ISSN: 0001-5113 AADRAY	ACTA ADRIAT, 40 (1): 7-21, 1999	UDC: 574.5 : 627.22 Original scientific paper

The significance of fouling investigations for the estimation in the construction of marinas

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In the Veruda Bay (Pula), due to the intention to construct new marinas, investigations were undertaken at the time of anchoring of navigable objects, in situ, at the entrance, in the middle and in the inner part of the bay.

*Quality, intensity and dynamics were of a typical port character, with dominant bioindicators of organic pollution (*Hydroides elegans, Janua pseudocorrugata, Balanus amphitrite amphitrite*).*

On the basis of biological characteristics and ecological indices, high pollution level signs were found in the inner part of the bay, where dystrophic and eutrophic conditions were noticed. Therefore, this part of the bay is not recommended for the extension of boat berths.

Key words: Fouling, indicator environmental quality, marina, northern Adriatic

INTRODUCTION

Management authorities and public members have expressed their concern for the deterioration of water quality, which could be caused by the activities in marinas located in closed and shallow coves. Potential environmental problems include the deterioration of water quality at residential boat sites by human faeces, nutrient enrichment of water, and increase of heavy metals and biocidal antifouling compounds, leading to adverse effects on marine organisms (McMAHON, 1989). In such environments, often rich with organic matter, some aquatic animals are closely associated with organic pollution and thus are significant indicators of anthropogenic influence on environmental changes (ANGER, 1977). In addition, the release of toxic elements originating from antifouling paints (e.g. Zn, Cu, Pb, Sn) into the sea is especially dangerous for the living world, particularly in closed shallow coves. In marinas where modern antifouling paints with biocidal organotins are in use (e.g. TBT, TFT, TBTO) toxicity data are available for target organisms (HALL, 1988; WILLEMSEN *et al.*, 1998), non-target organisms (WALSH *et al.*, 1985; HALL *et al.*, 1988), and fish (THAIN, 1983). They are particularly toxic to embryo and larval developmental stages (e.g. Bivalvia; HALL, 1988).

According to HAWKES (1978) running water organisms that best reflect the environmental quality are those which have limited or no mobility. Since fouling organisms are typically sessile, the structure of a fouling community is a biological variable being an important tool used to characterize the watercourses.

In the program "Study of the influence on the environment of the Marina Veruda" fouling research was included in the oceanographic section. This paper reviews fouling data collected with the aim to contribute to the evaluation of environmental quality in the Veruda Bay, as well as to predict the state of the bay after the increase of the capacity of the Marina Veruda.

STUDY AREA

The fouling process was investigated in the Veruda Bay (officially the Veruda Harbour) located near Pula on the Istrian Peninsula at three stations - at the entrance (reference station 2 at hotel "Histria"), in the middle of the bay (Marina, station 1) and in the inner part (station 3). The stations were suitable for investigations because they were different in their pollution status. One of them was mostly organically polluted (municipal sewage, station 3), one with organic pollution and with antifouling compounds (highest number of boat berths - 350, station 1), while the third (unpolluted) was the control one (station 2). The tested sites were at depths of 3.5 m (stations 1 and 2) and 2.5 (station 3) above the silting sea bottom (Fig. 1).

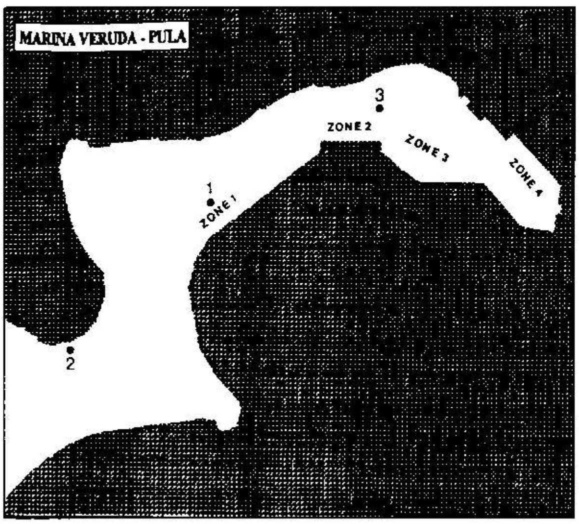

Fig. 1.Map of Veruda Harbour, north-eastern Adriatic, showing the locations of the investigated sites (stations 1, 2, 3) and depths of zones (zones 1 and 2 = 3.5 m, zone 3 = 2.5 m, zone 4 = 2.0 m)

Sea currents measured in the bay showed that the water enters along the shore near the hotel "Histria" and exits along the opposite shore. The current speed measured at the entrance was 40 cm s^{-1}, while inside the bay it was up to 10 cm s^{-1} (BRANA, unpublished). Because of such conditions and shallowness of the area in its inner part the water exchange is very low.

