
5. Colonization by benthic algae on submarine in the southeastern area of the Gulf of Trieste

Research unit

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Introduction

Colonization by benthic algae is a complex process, which runs through several stages, and also involves several intricate problems. It is dependent on the neighbouring vegetation, hydrographic conditions, water movement that prospers the transport of spores and propagula, sedimentation, turbidity, and the geological structure of the sea floor. It was studied in many different areas, as e.g. by Huvé, 1969; Kain, 1975; Belanger & Cardinal, 1977; Emerson & Zedler, 1978; Munda, 1977, 1985, 1991a; Murray & Littler, 1978; Gorén, 1979; Markham & Munda, 1980; Hawkins, 1981; Chalmer, 1982; Niel, 1979; Niel & Varela, 1984; Badalamenti *et al.*, 1984; Riggio *et al.*, 1985; Fernandez & Myares, 1989; Benedetti-Cecchi & Cinelli, 1992; Della Valle *et al.*, 1993; Falace & Bressan, 1994, 1999a, b, 2002; and others.

Our present interest in algal colonization is focused on conditions in the Gulf of Trieste, which is a shallow marine basin with maximum depths to 25m. There are only two depressions near-shore, at Punta Madonna, Piran and the cape of Salvore, with 37m and 40m depth respectively. The gulf is separated from the rest of the northern Adriatic by a shoal, running from Grado to Salvore. The most precise bathymetric chart of the area was done by Ranke (1976). The sedimentation rate is high in the gulf. In its central area, the sediment layer is about 230m thick, and 40m

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near-shore. There are, however, differences in the geological structure within the Gulf of Trieste, which are decisive also for the distribution of the benthic algal vegetation. Several geomorphological and geochemical studies deal with this complex area (e.g. Brambati & Venzo, 1967; Brambati, 1968; Giorgietti *et al.*, 1968; Ranke, 1976; Rossi *et al.*, 1969; Brambati & Catani, 1988; Ogorelec *et al.*, 1991; Faganeli *et al.*, 1991). There is a nearshore Karst area of Cretaceous limestone in the northwest, with Holocene alluvial deposits, and an enclave of Eocene flysch in the southeast, between Muggia (Milje) and Salvore, with a solitary limestone enclave at Izola. In the northwest sediments derive mainly from the river Isonzo, and from flysch erosion in the southeast.

Differences in the bottom configuration are, however, reflected in the distribution of the benthic algal vegetation. In the southeast it extends to about 10m deep, coinciding with the hard substrata. In the northwest, on the other hand, the sublittoral slopes are mainly covered by biogenic sediments, silt and clay, with a poor or even absent benthic algal vegetation.

The aim of this present work was, however, to observe differences of macroalgal colonization on artificial substrata in the northwest and the southeast of the Gulf of Trieste. This contribution deals with algal colonization on concrete structures (plates, pyramids) and plastic nets, placed sublittorally at a reference locality Punta Madonna outside Piran (Fig. 5.1). Extensive colonization experiments are running, on the other hand, at Punta Croce in the northwest of the gulf.

Hydrographic conditions and study area

In February/March, the water temperature is at its minimum and increases with depth. In April, the opposite trend was found at an elevated surface temperature over 11°C. In May, isothermic conditions occurred, and later, during the period from June to August, a temperature decrease with depth. Seasonal variations in salinity were, as usual in the Adriatic Sea, opposite to those of the water temperature, with minima in June/July and maxima in February/March. There was a general trend of salinity increase with depth. A decrease in inorganic N and P was usual during summer, when the phytoplankton blooms deplete the water of primary nutrients.

The shallow Gulf of Trieste contains approx. 9Km² water (Orožen Adamič, 1981) and receives a heavy load of industrial wastes and domestic discharges, leading to eutrophication and pollution (Ghirardelli *et al.*, 1973; Chiaudani & Vighi, 1982; Tušnik *et al.*, 1989; Degobbis, 1989; Justić, 1997).

