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ALGAL RESOURCES IN POLLUTED SITES OF THE NORTHERN ADRIATIC (VICINITY OF PIRAN)

RESURSI ALGI U ZAGAĐENIM PODRUČJIMA SJEVERNOG JADRANA (OKOLICA PIRANA)

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The benthic algal vegetation of the North Adriatic shelf area was impoverished in biomass, floristic diversity and main associations of fucoid algae. These changes are conditioned by the increased eutrophication of the area as well as river-born and direct industrial and domestic effluents. In spite of these changes the northern Adriatic still represents a resource of algal raw material, which could be exploited on a minor scale, mainly in food - and pharmaceutical industry.

With this in mind a survey of the main vegetation patterns and algal biomass is given, along with some data on the protein- and ascorbic acid content in some common species. Investigations were carried out in the vicinity of Piran, Gulf of Trieste.

INTRODUCTION

During the last few years interest arose about exploitation of algal resources in the Adriatic Sea as a whole. In this contribution some data and suggestions for the North Adriatic shelf area will be given.

The benthic algal vegetation of the northern Adriatic was impoverished in terms of biomass, floristic diversity and main associations of fucoid algae. Consequently changed zonation patterns were also observed. In spite of these changes the northern Adriatic still represents a resource of algal raw material, which could be exploited on a minor scale in food- and pharmaceutical industry or as animal fodder and as manure.

Vegetation patterns and algal biomass were studied in some areas of the northern Adriatic (Fig. 1), such as Rovinj with the Lim fjord (Limski kanal) on the Istrian coast and on some islands of the Gulf of Quarnero (e.g. M u n d a , 1961a; 1972 ; 1973 ; 1975 ; 1977 ; 1979 ; 1980 a,b; 1982 ; 1985). The chemical composition of North Adriatic seaweeds was investigated previously at Rovinj regarding the alginic acid, protein and mannitol content and was also connected with biomass studies (M u n d a, 1961b; 1962 ; 1964 ; 1973 ; 1974 ; 1979 ; 1988). The amino acid composition of some common species was also evaluated (M u n d a and G u b e n š e k , 1986).

Recent investigations of vegetation patterns, algal biomass and chemical composition of individual species were carried out around Piran in the Gulf of Trieste. Some data on the ascorbic acid content in algal material from this area are given (M u n d a , 1987). All these data yield, however, information about the availability of North Adriatic seaweeds as raw material for different purposes.

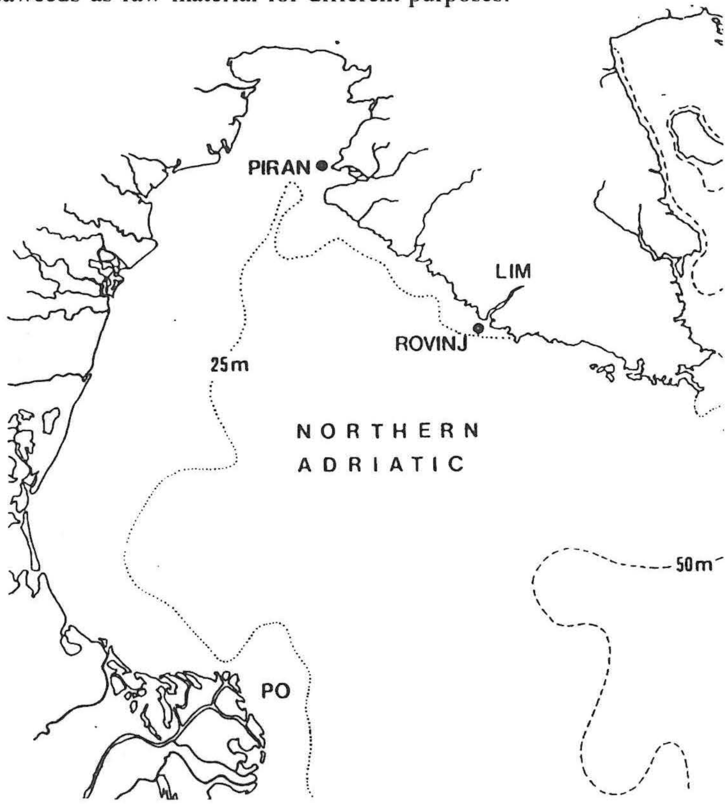

Fig. 1. Map of the northern Adriatic

ECOLOGICAL CONDITIONS

Changes of benthic algal vegetation in the North Adriatic shelf area were mainly conditioned by a heavy impact of organic and inorganic pollutants, which are carried in by rivers (e.g. Po, Adige, Tagliamento, Isonzo) or by direct industrial and domestic effluents. These pollutants are transferred in the surface water layers by a regular convection current. Local circuits of a changing direction were noticed in the Gulf of Trieste (R a j a r , 1990) indicating the maximum transfer of pollutants during calm weather.