MATERIAL AND METHODS

In situ research of fouling was carried out in two-weekly, monthly and several months expositions in the period from 5 June to 20 September 1989. Research was performed on several sorts of substrata and at different depths (Table 2). The following test-substrata were used: inert glass plates (145x100x2 mm) that were vertically placed into experimental frames at a depth of about 0.5 m, and plastic plates (200x200x2 mm) divided into squares (2x2 mm) at a depth of 1.5-2.2 m, horizontally placed one over the other at a distance of 10 cm and linked together with a rope. Moreover, one-shot fouling analysis was performed on four current meters (3 = at station 2, 1 = at station 1), which had been placed into the sea for sea current measurements in the period from 20 August to 20 September. Furthermore, during the installation of the test plates the old biological material was removed from the concrete pillars for comparison of that data with recent ones as follows: 4 samples (200x200 mm) were taken at stations 1 and 3, respectively. Every 15 days the seasonal distribution of organisms was investigated and after a month and several months the development of communities and intensity of fouling were studied. In total, 96 analyses of the fouling communities were performed: 38 at station 1 (33 = plates, 4 = concrete pillars, 1 = current meter), 22 at station 2 (19 = plates, 3 = current meter), and 36 at station 3 (32 = plates, 4 = concrete pillars). The uneven number of analyses was due to the loss of frames with glass plates at station 2. Concerning the different depths (Table 2) and positions where test substrata were placed it has to be mentioned that the test substrata were placed at depths, which corresponded to the levels of full draught of sailing objects. The plastic plates were horizontally positioned in order to obtain a greater number of analyses in the function of depth, while because of the technical reasons it was not possible for the glass plates.

The main population (dominance, frequency, spatial distribution) and coenological parameters (composition, abundance, biomass, species richness, evenness, diversity and similarity) were studied. The horizontal distribution of fouling organisms is discussed quantitatively in terms of abundance (numerical density), biomass (wet weight), presence (frequency percentage), and dominance (total population density percentage) = individual of a certain species.

The frequency of occurrence (F %) and dominance (D %) were calculated as follows:

$$F\,\% = \frac{\text{No. of species occurring in a series of samples}}{\text{No. of series of samples}} \times 100$$

According to constancy (frequency) the species could be divided into four categories:

- euconstant species that appear in 75 % of samples
- constant species that appear in 50-75 % of samples
- accessory species that appear in 25-50 % of samples
- accidental species that appear in 0-25 % of samples

$$D\,\% = \frac{\text{Sum of number of individuals of species}}{\text{Sum of number of individuals of all species}} \times 100$$

On the dominance basis the species could be divided into 5 categories:

- species with >10 % dominance - eudominant
- species with 5-10 % dominance - dominant
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- species with < 1 % dominance - subrecendent

For some of the organisms it was not possible to determine their abundance by counting, and therefore the relative quantity of organisms is shown by symbols (C, CC, CCC)* and grade of abundance (3, 4, 5, 6)* according to the methods of PÉRÈS and GAMULIN-BRIDA (1973).

*grade of abundance	characteristic of abundance	average number of individuals
1.	rr	to 0.5
2.	r	0.1-1
3.	±	1-10
4.	C	10-100
5.	CC	100-500
6.	CCC	over 500

Biological properties (frequency, dominance, abundance) were subjected by standard ecological methods according to ODUM (1971). The percentage frequency or presence (F %) and mean dominance (D %) are indicated for all the time and substrata studied at the tested sites (Table 1). The total covering rate for a test substratum is also presented (Table 2). The biomass was taken into consideration in the cases when the values were higher than 1 g on a test substratum and where there was no mud. The results shown in Table 2 are presented as average values of all analyses in the function of time, expressed on a surface of 1 m^2, while the data for current-meters were not converted into 1 m^2 and referred to the surface of a current meter.

