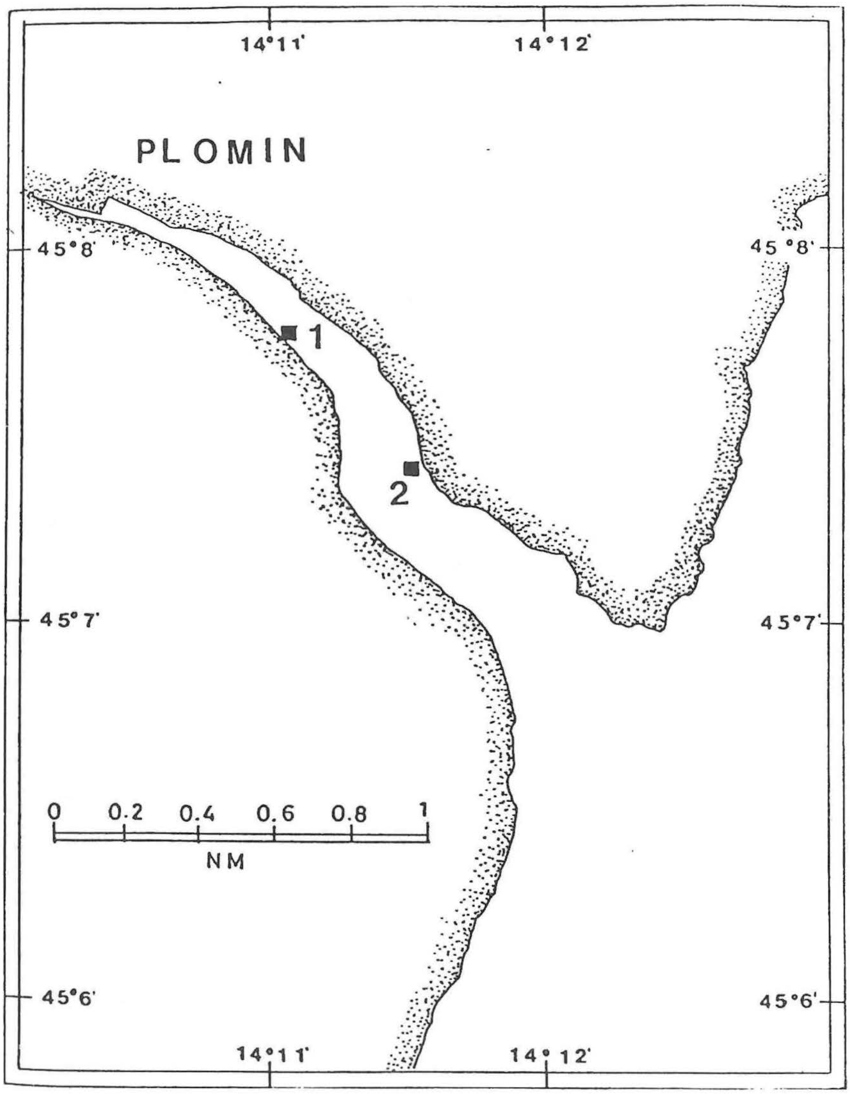

Fig. 1. The Plomin harbour - distribution of study sites

MATERIALS AND METHODS

Fouling quality and intensity were monitored at two stations from 15 March 1985 to 7 May 1986 on glass test plates (145x100x2 mm) placed in experimental metal frames at three depths: 0 - 0.15 m, 1.5 m (stations 1 and 2) and 10 m (station 2) (Fig. 1). Taxonomic composition and wet weight of the fouling communities were monitored using test plates exposed for 2.5, 5, 7.5, 10 and 14 months.

Analytical marks and properties with the nature of fouling organisms were studied using standard ecological methods, with frequency of occurrence (F%), average covering (%) and average abundance (Am) on 290 cm^2 of test substratum. It was possible to count both individuals and colonies of the fouling organisms. For unicellular and some pluricellular organisms it was not possible to determine the abundance by counting. So the relative quantity of fouling organisms is shown with symbols from r to CCC according to the methods presented by P é r è s and G a m u l i n - B r i d a (1973).

STUDY AREA AND ENVIRONMENTAL CONDITIONS

The Plomin harbour is a marine bay on the eastern coast of the Istrian peninsula. At the entrance the bay is wide 500 m, becoming gradually as narrow as 50 m at the end of the bay. The depths vary from 50 m at the entrance to 1 m in the inner part of the bay. The Boljunčica River affects the bay with the inflow of suspended material and warm water coming from the cooling systems of the Plomin steam power plant. In addition to thermal effects, the river also brings waste discharge from the plant and the "Raša" coal mines, such as coal and dust. The waste material inflows in the bay also by ground and underground waters (L u c u , 1986).