The bottom topography is responsible for the course of the main currents in the Gulf of Trieste, and the Adriatic as a whole (Zoré Armanda, 1968). A regular circular subsurface current transfers river-born and urban pollutants around the gulf

(Mosetti 1972, Stravisi 1983). There are, however, seasonal variations in the surface circulation. Variations within the current system are also dependent on the bora wind, which blows in an offshore direction (Zoré Armanda & Gačić, 1989).

Our vegetational studies within the Gulf of Trieste are located in its southeastern area, which is dominated by Eocene flysch and has a high degree of sedimentation. The bays of Muggia, Koper (Capodistria) and Piran are, however, submersed valleys of the rivers Dragonja, Rižana and Rosandra. Sediments of silt and clay are found in a narrow zone to about 5m bathymetric line. The detrital material originates from flysch. Lower down there are sandy slopes with biogenic deposits. The locality Punta Madonna where colonization experiments were carried out is situated in front of a northeast facing, heavily exposed concrete platform. The tidal range varies between 0.25m and 1.20m. In the sublittoral there are bigger stones and boulders and some horizontal rocky surfaces, mainly of flysch. There are, however, a few allochthonous limestone rocks in between. The hard substrata, reaching to about 9m depth, are surrounded by a sedimentary bottom of silt and clay, and lower down by fine grained sand. The coast slopes gently to 10m depth, and from there on steeply towards the sediment bottom. There is a threshold between the two slopes, which is broader on flysch than on limestone grounds (Ogorelec *et al.*, 1991).

Main features of the benthic algal vegetation around Piran

Vegetational studies in the southeast of the Gulf of Trieste were sporadically conducted along the coast line between Muggia and Salvore. Special attention was focused to the surroundings of Piran, where colonization experiments were carried out. It will be roughly presented here in order to elucidate the colonizing events.

Schemes of three different vertical transects near Punta Madonna are presented in Figs. 5.2, 5.3 and 5.4. There are mainly two types of the benthic algal vegetation: one dominated by furoids and the other poor or deprived of both *Fucus virsoides* J. Ag. and *Cystoseira* species. The eulittoral vegetation is poorly developed around Piran. It is mostly occupied by ephemeral species in spring. *Bangia atropurpurea* (Roth.) C. Ag., *Ulothrix* species, *Porphyra leucosticte* Thur., diverse *Ulva* species and *Scytosiphon lomentaria* (Lyngb.) Link. follow each other in a vertical sequence, while the slopes are mostly clean during summer. *Fucus virsoides* is rare and has a sporadic distributional pattern in the area. In the lower eulittoral and upper sublittoral there are perennial mats of *Gelidium* and *Gelidiella* species.

The sublittoral vegetation has a patchy distribution, due to the uneven substrata, and is not distributed into clear-cut zones. There are islets of benthic algal populations on the rocks, surrounded by soft substrata. Along the transect presented in Fig. 5.2.

the sublittoral slopes are to a great extent dominated by an association between *Dictyota dichotoma* and *Stypocaulon scoparium* (L.) Kützing, which follow each other in a “tiger-like” pattern. This association proved to be characteristic of moderately polluted sites (e.g. Munda 1993a, b), *Cystoseira* species (*C. compressa*, *C. barbata*) are found only sporadically in single, scattered specimens. In the upper sublittoral there are usually dense mats of *Corallina officinalis* L. as well as patches of *Pterocladia capillacea* (Gmel.) Santelices et Hommersand, with *Ulva rigida* C. Ag. and diverse tiny representatives of the Ceramiales dominated by *Ceramium ciliatum* (Ellis) Duclz. and *Callithamnion corymbosum* (Smith) Lyngb., which form prolific mixed populations in spring.