The following statistical methods were used: diversity measures = indices of diversity and evenness, which are two different aspects that contribute to the concept of community diversity. Species richness, a measure related to the total number of the species present and equitability, expresses how evenly are distributed the individuals among different species (CLARKE and WARWICK, 1990). The most common diversity measure was calculated - the SHANNON-WEAVER index (H') (SHANNON and WEAVER, 1949); the MARGALEF

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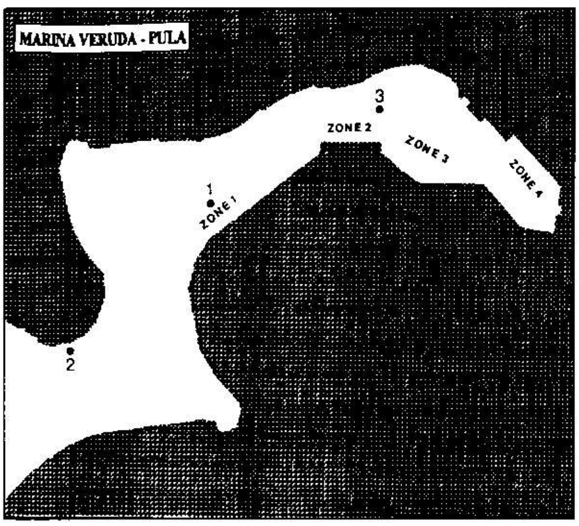

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RESULTS

In complex, fouling was rather homogeneous with a small number of species. Regarding the frequency and dominance of species in the communities accidental, accessory, recendent and subrecendent species were dominant (Table 1)

Fouling was rarely composed by the phytocomponent, especially by higher algae. Unicellular algae (Bacillariaceae) were constantly present, most commonly with the genera *Navicula* spp., *Nitzschia* spp., *Synedra* sp., while periphyton with silt covered completely all surfaces tested, especially at short-time exposures. Among animal foulers the most characteristic were some species from the Polychaetes group, cirripedes and to a certain extent Polyzoans (Tables 1, 2). Data on organisms with a higher frequency, with a distribution of over 10 % in the function of space, are shown in Table 2. The weakest settlement was on the current meters, while the most intensive was on plastic and particularly on concrete pillars (station 3). In the function of time at all three stations the weakest fouling was recorded after 15 days and it was mostly characterized by prevalent species (*Janua pseudocorrugata*, *Hydroides elegans*, *Balanus amphitrite amphitrite*) with the polyzoan *Schizoporella errata* and sinascidian *Diplosoma listerianum* at the reference station 2. All the other foulers (Table 1) settled with different intensity on several-month-exposed plates (Table 2).

Table 1. Qualitative list of the fouling species in Veruda Harbour at tested sites, with their percentage presence (constancy, frequency - F%) and mean dominance (D %)

Station	1		2		3	
	F %	D %	F %	D %	F %	D %
Cladophora prolifera (ROTH) KÜTZ	21.05	2.60	4.55	3.39		
Udotea petiolata (TURRA) BORGES	2.63	0.01				
Valonia utricularis (ROTH) C. AG.	2.63	0.01				
Ceramium sp. juv. form			4.55	7.08		
Corallinaceae (*Melobesia* sp.)	10.52	0.19				
Hydroidea indet.	13.16	0.32	13.64	3.80		
Ostrea edulis (LINNAEUS)	2.63	0.01	9.09	0.35	2.78	0.01
Mytilus galloprovinicalis LAMARCK	2.63	0.01			2.78	0.01
Venus verrucosa LINNAEUS	2.63	0.01			2.78	0.01
Hydroides elegans (HASWELL)	71.05	40.82	54.55	62.30	80.56	58.32
Janua pseudocorrugata (BUSH)	68.42	3.04	9.09	3.04	69.45	20.98
Filograna sp.	21.05	2.69	13.64	3.49	5.56	0.19
Balanus perforatus (BRUGUI RE)	5.26	0.03			5.56	0.06
Balanus amphitrite amphitrite (DARWIN)	44.74	7.03	45.46	7.78	66.67	20.46
Bugula neritina LINNAEUS			4.55	0.05		
Scrupocellaria betholletti AUDOUIN	2.63	0.03				
Cryptosula pallasiana (MOLL)	16.21	0.16			2.78	0.01
Schizoporella errata (WATERS)	31.60	1.08	54.55	7.38	8.34	0.06
Styela plicata (LESEUR)	2.63	0.01	18.19	0.75		
Ciona intestinalis (LINNAEUS)	2.63	0.01	4.55	0.40		
Diplosoma listerianum (MILNE-EDWARDS)	10.53	0.07	40.91	0.20		
Botryllus schlosseri (PALLAS)	7.90	0.04			5.56	0.01

Table 2. *Quantitative presence of common fouling species (frequency over 10 %) in relation to different substrata and depths - Veruda Harbour. A - glass plate, B - plastic plate, C - concrete pillar, D - current meter; N - average abundance, relative abundance: . (C), .. (CC), ...(CCC); G - grade of abundance; g - average wet weight; data are expressed as average values per square meter of substratum (A, B, C) and * on all parts of substratum (D)*