Two study sites were chosen, one directly influenced by the Boljunčica River discharges (station 1) and out of its reach (station 2) (Fig. 1). The metal frames at station 1 were placed above the sea floor, at the depth of 1.5 m. This location was exposed to high sedimentation of inorganic and organic particles together with peryphyton on the test plates, highly influenced by the vicinity of the sea floor. Station 2 was located about 50 m offshore at 22 m depth and 1.5 km from Boljunčica River mouth. During the experiment the standard oceanographic parameters, like temperature (t°C), salinity ($Sx10^{-3}$), pH and oxygen concentration (O_2%) were measured.

The extremely high temperature was measured in August at station 1 at both depths (31.5°C)(Table 1), influenced by the inflow of the warm water from the steam power plant cooling system. Lower surface salinity was measured in May at both stations (26.33×10^{-3} - 1985 and 28.16×10^{-3} - 1986 at station 1; 34.83×10^{-3} - 1985 and 35.21×10^{-3} - 1986 at station 2) (Table 1) probably influenced by much rain during that

Table 1. Hydrographic parameters measured at study sites during the investigated period

Parameter		t/ °C		S x 10^{-3}		pH		O_2 %	
Station		1	2	1	2	1	2	1	2
Month of sampling	**Depth (m)**								
1985									
V	0			26.33	34.83	8.08	8.20		
VIII	0	31.5	24.5	36.65	37.32	8.29	8.30	133.5	122.5
X	0	14.9	14.1	37.50	37.92	8.14	8.13	101.4	98.1
XII	0	11.8	11.5	36.48	37.59	8.03	8.00	106.6	97.0
1986									
V	0	15.8	15.9	28.16	35.21	8.18	8.15	109.7	100.9
V	1.5			35.63	37.14	8.25	8.22		
VIII	1.5	31.0		36.73		8.32		130.7	
X	1.5	14.9	14.1	37.61	37.99	8.15	8.15	102.1	96.7
XII	1.5	11.8	11.5	36.65	37.59			105.9	96.6
V	1.5	15.8	15.8	32.64	35.16	8.16	8.13	122.7	110.0
V	10	-		-	37.05	-	8.22	-	
VIII	10	-	23.8	-	37.48	-	8.33	-	109.0
X	10	-	16.9	-	37.99	-	8.12	-	97.4
XII	10	-	12.0	-	37.53	-		-	96.8
V	10	-	13.5	-	36.09	-	8.20	-	106.0

period. Other hydrographic parameters did not vary from typical for the northeastern Adriatic.

RESULTS AND DISCUSSION

Taxonomic composition of all fouling communities, mostly the fauna showed homogeneity between the species. Larvae and spore of fouler settlement were limited by substantial sedimentation of mud, especially at station 1 at 1.5 m depth. At that depth almost half of the plates did not contain any fouling organisms, with rare settlements of unicellular algae (Table 2). Not too many organisms can live in such unnatural environment. Only a few can, by "cleaning" the substratum with their extremities (barnacles) or defense mechanisms such as bryozoan species *Bowerbankia gracilis* (M a t u r o , 1959). It seems that another bryozoan species *Cryptosula pallasiana* disperses mud in similar way, being the most frequent fouler at station 1 (Table 2) although the colonies did not substantially grow (3 - 33 mm, 0 m; 2 - 32 mm, 1.5 m). The algae more sensitive to mud such as red alga *Polysiphonia* sp., settled only at station 2, where quantity of mud was much lower. Concerning the thermal effect, it is assumed that there was no influence during the study period, because only once in the year (August) the sea temperature was higher. In addition, present organisms tolerate higher temperatures: *Cryptosula* to 30°C (R i g g i o , 1979), *Balanus amphitrite* to 47°C (G e r a c i , 1974) and Cyanophyta (*Oscillatoria*) to 52°C (L a m b e r t i and R e i s h , 1985). The total absence of mussel at station 1 is in complete contrast with 0 m and 1.5 m depth at station 2 where mussels were the most dominant species. It is assumed that large amounts of mud restricted the settlement of mussels. C o l l i n s o n and R e e s (1978) reported that substantial amount of mud deposited on valve together with sewage, industrial discharges and heated water from a power station caused demise at 44.4% of mussel individuals. Nevertheless, mussels (*Mytilus galloprovincialis*) are more tolerant to thermal effect since lethal temperature is 40-41°C in the sublittoral zone in the Black Sea (G r a c i u n , 1980). In addition, there are some indications of the influence of waste waters from land at station 1. The primary bioindicator is *Cryptosula* (very frequent species) (Table 2), otherwise typical inhabitant of polluted harbour waters (mostly industrial and municipal effluents of organic origin). More frequent settlement of Cyanophyta (Table 2) could be an indicator of organic pollution (G o l u b i ć , 1960; R a s t t e t e r and C o o k e , 1978), or maybe brown alga *Ectocarpus siliculosus*, also favouring such environments with lower salinity (G o l u b i ć , 1968). That is probably why *Ectocarpus* settled dominantly at that station during the period of lower salinity, fouling the test substratum over 10%. In such environments the *Ulva-Enteromorpha-Cladophora* algal facies is typical, but in this case only *Enteromorpha* was somewhat more frequent and occasionally fouled the substratum to 45%. It appeared on the experimental framers together with *Ulva*, both growing to