There is, however, a cyclonic circulation over the Adriatic as a whole. In its northernmost part, which is a shallow shelf, the surface water is under the impact of freshwater runoff of the North Italian rivers, while the open North Adriatic water is influenced by advection from the south. Collected hydrographic data revealed the existence of a frontal zone between colder, low salinity water from the north and saltier and warmer water from the south (Z o r e - A r m a n d a *et al.*, 1983). The position of a semi-permanent frontal zone is influenced by the bora wind, which blows in an offshore direction.

In the northernmost part of the Adriatic Sea, the Po River affects the formation of a peculiar circulation. A line between the Po River mouth and Rovinj separates two gyres, an anticyclonic south and the cyclonic one north of this line (Z o r e - A r m a n d a and V u č a k , 1984). Influence of the Po River water along the Istrian coast is, however, more pronounced during bora wind and during summer stratification. In winter, the coastal flow shows vertical homogeneity. The response of the current field to the bora wind has been examined by current data analyses (M o s e t t i , 1972). In addition, the two-gyre current pattern was explained in terms of the alongshore variability of the bora wind (Z o r e - A r m a n d a and G a č i ć , 1987).

Temperature and salinity data were collected during algal samplings at Piran in the Gulf of Trieste. Monthly values are presented in Table 1. Water samples were taken simultaneously with algal samples at 0 m, 1 m, 3 m and 7 m depths. Results indicated that in February/March the water temperature increased with depth, while it decreased in April. Homeothermic conditions were indicated in May and October. During the summer stratification (June, July, August) the water temperature decreased with depth, whereas in November the opposite trend was again found. Maximum water temperature was observed in August. It fluctuated between 7.7°C in February/March to 25.5°C in summer. Salinity minima were observed in this area in June/July and maxima in February/March, coinciding with temperature minima. Salinity values fluctuated between 33.9 ‰ and 38.4 ‰. With exception of August, there was a tendency of salinity increase with depth.

The tidal range at Piran varies from 0.25 to 0.95 m. The main collecting site was Punta Madonna at Piran, facing north west. Below a concrete wall there are loose boulders of flysch and limestone, with sandy surfaces between them. Sandy extensions,

Table 1. Seasonal distribution of temperature and salinity at different depths near Piran

depth (m)	T°C	F	M	A	M	J	J	A	O	N
0		7.8	7.7	11.5	12.5	19.9	22.5	25.5	18.5	15.0
1		8.2	7.9	10.2	12.5	19.6	21.8	25.5	18.5	15.1
3		8.4	8.5	10.1	12.2	19.4	21.5	25.0	18.3	15.1
7		8.6	9.9	10.0	12.1	18.5	20.7	24.0	18.3	15.6
	Sal(‰)									
0		37.3	37.8	37.6	37.9	33.9	34.6	35.2	35.2	36.2
1		37.5	38.2	37.6	37.7	33.8	34.2	35.2	35.5	36.7
3		37.6	38.3	37.8	38.0	33.7	34.6	35.3	35.3	36.8
7		38.4	38.3	38.0	38.1	34.0	35.1	35.3	36.6	37.1

bare of benthic algae, prevail below 7 m depth. The second profile investigated is situated closer to the town of Piran, with huge concrete and limestone blocks in the eulittoral and upper sublittoral zone.

METHODS

Algal samples were collected by means of a 1/4 m^2 frame, within which the substratum was scrubbed clean. Three parallel samples were taken at each level: in the eulittoral and at 1 m, 3 m and 7 m depths. The samples were roughly sorted in the field and brought to the laboratory for further examination. The fresh weight biomass of the total samples was determined in the field.