The second transect, presented schematically in Fig. 5.3. is floristically richer and dominated by fucoids. *Fucus virsoides* is belt-forming eulittorally, while in the sublittoral *Cystoseira* species form islets of dense populations, first of all *Cystoseira compressa* and *C. barbata*, and lower down the sublittoral also *C. amentacea*. Diverse companion species are found in between the *Cystoseira* stands, as e.g. *Ulva rigida*, diverse other *Ulva* species (former *Enteromorpha*), *Corallina officinalis*, *Jania rubens*, *Padina pavonica*. Lowermost follow several crustose floristic elements, forming the undergrowth, as e.g. *Zanardinia typus*, *Peyssonnelia* species, *Codium effusum* (Raf.) Delle Chiaje and diverse crustose corallines.

Fig. 5.4. presents a *Cystoseira*-dominated sublittoral transect. *Cystoseira* stands are locally interrupted by continuous populations of the perennial *Halopythis incurvus* (Huds.) Batters, which is heavily epiphytized. Also *Cladostephus spongiosus* (Huds.) C. Ag. f. *verticillatus* (Lightf.) Prud'homme van Reine forms patches of pure stands in between the *Cystoseira* populations. *Dictyota dichotoma*, *Stypocaulon scoparium* and *Padina pavonica* are interspersed between the sublittoral stands. Noteworthy is also the occurrence of usually deep-water species close to the surface, as e.g. *Codium* species (*C. bursa* (L.) C. Ag.), *Halimeda tuna* (Ellis & Sol.) Lam., *Rhodymenia pseudopalmata*. The most frequent are, however, *Cystoseira compressa* and *C. barbata* followed by *C. amentacea*, while *C. schiffneri* is found in the lower sublittoral, mainly in single specimens. Regarding the rest of the fucoids, both, *Cystoseira crinita* Duby and *C. corniculata* (Turn.) Zanard. are rare, while *Sargassum hornsouchii* was absent in the area during the time of our studies.

A complete floristic list and vegetational description of the surroundings of Piran is in preparation.

Methods

Concrete pyramids, constructed of octangular plates with holes (diameter 80cm with edges of 33cm) were placed at 5m and 9m depths at Punta Madonna (Fig. 5.5a, 5.5b) in June 2003. Colonization by macroalgae was observed by Scuba diving after 2 months, 6 months, and later after 12 and 24 months. Samples were taken by scratching off the surface of each side of the pyramids. They were preserved in 2.5% of formaldehyde in seawater and taken to the laboratory for further investigation. At the same time, a plastic net with meshes of 45mm and 3mm thick was fixed to one side of the lower pyramid.

After 24 months, the total surfaces of the pyramids were scratched clean and the net removed as a whole.

In August 2005, a further set of nets was placed at 5m and 9m depths and fixed to the surface of the rocks. Two nets were used at each depth. The surface of each net was 1m². These experiments are still in progress. For the relative abundance of the single species an arbitrary scale was used, like in my previous works (e.g. Munda, 1978, 1979, 1991a, 2005):

D-dominant	CD-codominant
M-common	A-abundant
R-rare	RR-very rare
S-single specimens	

Previous experiments with concrete plates were carried out at the same locality at Punta Madonna (Munda, 1991a). The plates were placed at 1m, 3m and 7m depths, two at each level. One plate was scratched clean monthly, while from the other only representative samples were taken. This method allowed studying both, the seasonality of colonization and its succession. Results of previous experiments, which were running for one year with monthly samplings, are compared with the recent ones.

Results

The very first stage of colonization observed on the pyramids at both depths were rounded, a few mm wide patches containing *Polysiphonia tenerrima* cf. (Fig. 5.6). The plants with four pericentral cells were 2 to 5mm long and fertile, with viable spores (Fig. 5.7). The first colonization of still undeterminable crustose corallines was slightly indicated. Observations after 6 months from the start of the experiment revealed a development of crustose floristic elements, such as *Peyssonnelia squamaria*, *Lithophyllum incrustans*, *Zanardinia typus*. A few red algae appeared beside *Polysiphonia tenerrima*, such as *Boergeseniella fruticulosa* and *Ceramium*

codii. At this stage brown algae were outstanding, first of all *Dictyota dichotoma*, *Stypocaulon scoparium*, *Padina pavonica* and *Ectocarpus siliculosus*. Small plants of *Cystoseira compressa* appeared scattered.