Station		1				2		3		
		A	B	C	D	B	D	A	B	C
Depth (m)		0.5	1.5-2.2	1	6	1.5-2.2	4 and 6	0.5	1.5-2.2	1
Cladophora prolifera	N	155	C	971		283				
	G	5	5	6		5				
	g			984						
Hydroidea indet.	N	69	31	124	1	242	1			
	G	4	4	5	3	5	3			
Janua pseudocorrugata	N	10733	1237	CC		150		4698	1906	
	G	6	6	5		5		6	6	
Hydroides elegans	N	759	3005	16	256	304	265	8786	19465	58
	G	6	6	4	5	5	5	6	6	
Filograna sp.	N	1431		168		292				
	G	6		5		5				
Balanus amphitrite amphitrite	N	537	691	56		103		4503	2209	348
	G	6	6	4		5		6	6	5
	g	69		24						
Schizoporella errata	N	80	102	1043	39	84	4		25	5600
	G	4	5	6	4	4	3		4	6
	g			8340						7860
Cryptosula pallasiana	N	86	25					8		
	G	4	4					3		
Diplosoma listerianum	N	77			1	462	36			
	G	4			3		4			
Styela plicata	N	35				63			48	
	G	4				4			4	
Average covering rate	(% m^{-2})	19	55	95	15*	29	17*	44	73	98
Average wet weight	(g m^{-2})	148	1550	9385	17*	9 25	16*	725	3275	8691

Station 1 - the biggest influence on the intensity of fouling had the biomass of the species *Sc. errata* (8340.0 gm^{-2}) as the colonies on concrete pillars reached the height of 10 cm. They were dead, partly broken and did not have their natural color. The alga *Cladophora prolifera* settled densely on the pillars (984 gm^{-2}) which carpet-like covered the surrounding sea bottom. The polychaete *H. elegans* very abundantly settled on the plastic test plates. After 2.5-3.5 months of exposure it fouled in average around 37.6 % to a maximum of 70-80 %. In that part of the Veruda cove the settlement of the barnacle *B. amphitrite amphitrite* was noticeable with the dominance of juveniles (in average 2.5 mm) that fouled the glass plates in average by 5.5 %, and preadult individuals (in average 5 mm) up to 15 % of the plastic test substratum. The fouler *J. pseudocorrugata*, due to its miniature dimensions, had no influence on the weight of fouling. The species appeared in July (*H. elegans*), August (*B. amphitrite amphitrite*) and lasted till the end of the experiment having their settlement peak from 03-22 August.

Station 2 - the mentioned species dominating in the Veruda Bay at the referent site settled weakly comparing to the other two tested sites. Therefore, at this station hydroids indet. and the species *D. listerianum* were more present (juvenile colonies prevailed). The ecologically important species *D. listerianum* was rather numerous as the colonies fouled the plastic plates from 7-50 %, and after 3.5 months of exposure some of the colonies reached the size of 100 mm. Similarly, the colonies of *Schizoporella errata* fouled up to 28-30 % and by the end of the experiment they covered the substratum from 85-95 %. The other foulers according to analytical remarks were of secondary importance (Tables 1, 2). The negligible settlement started in July (hydroids, *Schizoporella errata*), August (*B. amphitrite amphitrite, J. pseudocorrugata*) and September (*D. listerianum*). Generally, in this community the development was slower and the intensity weaker which especially reflected on almost unfouled short-time test substrata.

Station 3 - it is especially characteristic for the smallest number of species in macrofouling and higher number of genera in microfouling, particularly of diatoms (*Tabellaria* sp., *Achnantes* sp., *Licmophora* sp., *Striatella* sp.) and abundant Cyanophyta group. Among macrofoulers the species *B. amphitrite amphitrite* stood out with a frequency of 100 % (plastic plates, concrete pillars) and 86 % (glass plates). Juvenile individuals prevailed (2.5-3 mm in size), while preadult individuals (5-6 mm) rarely. Together, after 2.5 months of exposure, they fouled up to 55 % (plastic) and 68 % (glass). On concrete pillars the individuals were often in decomposition so it was difficult to identify them, and often they formed epibioses of the first and second rank. In that inner part of the bay the species *H. elegans* dominated, fouling the plastic plates from 60-90 %, and often it was impossible to count the individuals because of their dense fouling. Due to such occupation of the space other foulers overgrew the individuals of this species, e.g. juvenile colonies (2-3 mm) of the polyzoan *Schizoporella errata*. On the contrary, this polyzoan prevailed in the old biological material from the concrete pillars, where in 98 % of the cases the colonies were old, grown up to 150 mm, broken, black colored, dead with the unpleasant sulfide smell. In this locality fouling was the heaviest (Table 2), and the fouling process the quickest, double than in the middle of the bay ("Marina"), and twice more than at the referent station. In a record short time most of the plates were totally fouled by the dominant foulers. The colonization of the dominant species *B. amphitrite amphitrite* started earlier (June) in relation to the zone 1 (one month), and especially to the cleaner zone 2 (two months).