The dry weight of individual species was determined by drying at 105°C for 24 hours. The protein content was evaluated in some dominant species by the micro Kjeldahl procedure. For ascorbic acid analyses the samples were stored by deep-freezing at -18°C. After vacuum drying at 30°C samples were ground and ascorbic acid determined spectrophotometrically by the 2,4 - dinitrophenylhydrazine method according to Röe and Österling (1944).

RESULTS

The results presented here refer to recent investigations at Piran, while those from the Rovinj area and the island of Krk were reported in previous works, cited in the introduction.

Main vegetation patterns

A rough survey of the main vegetation patterns around Piran is presented here, while detailed information with all the floristic elements included will follow separately. Schemes of two characteristic transects in this area are given in Figs. 2 and 3. They represent the zonation in a relatively undisturbed - and in a moderately polluted site.

The main characteristic feature of the vegetation of this area was a reduction of fucoid stands and reduced quantities of red algae.

In relatively undisturbed sites *Catenella caespitosa* (With.) Dixon et Irvine occurs in patches in the level of the littoral fringe, whereas in polluted sites Cyanobacteria prevail (e.g. *Calothrix crustacea* Thur., *Rivularia* spp., *Lithonema adriaticum* Erc.). The narrow eulittoral zone around Piran was depleted of fucoids in most sites. Spring annuals were dominant at this level, which was characterized by a low algal biomass and reduced species diversity. *Ulothrix* spp., *Bangia atropurpurea* (Roth.) C.Ag., *Porphyra leucosticta* Thur., *Ectocarpus siliculosus* (Dillw.) Lyngb., *Scytosiphon lomentaria*

(Lyngb.) Link., *Ceramium diaphanum* (Roth.) Harv., *Griffithsia* spp., single specimens of *Callithamnion corymbosum* (Smith.) Lyngb. along with green algae (*Ulva rigida*

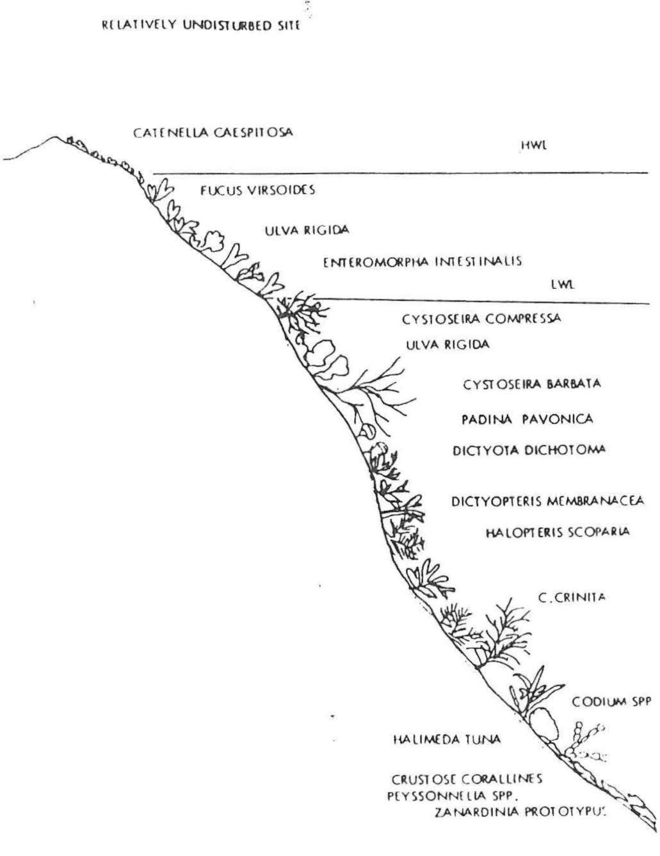

Fig. 2. Scheme of algal zonation at a relatively undisturbed site

C.Ag., *Blidingia minima* (Näg.ex Kütz.) Kylin, *Enteromorpha* spp. were common at this level. Green algae occur, however, during the year in several subsequent generations. Turf-like mats of *Gelidium pusillum* (Stackh.) Le Jol. with diverse *Gelidiella* species were also frequent at this level. *Cladophora* species were found in eulittoral depressions and small tide pools (*Cladophora ruchingeri* (C.Ag.) Kütz., *C.dalmatica* Kütz.). In some relatively undisturbed sites outside Piran the eulittoral was occupied by the endemic fucoid *Fucus virsoides* (Don.)J.Ag. which occurred discontinuously. Green