Chlorophyceae were absent in the fouling community, and the animal fouling component was already conspicuous, first of all the Bryozoa.

After 12 months, the poorly developed fouling community was improved and enriched by several red algae. *Erythrotrichia carnea* and *Audovinnella membranacea* were found singly, while the previously present *Boergeseniella fruticulosa* and *Ceramium codii* increased in quantity. The prolific growth of *Antithamnion cruciatum* is noteworthy. Observations were carried out, however, in August, when this species was already absent from the upper water levels, where it forms prolific populations in spring together with other tiny representatives of the Ceramiales. Creeping representatives of the Rhodomelaceae, such as *Dipterosiphonia rigens* and *Lophosiphonia obscura* became conspicuous, as did some *Polysiphonia* species, first *Polysiphonia sertularioides*. Characteristic of the vegetational aspect were bushes of *Wrangelia penicillata* at 5m depth.

At this time the fouling community became dominated by juvenile plants of *Cystoseira compressa*, which exhibited a high degree of cover. *Cystoseira barbata*, on the other hand, appeared only in single specimens at 9m depth. Among the brown algae, *Dictyota dichotoma* was abundant, and even dominant at the lower pyramid. *Halopteris scoparia* was still rare, as did the diverse *Sphacelaria* species. *Padina pavonica* diminished in quantity, while *Ectocarpus siliculosus* disappeared. *Zanardinia typus*, on the other hand, increased prominently in quantity and dominated the lower stratum.

In general, after one year of inundation the pyramids were colonized to a great extent by crustose, prostrate floristic elements (*Zanardinia typus*, crustose corallines, *Peyssonnelia* species).

The increased amount of the animal colonizing species is noteworthy, first of all representatives of the Bryozoa and Tunicata.

After 24 months, at the final observation, the concrete pyramids were covered by a sedimentary layer, embedded into a gelly, amorphous matrix, which suffocated greatly the macroalgal fouling community. Nevertheless the colonization by macroalgae was improved both, regarding the number of species and the degree of cover. *Cystoseira compressa* was dominant at both levels, forming relatively prolific stands of 3 to 10cm long plants. They were already epiphytized by *Titanoderma cystoseirae*, *Sphacelaria* species and a few red algae. Thus, a stratification of the colonizing algal community was already established. Second in abundance of the *Cystoseira* species was *C. amentacea*, found mainly as its basal

parts (tophuli). *C. barbata* was relatively rare, while *C. schiffneri* was found at 9m depth in single specimens.

Particularly noteworthy is the find of up to 10cm long plants of *Sargassum hornsouchii* at 5m depth.

Main colonizing species from the pyramids at 5m and 9m depths, scratched from about 1/2 of the side of a pyramid, and placed in plastic dishes, are presented in Figs. 5.8 and 5.9 (*Cystoseira* species, *Sargassum hornsouchii* and *Zanardinia typus*).

Among the brown algae representatives of the Dictyotales were less abundant than before (*Dictyota dichotoma*, *Dilophus fasciola*) while *Padina pavonica* disappeared. *Halopteris scoparia* was still present and some of the *Sphacelaria* species became more abundant (*S. cirrosa*, *S. plumula*) and a few joined the vegetation on the pyramids (*S. tribuloides*, *S. nana*). Noteworthy is the find of *Striaria attenuata*, and the prominently increased quantity of *Zanardinia typus*, which covered the greater part of the surfaces not colonized by the Bryozoa and Tunicata.

Green algae were, however, even after two years of exposure, absent.