The values of diversity indices (Table 3) were the lowest at the station 3 and among selected parameters only the total number of individuals (N) and dominance (D) were higher than at the other two sites. Quite the opposite was at the station 1, all the parameters were at their highest except for the values of total number of individuals (N), evenness (J) and dominance.

Table 3. Spatial distribution of fouling ecological indices - Veruda Harbour (Pula). Note: S - species abundance; N - number of individuals (population diversity); d - MARGALEF's species diversity; Hmax - maximum diversity index; H′ - SHANNON-WEAVER diversity index; J - PIELOU's evenness index; D - dominance; SR - relation of number of species and total number of individuals

Station	1	2	3
S	20	13	11
N	520.64	341.52	691.87
SR	0.832693	0.649342	0.380179
d	3.037541	2.057117	1.529193
Hmax	4.321928	3.700440	3.459432
H′	2.682024	2.502297	1.649364
J	0.620562	0.676216	0.476773
D	0.379438	0.323784	0.523227

The similarity between the fouling communities was as follows:

Qualitative similarity (QS)
between stations
1:2 = 75.67 %
1:3 = 68.57 %
2:3 = 61.53 %

Quantitative similarity (QS_1)
between stations
1:2 = 35.0 %
1:3 = 49.0 %
2:3 = 9.0 %

The relatively smaller qualitative similarity between the fouling communities at stations 2 and 3 is due to the substantial abundance (abundance grade 6) of polychaetes and cirripedes at station 3 (Table 2), while at station 2 only the species *C. intestinalis* (abundance grade 4) was more present. A significantly smaller quantitative similarity between stations 1 and 2 was noted because of the enormous settlement of prevalent organisms (*J. pseudocorrugata, H. elegans, B. amphitrite amphitrite*) at station 1, or because of some other foulers (hydroids, *D. listerianum* and *C. intestinalis*) at station 2. On the quantitative higher similarity between station 1 and 3 (49.0 %) the biggest influence had the high abundance grade (6) of prevalent species at both stations. The weakest quantitative similarity between the communities at station 2 and 3 was influenced by the absence of some foulers in the communities of station 3 (*D. listerianum*, hydroids, *Filograna* sp., *Cladophora prolifera*), (Tables 1, 2).

DISCUSSION

In short-term investigations bioindicators have to be used independently of physical and chemical parameter measurements (as T°C, salinity, pH, oxygen, nutrients) since living organisms are used more widely for detecting the complete effects of environmental pollution (GRAY, 1981; KOVÁCS and PODANI, 1986). The fouling of the Veruda Bay for what concerns the qualitative-quantitative parameters is of a typical harbor character, homogeneous in species structure, with some species in the prevalent position, a characteristic of polluted waters (CRIPPEN and REISH, 1969; GRAY, 1982). In such communities organisms tolerant to environmental factors dominate, and they are of cosmopolite, nitrophile, euryhaline and eurytherm character (PÉRÈS, 1961). These species of a relatively higher numerical abundance and dominance are often considered to be the measures of successful adaptation (BRIGGS, 1974) and are called opportunistic species since they are living in an inadequate environment (PEARSON and ROSENBERG, 1978; HILY, 1983). Some species are typical indicators of harbour waters, especially the barnacle *B. amphitrite amphitrite* (SARÀ, 1976; RASTETTER and COOKE, 1979) and polychaete *H. elegans* (ZIBROWIUS, 1978; BIANCHI, 1981). In harbours they form the fouling facies *Hydroides-Balanus-Ciona* (RIGGIO, 1979). These organisms are found in the macrofouling of many Mediterranean harbours (RELINI, 1980), especially in those with urban pollution to which they are resistant, where they create extreme weights and change the state of the environment (RELINI *et al.*, 1972). Most of the harbours with inner waters under the impact of urban pollution, of a high amount of organic matter and high concentration of nutrients, bacteria or low dissolved oxygen are characterized by a most intensive and quick fouling process (CANTONE *et al.*, 1980; RELINI, 1980), as recorded at station 3.