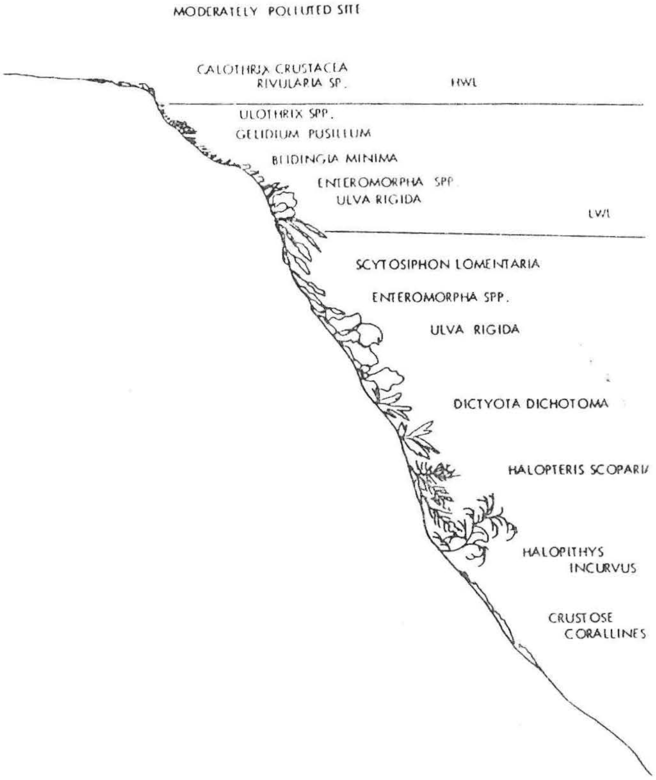

Fig. 3. Scheme of algal zonation at a moderately polluted site

algae were conspicuous in its stands as epiphytes and companion species (*Ulva rigida*, *Enteromorpha prolifera* (O.F.Müll.)J.Ag., *E.intestinalis* (L.)Link.) and *Hildenbrandia rubra* (Sommerf.) Menegh., *Ralfsia* spp., *Phymatolithon lenormandii* (Aresch.) Adey in its undergrowth. Under conditions of high exposure *Cystoseira compressa* (Esper) Gerloff et Nizamuddin stands were lifted up into the eulittoral zone. On the concrete wall at Punta Madonna Cyanobacteria (*Oscillatoria* sp., *O.nigroviridis* Thwaites) covered extensive surfaces in summer. Sandy slopes were populated by interwoven mats of *Ceramium ciliatum* (Ellis) Ducluz. in spring.

In some exposed sites, the level of the eulittoral / sublittoral junction as well as the upper sublittoral were populated by mats of *Corallina officinalis* L.

In the sublittoral, *Cystoseira* species were still common in relatively undisturbed sites, though their populations were discontinuous. *Cystoseira compressa* and *C. barbata* (Good.et Woodw.)J.Ag. were rather frequent in the upper sublittorall, while *C. crinita* (Desf.)Bory and *C.corniculata* (Wulf.)Zanard. occurred in scattered stands lower down, between 3 m and 7 m depth. Dense populations of *Dictyota dichotoma* (Huds.)Lam. and *Halopteris scoparia* (L.)Sauv. were characteristic of this area and the northern Adriatic as a whole. They interrupt or even replace *Cystoseira* populations. In some moderately polluted sites, closer to the town of Piran, dense stands of *Halopythis incurvus* (Huds.)Batt. were common between 1 m and 3 m depth. The dominant species was densely covered with epiphytes. *Padina pavonica*(L.)Thivy was found in patches throughout the sublittoral slopes and was especially prolific in summer, while *Dictyopteris membranacea* (Stackh.)Batt. was relatively rare. Further species, which occurred in notable quantities along the investigated profiles were *Nitophyllum punctatum* (Stackh.)Grev. in spring and *Laurencia obtusa* (Huds.)Lam. along with *Wrangelia penicillata* J.Ag. in summer. *Pterocladia capillacea* (Gmel.)Born. et Thur. was found in patches at lower sublittoral levels. *Codium* species increased in quantity (*Codium vermilara* (Olivi)Delle Chiaje, *C. effusum* (Raf.)Delle Chiaje) and were also found in the upper sublittoral even between *Corallina* mats. *Codium bursa*(L.)C.Ag. was rather frequent in the lower sublittoral.