Among the red algae, several additional species joined the colonizing community, such as e.g. *Stylonema alsidii*, *Audouinella* species, *Ceramium diaphanum*, *C. tenerrimum*, *Gelidiella* species, *Gracilaria gracilis*, *Rhodymenia pseudopalmata*, *Radicilingua thysanorhizans*, *Spermothamnion flabellatum* and a few others. The crustose algae extended, beside *Zanardinia typus*, over the greater part of the disponible area. *Peyssonnelia squamaria* increased in quantity, as did *Lithophyllum* sp. and *L. incrustans*, joined by *L. stictaeforme* and *Phymatolithon purpureum*.

The general aspect of the colonizing community on the perforated concrete pyramids was a prostrate and well developed undergrowth of crustose algae, dominated by *Zanardinia typus*, and an upper stratum, dominated by *Cystoseira* species, first of all *Cystoseira compressa*. Epiphytic species found on the *Cystoseira* thalli proved, however, a three layered stratification of the colonizing community.

The inner surfaces of the submersed concrete pyramids were likewise examined. They proved to be bare of macroalgae and colonized by Avertebrata.

The only algal species was *Spirulina* sp., found in entangled mats. The surfaces were covered by the Bryozoan *Membranipora membranacea* and *Schizobranchiella sanguinea* in an almost continuous layer, interspersed by gelly mats of the Tunicate *Diplosoma listerianum*. They were covered by sediment grains and were present, however, also on the outer surfaces of the pyramids. The Hydrozoans were represented by *Eudendrium rameum*.

Colonizing by macroalgae on plastic nets gave a slightly different picture. A net, fixed to one side of the lower pyramid at 9m depth was examined after 24 months of inundation.

About one third of the plastic net (1/2m²) was totally clean. The rest was covered by *Cystoseira* species, first of all *C. compressa*, in up to 10cm long plants. Like on the pyramids, *C. amentacea* was rather frequent, but appeared mostly as its basal parts (tophuli). *C. barbata* was rare, found only in single specimens. It seems likely, however, that the smooth surface of the plastic nets favours the attachment of the *Cystoseira* thalli. As contrast to conditions on the pyramids, *Dictyota dichotoma* was rare and *Dilophus fasciola* absent. *Stypocaulon scoparium* was abundant on the meshes of the net, and *Sphacelaria* species were well represented. Like on the pyramids a crustose algal layer was well developed. It was dominated by *Zanardinia typus* and accompanied by *Peyssonnelia squamaria* and crustose corallines. On the net, *Polysiphonia* species were especially well represented, as e.g. *Polysiphonia furcellata*, *P. opaca*, *P. fucoides*, *P. tenerrima* cf. and *P. sertularioides*. Conspicuous was also *Dipterosiphonia rigens*. A characteristic feature of the colonizing community was the abundance of *Rhodymenia pseudopalmata*.

A few species, not found on the concrete pyramids, were found on the plastic net, such as *Rhodophyllis divaricata*, *Rityphloea tinctoria*, *Crouania attenuata* and *Griffithsia opuntioides*. In general, however, fewer species were found as on the pyramids.

A noteworthy contrast to conditions on the concrete pyramids was the presence of green algae, although only in fragments (*Cladophora prolifera* and *Cl. rupestris*). Further experiments about colonization on plastic nets, carried out by Battelli, are still in progress.

Colonization on submersed concrete plates

Previous experiments with submersed concrete plates, placed at different depths at Punta Madonna (1m, 3m, 7m) were run during one year. Two plates were placed at each level in order to follow the seasonal course of colonization and at the same time the succession of the colonizing events (Munda, 1991a).

As contrast to the perforated pyramids and the plastic nets, the concrete plates represent a continuous virgin surface placed horizontally on the sea floor. On the plates, denuded monthly, the seasonality of colonization could be followed, and on the permanent plate the succession of colonization.