In the Veruda Bay the most common species in the communities were *H. elegans, J. pseudocorrugata* and *B. amphitrite amphitrite* similar to many other harbors, *e.g.* in Spain (ARIAS and MORALES, 1979; MORALES and ARIAS, 1979), even in the harbours of the far Japan (KAWAHARA, 1965, 1969). In the harbour fouling the species *H. elegans* forms dense communities on immersed surfaces where it colonizes in a way typical for pioneer species, quickly and in a large number on all sorts of substrata (BIANCHI, 1981; MATARRESE *et al.* 1983). Such a quick and intensive settlement of this species was particularly noted on plastic plates, probably because of the micro relief structure of these substrata (divided into squares). But on concrete pillars in the old biological material the settlement was negligible, partly because of the spatial competition and defence mechanisms of the polyzoan *Schizoporella errata*. Besides, due to the decomposition process of the material it was not always possible to identify the individuals of this species. Considering the environmental quality, the tuberworm *H. elegans* is highly adaptable to harbours with strong eutrophication as well as with a low water exchange. This species is common in environments with waters rich in organic contents from sewage systems, high mean summer temperature, high turbidity level, and noticeable concentrations of hydrogen sulfide near the bottom (RIGGIO, 1979). Situations like that one were very similar to those registered at station 3. This species is also settled at the reference station 2, in cleaner waters with a low organic content and active water-change as it was proven for other such sites (RIGGIO, 1979).

Another important species, *Balanus amphitrite amphitrite*, similarly to the previous species, tolerates the same conditions and quality of the environment, and with a wide ecological valence it prefers organic pollution (IGIĆ, 1994), heavy or relatively lower enriched pollution (especially near sewage outfalls; SARÀ, 1976), higher $N\text{-}NH_4$ concentrations, oxygen depletion (low oxygen saturation; RELINI and RELINI-ORSI, 1971). Due to the fact that this species has developed an ecological capacity, and lives in badly polluted environments (CECERE and MATARRESE, 1983), especially in protected ones, as for instance in coves (YAMAGUCHI, 1977a,b; ANIL *et al.*, 1990). Therefore, it was not surprising that this barnacle was the most abundant one at station 3. The old biological material did not give us the insight of the real state since all the individuals could not be identified because of the high mortality of the crashed shells (stations 1,2) and degradation process (station 3). Such a phenomenon was characteristic for the species *J. pseudocorrugata* but the situation was much more complicated due to the miniature and delicate habits of this fouler, or with *Filograna* sp. and its identification in the material on concrete pillars. Especially, the tubeworm *J. pseudocorrugata*, although abundant in this investigation, due to its miniature size did not have a significant ecological importance for what concerns the covering rate. But as a fouler the tubeworm

H. elegans, and generally Sprirobidae of the Mediterranean, is one of the pioneers in the fouling complex and it settled as one of the first foulers in 15-day periods (RELINI *et al.*, 1970; MATARRESE *et al.*, 1983).

Between other species, the polyzoan *Schizoporella errata* is worth mentioning, which at station 3 was severely endangered because of the degradation process on concrete pillars. On the test plates such a degradation process of fouling did not occur, as the communities were of recent origin and the colonies of the species reached only the juvenile phase, most probably because of the spatial competition, and besides the colonization process was in progress. The relation of this polyzoan to the degree of pollution could be defined very difficulty because of a wider ecological valence in relation to pollution. But, because of that, the species *Schizoporella errata* is more frequent in cleaner than in a semi-polluted waters (IGIĆ, 1994), although some of the records come from harbor installations (HAYWARD and RYLAND, 1979).

The vegetation in such conditions, *i.e.* phytoplankton, was abundant and macroalgae were absent (Table 1, station 3). In inner harbour waters, with a low water exchange, the overabundance of nutrients favorable for an uncontrolled algal growth is characteristic. During summer, especially in anoxia conditions, macroalgae rapidly decompose (SFRISO *et al.*, 1988), nutrients are suddenly released in very high concentrations into the water, triggering phytoplankton blooms (PAVONI *et al.*, 1990). Such a process took place during summer at station 3, while for the winter period, when phytoplankton systematically decreases (SFRISO *et al.*, 1988) we have no evidence as there were no investigations in that period. But, at the other two stations the vegetation was slightly more presented by the macroalga *Cladophora prolifera* (station 1) indicating a medium degree of eutrophication, as indicated by *Cladophora* spp. and *Caulerpa* sp. in some Indian harbors (TEWARI and JOSHI, 1988).