Around the eulittoral/sublittoral junction and in the uppermost sublittoral, *Ulva rigida* formed prolific populations together with diverse *Enteromorpha* species in spring and early summer. *Scytosiphon lomentaria* was prolific at the same levels in spring. The development of such dense populations of seasonal annuals was possible in sites, where there is no competition with fucoids. In the upper sublittoral spring annuals appeared mainly as epiphytes on the perennial macroalgae, such as *Cystoseira* species, *Corallina officinalis* and *Halopythis incurvus* (e.g. *Callithamnion corymbosum, Ceramium diaphanum, C. ciliatum, C. gracillimum* (Griff.ex Harvey) G.Feldm., *C. codii* (Richards) G.Feldm.,*C.rubrum* (Huds.)C.Ag., *Ptilothamnion pluma*(Dillw.)Thur., *Spermothamnion flabellatum* Born., *Griffithsia* spp., *Compsothamnion thuyoides* (Smith) Schmitz, *Spyridia filamentosa* (Wulf.) Harvey, *Antithamnion cruciatum* (C.Ag.)Näg., *A. plumula*(Ellis)Thur., *A. tenuissimum*(Hauck)Schiffner, diverse *Polysiphonia* species with *P. furcellata*(C.Ag.)Harv. as the most common, *Nitophyllum punctatum, Ectocarpus siliculosus, Cladophora dalmatica*).

It is noteworthy, that in some polluted sites *Cystoseira* species were absent along the entire transect (Fig.3). In such cases, *Dictyota dichotoma, Halopythis incurvus* and *Halopteris scoparia* formed the main standing crop. In the lower sublittoral, at 7 m depth, the vegetation was changed and crustose floristic elements prevailed, such as *Peyssonnelia squamaria*(Gmel.)Decne., *P. polymorpha* (Zanard.)Schmitz, *Zanardinia prototypus* Nardo, *Pseudolithophyllum expansum* (Phil.)Lemoine, *Lithophyllum incrustans* Phil., *Lithothamnion* spp. At this level tropical floristic elements joined the vegetation (e.g. *Halimeda tuna* (Ellis.et Sol.)Lam., *Anadyomene stellata* (Wulf.)C.Ag., *Udotea petiolata* (Turra)Börg.). *Sargassum* species, which were well represented in the northern Adriatic before the severe pollution impact, are likely to disappear and were not found in the area under discussion.

Number of species

Only the main floristic elements, which are outstanding in the vegetation around Piran, were mentioned above. The total number of species found along the profiles investigated, is presented in Table 2. The lowest number of species was found in the eulittoral zone with seasonal maxima in spring (April) and autumn (October). The number of species was notably higher in the upper sublittoral, between 1 m and 3 m depth and was again lower at 7 m, where seasonal variations were inconspicuous. There were some differences in the seasonal variations in species number between the investigated profiles. At 3 m and 7 m depth the highest number of species was found in June. Maxima at these sublittoral levels are obviously due to the rich epiphytic cover of *Cystoseira* species and of *Halopythis incurvus.*

Fresh weight biomass

The fresh weight biomass of total algal populations at different depths is presented in Table 3. In the eulittoral, the algal biomass was low, with a peak in April, which conicided with the highest species diversity. The autumn maximum in species number did not, on the other hand, contribute to an increased biomass. Measurements at this level were carried out at a typical locality, depleted of fucoids. The main algal biomass in this area was concentrated between 1 m and 3 m depth, on account of *Cystoseira* species, *Halopythis incurvus, Halopteris scoparia* and *Dictyota dichotoma* as dominants. The rest of the species contributed only a minor part to the biomass of the entire populations. The fresh weight biomass was notably higher at the second investigated locality, closer to the town of Piran than at Punta Madonna. At this locality *Halopythis incurvus* was dominant between 1 m and 3 m depth. At 1 m depth the highest biomass was found in April on account of the appearance of diverse spring annuals, first of all representatives of the Ceramiaceae and of the genus *Polysiphonia.* In addition, at this level the autumn maximum in species number was not connected with an increased fresh weight biomass. At 3 and 7 m depths the seasonal maximum in biomass was transferred to June at the first, and to May/June at the second locality, mainly on account of the fully grown and fruiting *Cystoseira* thalli and their epiphytic cover. At the second locality the admixture of notable quantities of *Halopythis incurvus* and its numerous epiphytes contributed to the greater part of the fresh weight biomass. At 7 m the biomass was lower than at the two intermediate levels of 1 m and 3 m. It exhibited maxima in June at the first and in May at the second locality. It is noteworthy, however, that an elevated number of species was not always consistent with an increased biomass.