Table 2. Taxonomic composition of fouling communities at station 1. Frequency of appearance (F%), average abundance (Am);C - average of 10-99.99 individuals (colonies), common species; CC - average of 100-499.99 individuals (colonies), very common species; CCC - average over 500 individuals (colonies); most common species

Depth (m)	0 - 0.15		1.5	
	F(%)	Am	F(%)	Am
Cyanophyta	100.0	CC	50.0	C
Diatomeae	100.0	C	100.0	C
Enteromorpha intestinalis	33.3	C	25.0	C
Enteromorpha compr.	11.1	C		
Ulva rigida	11.1	10		
Chlorophyta indet.juv.form	33.3	C	25.0	C
Ectocarpus siliculosus	55.7	C	12.5	C
Melobesiaceae	66.7	28.8	12.5	4.5
Hydrozoa indet. juv.form	33.3	7.5	12.5	8.0
Anomia ephippium			37.5	13.3
Spirobis sp.	11.1	37	44.5	49.7
Pomatoceros triqueter			11.1	1
Balanus amphitrite	25.0	8.4		
Balanus eburneus	33.3	5.8		
Balanus improvisus	44.5	12		
Bowerbankia gracilis			25.0	C
Cryptosula pallasiana	66.7	9.0	62.5	14.4

Blank areas show that no species (colonies) were present on test substratum (290 cm²)

unusual dimensions in fouling complex - *Enteromorpha intestinallis* thalli to 20 cm, *Ulva rigida* thalli to 25 cm. The euryhaline animals preferring organic pollution and lower salinities (R e l i n i *et al.*, 1982; I g i ć , 1983) at this station were represented by *Balanus amphitrite, Balanus eburneus* and *B. improvisus* as the particularly characteristic, but completely absent at station 2.

At station 2 fauna was more dominant than flora, and taxonomic composition was indicative of the communities of clear waters; the presence of eurybathic species characteristic of clear waters was noted especially at 10 m depth: the species *Anomia ephippium* and *Pomatoceros triqueter* (Table 3). At the same depth the most abundant settlers were Hydroids, fouling the substratum at 28-83%. At 0 m and 1.5 m the mussel, *Mytilus galloprovincialis*, was the most dominant species fouling 30-96% (0 m) and 4-73% (1.5 m). The abundance of mussels and their larger dimensions (average 38.4 mm - 0; 39.8 mm - 1.5 m depth)contributed to an enormous value of biomass (Table 4). However, mussel is not the representative environmental indicator although it seems to favour more lower level organic pollution (P é r è s , 1967; S a r à , 1976; I g i ć , 1988). As a very adaptable species, mussels cover all surfaces in different environments if there is sufficient food available. However, the most favourable environments for mussels are mediolittoral and upper infralittoral (I g i ć , 1988), and that is why the population density decreased with increasing depth (Table 3). At this station the red alga Melobesiaceae type had even more frequent settlement. It has ecological significance because it helps easier fixation of larvae and spore of other foulers.

The seasonal aspect was not monitored in detail in short time intervals, because the seasonal distribution can be obtained on the basis of growth intensities. Unicellular algae settle in all seasons, except in January and February, having spring maximum. Higher algae and animals are present from April to January with the most intensive settling in spring (algae) and summer-autumn season (fauna). However, the time intervals of exposure of test plates had no influence on the intensities of fouling, and it was in correlation with the structure of fouling community. Thus different density and size of mussels at station 2 affected greater biomass (about 27 times) for the same time and place of exposure (Table 4). Concerning the biomass at station 1 where accumulation of mud was intense, the values were not real - 3586.21 g/m² (Table 4) since small size *Enteromorpha intestinallis* and *Enteromorpha compressa* (density CCC, thalli height 12-35 mm) were most abundant of multicellular organisms.