Concerning the relation of organisms and surface type (Table 2) it could be said in general that the most common organisms and most of the leading animals settle on rough (plastic plates, concrete pillars), black, shaded and under horizontal surfaces (plastic plates), rather than on smooth, illuminated and vertical surfaces (glass plates), and on the concave rather than on convex surfaces (RIGGIO and Di PISA, 1982; CLIFFORD *et al.*, 1989, 1992; WALTERS and WETHEY, 1996; HILLS and THOMASON, 1996, 1998). The weakest fouling was registered on current meters (Table 2), but not because of their convex surface, since we have previous evidence that such substrata were completely fouled, especially with the foulers *B. amphitrite amphitrite, H. elegans* and Hydroidea (IGIĆ, unpublished). One of the hypotheses is that it was because of their position close to the muddy bottom, and possibly shorter exposure time. It is especially supposed that the weakest fouling on current meters was caused mostly by strong sea currents on that side of the coast of the bay where the instruments had been immersed (up to 40cm s^{-1}).

In shallow and closed areas, most characteristic in bays with low water recycling, due to the low inflow of nutrients, the entrance of oxygenated waters from the open sea is prevented. Most data suggest that eutrophic conditions are limited to the innermost part of a bay (KOCATAS and GELDIAY, 1980; THEODOROU, 1995), or a lagoon (PAVONI *et al.*, 1990), often with characteristics of anoxic conditions in summer (FRILIGOS and ZENETOS, 1988) creating an azoic zone (KOCATAS, 1980). In such areas almost simultaneous processes of biomass production and decomposition are established as it happened at station 3. During decomposition process respiration exceeds photosynthesis and water becomes an anoxic, with the presence of hydrogen sulphide and other reduced sulphur compound.

The degree of pollution is estimated on the basis of biodiversity ecological indices. Our results show that all parameters, except for the number of individuals, had the lowest values in the inner part of Veruda Bay (Table 3). CLARKE and WARWICK (1990) consider such a diversity decrease (*e.g.* H′), species richness (*e.g.* d), evenness (*e.g.* J), dominance increase (D) as the criteria for the determination of stress levels. Thus, it could be formulated that environmental stress mainly affects the evenness compound. This agrees well with the hypothesis of TRAMER (1969) that under unpredictable, in some respect, extreme conditions diversity is regulated by evenness, while a predictable (stable) system is regulated by species richness. When the stations are compared for what concerns species richness, an increase could be seen from totally polluted to clean zones (KOCATAS and GELDIAY, 1980). But, this could not be said for our investigations as in the cleanest zone (station 2) the species richness was not at the highest (Table 3). Species richness and equatability were generally low in the Veruda Bay. Equatability was found to be inversely related to population density (station 3). Naturally, the lowest values were marked at stations with species population at their peak resulting from the increase in density of one or few species (FRONTIER, 1985; HUSTON, 1985) as it was the case at stations 1 and 3 (Table 2). Low indices were also at station 2, probably because of the fact that communities did not show notable structural changes, happening when the number of species and individuals is small (PEARSON and ROSENBERG, 1978), or maybe because of the low level of nutrients (RASTETTER and COOKE, 1978; MADHUPRATAP and ONBÉ, 1986).

On the basis of biological characteristics (structure and dynamics of communities; ecological indices) the inner part of Veruda Bay delineates the extent of the "polluted" zone with the beginning of anoxic conditions, as it is the case in some bays during summer in the near-bottom layer (azoic zone; KOCATAS, 1980; FRILIGOS and ZENETOS, 1988). The other stations according to ecological indices negligibly differed. It is to be said that at station 1 the process of fouling was more intensive and quicker with an abundant presence of bioindicators of organic pollution (*B. amphitrite amphitrite, J. pseudocorrugata, Styela plicata, Cryptosula pallasiana*), and that the region is moderately polluted and weakly eutrophied. At the entrance of the bay, the community dynamics decreased, the fouling intensity was weaker, the bioindicators of organic pollution were less present, but bioindicators of cleaner waters (Hydroids) were relatively more present. Therefore, the entrance of the bay, referent station 2, could be described as an intermediate between "semi-polluted" and "semi-healthy" stage, *i.e.* cleaner zone. The terms "polluted", "semi-polluted" and "semi-health" and divisions were made by KOCATAS and GELDIAY (1980) on the basis of almost identical criteria for benthic communities.