On these concrete plates, however, diatoms were the primary and most outstanding colonizers (Munda, 2005). During the first stages of colonization, the plates were covered by an almost continuous gelly layer of colonial diatoms with *Berkeleya* species as dominant (Fig. 5.10a, 5.10b). Macroalgae were in minority. In spite of a relatively high number of colonizing species their degree of cover was less than

50%. Macroalgae appeared succeedingly at the different depths, contributing to the physiognomy of the diatom-dominated fouling community. They increased toward the end of the year regarding the number of species and their relative degree of cover. In autumn, the dominant colonial diatoms of the genus *Berkeleya* were in decline, and were replaced by gelly, polychotomously branched, up to 1 cm or more high colonies of *Navicula ramosissima* (C. Ag.) Cleve (Fig. 5.11). They exhibited the habitus of a macroalga.

Among the colonizing brown macroalgae, *Zanardinia typus*, *Scytosiphon lomentaria*, *Dictyota dichotoma*, *Stypocaulon scoparium* and *Sphacelaria* species were the most common. Small germlings of yet undeterminable *Cystoseira* sp. appeared only later during the year, in summer. During the time of our observations, they were inconspicuous in the fouling community.

Conspicuous among the brown algae was also *Padina pavonica*.

Red algae were poorly represented quantitatively. In spite of a relatively high number of colonizing species they appeared mostly in single specimens or in small patches (representatives of the genera *Antithamnion*, *Pterothamnion*, *Algaothamnion*, *Ceramium*, *Neomonospora*, *Ptilothamnion*, *Spermothamnion*). During the second half of the observation period, *Gelidiella* species joined together with crustose red algae (*Hildenbrandia rubra* (Sommerf.) Menegh., *Phymatolithon* and *Lithophyllum* species).

As contrast to conditions on the pyramids, green algae were found.

There were several differences in the colonizing events related to depth.

At a 1m depth macroalgae were initially represented only by a few filaments of *Ulothrix* sp. and *Oscillatoria* sp. on a surface densely covered by *Berkeleya* spp. colonies. In April *Scytosiphon lomentaria* appeared on both of the experimental plates. On the permanently exposed one, single juvenile specimens of *Dictyota dichotoma* and *Stypocaulon scoparium* appeared in April. In May, *Scytosiphon lomentaria* still proved its seasonal appearance. Fouling by macroalgae continued succeedingly by addition of new species. It was even intensified in June, when *Scytosiphon lomentaria* still appeared on the monthly denuded plate, while it was already absent from the neighbouring vegetation. *Lithophyllum incrustans* appeared on the permanent plate together with representatives of the family Ceramiaceae (e.g. *Ptilothamnion pluma*, *Antithamnion* and *Aglaothamnion* species). In July, colonization by macroalgae proceeded. *Scytosiphon lomentaria* was absent at this time, but other species joined (*Padina pavonica*, *Cystoseira* sp. germlings, *Zanardinia typus*, *Polysiphonia* and *Ceramium* species). Simultaneously the *Berkeleya* spp. colonies were in decline and polychotomously branched, up to 1cm

high colonies of *Navicula ramosissima* became outstanding. In August, crustose, prostrate, floristic elements were conspicuous within the macroalgal colonizing community, while the *Berkeleya* colonies disappeared (*Phymatolithon purpureum*, *Lithophyllum incrustans*, *L. stictaeforme*, *L. sp.*, *Hildenbrandia rubra*, *Zanardinia typus*). They were found on the permanent plate and contributed notably to the percentage of cover. On the monthly denuded plate the seasonality of colonization was obvious also for *Cystoseira* sp., *Dictyota dichotoma* and *Stypocaulon scoparium* along with *Zanardinia typus*. Finally, in October, the increased macroalgal colonization indicated the initiation of a *Stypocaulon scoparium*-*Dictyota dichotoma*, although in a reduced form. It was accompanied by *Padina pavonica*.