The dynamics of fouling communities was slow, especially at station 1, due to poor immigration of organisms, almost without inter and intraspecific relationship and invisible structural changes. Such development did not help communities to gradation, but it led to discrete degradation which mostly showed as relatively early mortality and slower growth of foulers. However, at station 2 the dominant position of mussels did not significantly affect the genesis of communities, because intraspecific relationships between individuals did not lead to mutual destruction nor visible reduction in growth, since individuals formed epibioses of first and second grade. However, due to spatial competition, other foulers showed reduced growth not being capable to overgrow other individuals in the community. Such process led communities to dynamic equilibrium, but not to a completely stable state, although it is believed that such communities with mussel as the dominant fouler, accomplish such state - climax (S c h e e r , 1945; R e l i n i and S a r à , 1971).

Table 3. Taxonomic composition of fouling communities at station 2

Depth (m)	0 - 0.15		1.5		10	
	F(%)	Am	F(%)	Am	F(%)	Am
Cyanophyta	70.9	C	50.5	C	50.9	C
Diatomeae	100.0	CC	100.0	CCC	100.0	CC
Enteromorpha intestinalis	23.1	3.3				
Ulva rigida	7.7	1.0	16.7	8	15.4	1.0
Polysiphonia sp.	7.7	C	8.3	C	53.9	C
Melobesiaceae	76.9	14.8	46.2	24.8	53.9	14.3
Hydrozoa indet.juv.form.	7.7	3.0			46.2	CC
Anomia ephippium	76.9	4.5	69.3	8.6	100.0	23.3
Hiatella arctica	53.9	5.5	41.7	5.3	30.8	2.5
Musculus sp.	33.4	2.4	8.3	1.0	30.8	5.7
Mytilus galloprovincialis	84.6	81.5	100.0	33.6	7.7	1.0
Spirorbis sp.	7.7	8.0			7.7	3.0
Pomatoceros triqueter	15.4	2.0	8.3	2.0	61.5	2.3
Balanus trigonus	7.7	1.0				
Balanus perforatus			8.3	1.0		
Bowerbankia gracilis	15.4	C	16.7	C	46.2	CC

The values of biomass at station 2 (0 and 1.5 m) with enormous settlement of mussels is an excellent example of intensive fouling on the eastern Adriatic coast. The greatest average biomass of 19.4 kg/m^2 can be compared to the most intensive settlement on

Table 4. Fouling biomass in Plomin harbour at tested sites, average values of wet weight (g) per 1 m^2 of substratum

Station	1		2		
Depth (m)	0-0.15	1.5	0-0.15	1.5	10
Exposition of test substratum (months)					
2.5 months					
III-V	3586.21	482.76	1862.07	1317.25	137.94
V-VIII	827.59	72.42	140.69	19406.90	248.28
VIII-X	1444.83	103.45	1382.76	6393.11	182.76
X-XII	79.31	965.52	7586.21	4327.59	979.31
5 months					
III-VIII	483.45	261.38	2551.73	1235.87	275.87
XII-V	*	*	72.42	2637.94	134.49
7.5 months					
III-X	110.35	*	11248.28	658.62	198.28
X-V	1172.42	186.21	186.56	9934.49	871.73
10 months					
III-I	41.38	189.66	2758.62	1875.87	210.35
14 months					
III-V	968.97	413.80	8113.80	586.21	996.56
III-V	*	*	6817.25	11000.00	1241.38
III-V	*	*	1865.52	16751.73	803.45

* test substratum lost

plastic collectors in the Bay of Raša (20.1 kg/m^2). The weight of 15.7 kg/m^2 is comparable to average biomass on shells or oysters from shellfish culture parks on the western Istrian coast (I g i ć , 1986). In relation to the same substratum (glass plates) the biomass was over seven times greater, because such substratum is maximum fouled only to 2.6 kg/m^2 (I g i ć , 1986) (eastern coast of the Adriatic). Since the greatest values of biomass in the Bay of Plomin were accumulated in only 2.5 months (Table 4), if the quoted data refer to annual period, the fouling intensity can be compared with an example of record mussel fouling of 900t/9000 m^2 on wooden pillars on the western Adriatic coast (R e l i n i , 1977).