Taking into consideration the number of ship berths (350) at station 1, during a contemporary analyses of antifouling paints used in the Veruda Bay, a high concentration of toxic elements (Tl, Cu, Zn, Pb, Sn) in these protection coatings was detected. Parallel concentrations of heavy metals (Fe, Cu, Zn, As, Pb, Sr), toxic elements in antifouling paints, were tested in the sediment and chosen organisms (*Phallusia mammilata, Udotea pethiolata, Cladophora prolifera*). The results showed that concentrations of Zn and Cu were higher at station 3 than legally allowed concentrations (LUCU, unpublished). In some other marinas, the major impact was found to be the build-up of heavy metals (Pb, Cu, Zn, Hg) and were not indicative for a significant water pollution (McMAHON, 1989). Especially in marina areas people should be very cautious while applying modern antifouling coatings with biocidal organotins (TBT, TFT) with tin (as used in the Veruda Bay) on navigable objects. Namely, significantly lower TBT (tributyltin) concentrations generally occur in non-marina areas (HALL, 1988), while maximum concentrations occur in marina or harbour areas at the beginning of the boating season when freshly painted boats enter the water (HUGGETT *et al.*, 1986).

CONCLUSIONS

The panel monitoring technique of fouling used in this *in situ* study might be useful in establishing the ecological realistic effluent standards. Fouling was of a typical harbour character, most intensive at the inner station 3, and weakest at the entrance at reference station 2. In the inner part of the bay due to the low water exchange and rich organic matter bioindicators of organic pollution were significantly present, very harmful to navigable objects (barnacle *Balanus amphitrite amphitrite*). The older biological material was in a degradation stage with beginning signs of anaerobic processes. It is expected that the inner bay would be transformed into an azoic zone in the near future.

Due to the increase of boating activities in the Veruda Bay the marina management authorities and public have expressed their concern for the deterioration of water quality induced by the development of the marina.

The widening and improving of water circulation within the Veruda Harbour is advisable, while it is not advisable to expand number of boat berths. The number of boat berths could be expanded in areas close to the open sea. Besides, it is not recommended to use antifouling coatings based on tin (TBT, TFT) because of its high toxicity and persistence in the sea.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the financial support provided by the Ministry of Science and Technology of the Republic of Croatia.

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Accepted: 9 March 1999

Značaj istraživanja obraštaja za procjenu izgradnje marina

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SAŽETAK

U područjima gdje su izgrađene marine nastaju potencijalni problemi zbog pogoršanja kvalitete sredine, uzrokovani urbano-industrijskim zagađenjem, a posebno teškim kovinama iz antivegetativnih premaza za sprječavanje obraštaja na plovnim jedinicama.

Budući da se kvaliteta sredine može najbolje odraziti na pričvršćenim organizmima, kao što su uglavnom obraštajni organizmi, istraživanja su obraštaja korisna kod testiranja sredine, podvodnih dijelova plovnih jedinica, hidropostrojenja itd., prije svega zbog njihovog sprječavanja.

U studiji je utjecaja na okolinu "Marina Veruda" (Pula) bilo uključeno istraživanje obraštaja s ciljem da se na osnovi kvalitete i intenziteta obraštajnog kompleksa omogući lakša procjena značajki sredine. Osim toga, nastojalo se procijeniti intenzitet i brzina obraštajnog kompleksa u funkciji vremena na plovnim i drugim objektima, a što bi bilo značajno kod predlaganja kapacitiranja brodova i čamaca u pojedinim dijelovima Verudskog zaljeva.

U kratkoročnim istraživanjima obraštaja (3.5 mjeseca) u vrijeme sezone rada marine, obraštaj je po sastavu bio tipičnog lučkog značaja, sa samo tri prevladavajuće vrste (*Janua pseudocorrugata, Hydroides elegans, Balanus amphitrite amphitrite*), karakteristične za organsko zagađenje. Poslije 3.5 je mjeseca najizraženiji bio obraštaj u unutarnjem (3375 gm-2), slabiji u srednjemu dijelu (1550 gm-2) gdje je smještena marina (350 vezova) i neznatan na ulazu u zaljev (926 gm-2). U unutarnjem najplićemu dijelu, sa slabim kruženjem vode, bogatim sadržajem organskih tvari i početkom anaerobnoga procesa, obraštajni je proces bio dva puta brži nego u najčišćemu dijelu na ulazu u zaljev. U tako eutrofiziranom unutarnjemu dijelu zaljeva učinak zaštitnih antivegetativnih brodskih boja znatno brže slabi, što bi u rekordnom vremenu ugrozilo područje s otrovnim pigmentima. Također, istodobna su istraživanja teških kovina u Verudskom zaljevu pokazala samo u tome dijelu uvale nešto veću nedozvoljenu koncentraciju bakra i cinka u sedimentu (LUCU, neobjavljeno). Na osnovi se iznijetoga predlaže da se marina ne proširuje u unutarnjemu dijelu uvale, već što je moguće više k najčistijem ulaznomu dijelu zaljeva.