At a 3m depth, the number of colonizing macroalgae was lower than at 1m, as contrast to conditions found for the diatom colonizers (Munda, 2005). Macroalgal colonization started in March with *Ectocarpus siliculosus* and a few filaments of *Ulothrix* sp. In April, they were joined by *Ceramium* species, but the monthly denuded plate was still clean. Colonization by macroalgae was delayed at this level, and that of the diatoms improved. *Scytosiphon lomentaria* and *Dictyota dichotoma* appeared only as late as in May. In June, *Sphacelaria* species and *Zanardinia typus* joined on both of the experimental plates. *Berkeleya* species were extremely prolific at this level and prevented macroalgal colonization (Fig. 5.10a, 5.10b). In July, when they were already in decline, *Cystoseira* germlings appeared together with *Padina pavonica*. First in August, macroalgal colonization became more intensive. Additional species joined and *Cystoseira* germlings increased in size and number, and were found on both plates. The development of a *Dictyota dichotoma*-*Stypocaulon scoparium* association was even more pronounced than at a 1m depth. It was indicated even on the monthly denuded plate, having a tendency of seasonal appearance. Within the crustose layer, *Zanardinia typus* was the most frequent.

At a 7m depth, irregular seasonal fluctuations in the degree of cover were observed. At this depth macroalgae started to appear only as late as in May, but were then found on both plates. They exhibited thus a seasonal appearance.

Beside the brown macroalgae found in the upper water layers, also *Striaria attemuta* (Greville) Greville and *Stilophora tenella* were found, while *Scytosiphon lomentaria* was absent at this level.

As contrast to conditions in the upper water layers, red algae, representatives of the Ceramiales in particular, were numerous and conspicuous in the colonizing community. They appeared mainly during the second half of the observation period, when they were already absent from the original vegetation near the surface (e.g.

Ceramium species, *Antithamnion cruciaum*, *Pterothamnion plumula*, *Spermothamnion flabellatum*, *Pleonosporium borreri*, *Aglaothamnion* and *Polysiphonia* species). *Nitophyllum punctatum* was abundant on both plates all the time between April and July.

Colonization by macroalgae exhibited, however a different trend at a 7m depth than at 1m and 3m, mainly on account of the red algae just mentioned. Also crustose floristic elements were better developed here, and the same was true for the initial stages of the *Dictyota dichotoma* - *Stypocaulon scoparium* association. Already in July, fouling by macroalgae was more vigorous on the monthly denuded than on the permanent plate, indicating seasonality of the colonizing events.

As an example of colonization on the concrete plates conditions found in July are presented in Figs. 5.12a, 5.12b for the different depths, viz. 3m and 7m.

Number of species

Red algae were numerically dominant in all the cases. In the original population, a decrease of the number of the red algae with depth was obvious, at a simultaneous increase of the brown algae, and a decrease of the number of the green ones. On the concrete plates red algae were numerically dominant, followed by the green algae, while the brown ones were in minority. In this case the number of the red algae increased with depth, and that of the green ones decreased. Brown algae were numerically approximately constant at all the depths, although there were several differences in the species composition.

On the concrete pyramids, the number of the colonizing red algae was approx. equal at 5m and 9m depths, and the number of the browns only slightly higher at 5m than at 9m. Green algae were absent on these structures, which allowed a vigorous cover of the animal component, of Bryozoa and Tunicata, along with an accumulation of sedimental particles in a gelly matrix.

The number of colonizing species was the lowest on the plastic net, although with a dominance of the red algae component, and the presence of only two species of the green algae.

The main colonizing species from the original population are presented in Figs. 5.13÷5.23.

Concluding remarks

The goal of this study was to examine colonization by benthic algae on different substrata in a highly polluted and eutrofied area of the northern Adriatic Sea.

Previously the sublittoral slopes of the Istrian coast and the bays of Piran and Koper (Capodistria) were populated by prolific associations of diverse *Cystoseira* and

Sargassum species (Munda, 1979). Later, at the beginning of the eighties, profound changes of the benthic algal vegetation occurred in the entire area. The Fucacean associations disappeared or were extremely reduced (Munda, 1980). These drastic changes were tentatively ascribed to the increased organic pollution. They were reported in several contributions, dealing both with the occurrence and distribution of the individual species, as well as their chemical composition and biomass (Munda, 1982a, b, 1988a, b, 1991 b, 1993a, b).