Toxicological and radiological investigations have shown concentrations of some heavy metals (nickel, vanadium, chromium) (L u c u , 1986) and radioactivity (radiouranium, radiothorium) (J e l i s a v č i ć , 1986) in organisms and sediments approximately to the middle of the bay, as a consequence of activities in the "Raša" coal mines and the steam power plant. It is assumed that higher concentration of mentioned metals and radioactivity have no influence on the structure and dynamics of the fouling processes. However, every other new activity in the area such as a new power plant could cause bigger damages to the ecosystem due to higher amounts of waste discharges not only in the inner part of the bay, but further out as well (L u c u , 1986).

CONCLUSIONS

The composition of the fouling complex is relatively homogeneous due to high sedimentation of seston on the test plates, especially in the inner (shallow) part of the bay, near the sea floor (1.5 m depth). Waste impact on this area is quite evident, so the living communities are characterized by organisms typical for urban-industrially polluted harbour waters (effluents of organic origin). In the clearer (middle) part of the bay (above 22 m depth) the fouling is more homogeneous in species because of deeper study location (10 m) and very intensive settlements of mussels at the surface and 1.5 m depth.

The accumulation of mussel *Mytilus galloprovincialis* (average biomass 19.4 kg/m^2 of substratum) in only 2.5 months represents the most intensive fouling on the eastern Adriatic coast, comparable to the heaviest fouling generally in the world.

It is assumed that the consequences of activities from the "Raša" coal mines and the steam power plant do not yet have adverse impact on the structure and dynamics of the fouling process.

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KRATKI SADRŽAJ

Obraštaj kao povoljan bioindikator kvalitete sredine bio je uključen u jednogodišnja istraživanja zajedno sa radiološkim, toksikološkim, biocenološkim i fizikalno-kemijskim studijama dosta atraktive plominske luke, obzirom na relativno specifične prirodne i antropogene utjecaje (geomorfološka raznolikost terena, ulijevanje rijeke Boljunčice, aktivnost rudnika ugljena "Raša", termoelektrana, itd.) na morski ekosistem.

U zaljevu su testirane dvije postaje i to u unutrašnjem plitkom dijelu skoro neposredno iznad muljevitog dna (1.5 m) na udaljenosti od ušća rijeke Boljunčice (postaja 1). Druga se postaja nalazila skoro u sredini zaljeva iznad 22 m dubine, oko 1.5 km od ušća rijeke Boljunčice koja doprinosi donosu sedimenta, produkata tehnološkog procesa rudnika ugljena "Raša"i termoelektrane.

Taksonomski sastav obraštajnih zajednica bio je dosta homogen na obje postaje na što je utjecala velika sedimentacija sestona, posebno na postaji 1 na 1.5 m dubine, uglavnom zbog neposrednog utjecaja muljevitog dna. Kod te su postaje prevladavali organizmi

tipični za lučke vode, tj. organizmi koji toleriraju urbano-industrijsko zagadjenje pretežno organskog porijekla (*Cryptosula pallasiana*, balanidi) i niži salinitet (Cyanophyta, *Enteromorpha intestinalis*, *Ectocarpus siliculosus*, *Balanus amphitrite*, *B. eburneus*, *B. improvisus*). Medjutim, na postaji 2 na 10 m dubine dominirali su organizmi koji preferiraju čistije vode (Hydrozoa) euribatnog karaktera (*Anomia ephippium*, *Pomatoceros triqueter*). Na površini i 1.5 m dubine u obraštaju je apsolutno prevladavala dagnja *Mytilus galloprovincialis*, koja zbog eurivalentnih adaptivnih svojstava nije bioindikator sredine. Medjutim, posebno je prihvat dagnje značajan, budući da je utjecala na enormnu težinu (19406,9 g/m^2) koja je ikada zabilježena na istočnoj obali Jadrana, a u rangu je najvećeg intenziteta obraščivanja širom svijeta.

Razvoj obraštajnog procesa na obje je postaje vodio ka diskretnoj degradaciji koja se manifestirala u smanjenom rastu obraščivača i dosta ranom mortalitetu (posebno na postaji 1). Na takav proces i posljedice razvoja utjecalo je i znantno nagomilavanje mulja (postaja 1) i velika prostorna kompeticija (postaja 2).

Istovremena toksikološka i radiološka istraživanja u zaljevu pokazala su povišenu radioaktivnost i povećanu koncentraciju nekih teških metala u organizmima i sedimentu u užem dijelu zaljeva. Pretpostavlja se da ove posljedice rada termoelektrane i rudnika za sada nemaju štetnog utjecaja na strukturu i dinamiku obraštajnog procesa, ali svaka daljnja izgradnja (npr. termoelektrane) mogla bi imati većih negativnih posljedica na ekosistem i u širem dijelu zaljeva.