Interest arose, however, about the initial stages of algal colonization in this heavily perturbed area and the possible restitution of the benthic populations on virgin surfaces.

There was a trial with differently shaped substrata. Concrete plates, placed horizontally on the sea floor represented continuous disponible surfaces for algal colonization at different depths. Concrete pyramids, placed vertically, with perforated sides, represented uneven, discontinuous fouling surfaces, which were difficult to control. And finally, plastic nets were also used.

Results indicated, that the percentage of colonizing algae, as related to those of the original population, was the highest on the horizontal concrete plates, and the lowest on the plastic net. There were notable differences in the colonizing events on the three substrata applied. The concrete plates represent, however, continuous surfaces for the attachment of diverse benthic organisms. During our observations, the animal component was excluded. The dominant colonizing component were diatoms (Munda, 2005). The sequence of events during seasonal colonization and succession were different for the diatoms and the macroalgae (Munda, 1991a, 2005). Diatoms were the primary and main colonizers, and macroalgae in minority. There was variability in colonization related to depth, and also differences between the trends of macroalgal and diatom colonization. A lag period in the appearance of some macroalgae was observed, as related to depth. *Scytosiphon lomentaria* appeared eulittorally (on denuded surfaces) in March, at 1m depth in April, at 3m in May, and was absent at 7m depth. *Dictyota dichotoma* appeared at 1m in April, at 3m in May and at 7m in June. Representatives of the Ceramiales, which form dense and continuous populations in the uppermost sublittoral in spring, were found as enough prolific at 7m depth during August. Also representatives of the Gelidiales and of the crustose corallines were found during the second half of the year, and their quantity increased with depth. *Cystoseira* species, on the other hand, were poorly represented. Scattered small germlings appeared only as late as in summer, and did not form continuous stands. *Dictyota dichotoma* and *Stypocaulon scoparium*, on the other hand, tended to form an association, which is characteristic of moderately polluted sites in the northern Adriatic (Munda, 1993a, b).

On the concrete pyramids, which offer a discontinuous surface for colonization and were placed upright down, the animal fouling component was outstanding. Bryozoa and Tunicata had overgrown the greater part of the fouling area, which was in addition covered by a layer of coarse grained sediment. It was obvious, however, that sedimentation has a preventing effect on the attachment of macroalgae (cf. Airoidi & Cinelli, 1997), and that it was higher on the vertically placed pyramids than on the horizontal concrete plates. On the pyramids, red algae (*Polysiphonia tenerrima* cf) were the initial colonizers. Later *Cystoseira* species started to form an almost continuous stand. It was dominated by *Cystoseira compressa* and undergrown by *Zanardinia typus*. A stratification of the fouling community was established soon, with a conspicuous crustose undergrowth (also *Peyssonnelia* species and crustose corallines). It is noteworthy that *Sargassum hornsouchii*, absent from the surrounding vegetation, settled on the pyramid at 5m depth.

The plastic net, used in our experiments, was the least colonized, but was covered by both Avertebrata and macroalgae. It is likely a suitable substratum for the attachment of *Cystoseira* species.

This study provides thus information about colonization by macroalgae in an impacted environment. Less than 50% of the algae from the surrounding vegetation were found on the concrete plates, only 28% on the pyramids and even less on the plastic nets. The position of the fouling surfaces seems decisive, since diatoms occupied, beside macroalgae, the horizontal concrete plates, while the animal fouling component was outstanding on the vertical surfaces and also on the plastic net.

It was observed, however, that the horizontal surfaces were suitable for the attachment of numerous red algae and for the development of the typical *Dictyota dichotoma* - *Stypocaulon scoparium* association. The vertical, perforated surfaces and the net were, on the other hand, suitable and prosperous for the attachment of *Cystoseira* species and the gradual development of a three layered *Cystoseira* spp. population.

The next step would be to perform chemical analyses of the colonizing species and to follow step by step the colonizing events, also in relation to the Avertebrata and the progressing sedimentation.

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