Table 2. Seasonal variations in the number of species at different depths at Piran

depth (m)	Locality 1	F	M	A	M	J	J	A	O	N
0		12	17	20	15	14	10	10	17	12
1		26	29	32	25	25	24	25	30	16
3		17	20	2:	26	31	30	25	20	17
7		21	20	25	23	25	25	25	24	20
	Locality 2									
0		15	20	25	25	30	26	23	22	15
1		20	25	28	29	33	26	25	28	17
3		11	19	21	21	27	21	19	21	13
7		38.4	38.3	38.0	38.1	34.0	35.1	35.3	36.6	37.1

Table 3. Seasonal variations of fresh weight algal biomass at different depths at Piran ($g\ m^{-1}$)

depth (m)		F	M	A	M	J	J	A	O	N
	Locality 1									
0		240	360	620	430	400	120	80	40	40
1		2480	3000	6000	5040	4800	4400	3400	1200	1400
3		840	2120	4040	5200	5200	4020	1800	2000	800
7		680	400	400	3200	1400	1200	1000	400	200
	Locality 2									
0		360	1960	4200	1800	1700	1000	800	800	600
1		480	520	730	1200	6000	4000	2100	600	600
3		220	400	400	1400	2600	1000	440	200	200
7		38.4	38.3	38.0	38.1	34.0	35.1	35.3	36.6	37.1

Chemical composition

Recent data on the protein content of some common brown algae from Piran are presented in Fig. 4. Among the fucoids, the eulittoral *Fucus virsoides* had the highest

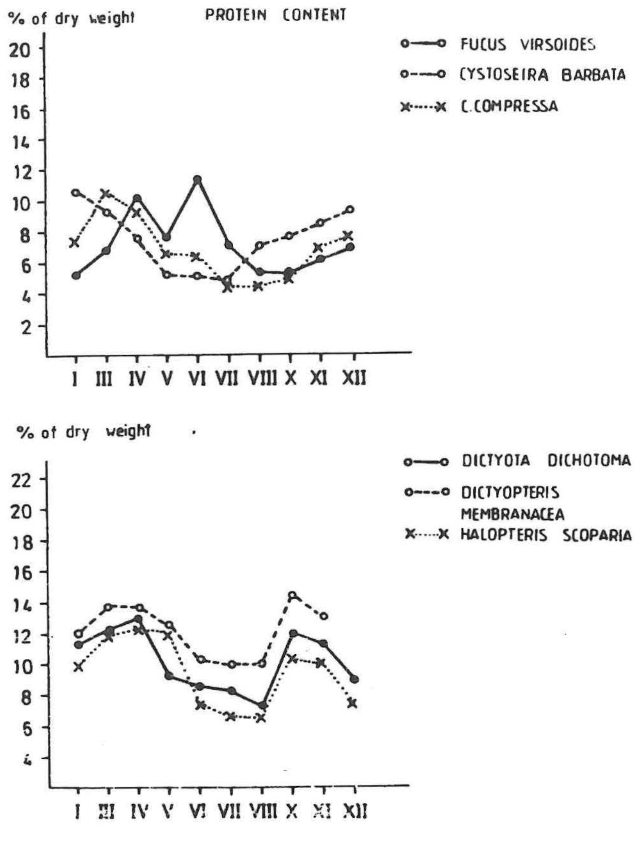

Fig. 4. Protein content in some common brown algae from Piran

protein content, with a maximum in June during the peak of its vegetative period. The highest protein content was found in March for *Cystoseira compressa* and in winter for *C. barbata*. It appeared likely, that maxima in protein content are transferred from winter/spring towards summer in correlation with depth. *Fucus virsoides* grows in the eulittoral, *Cystoseira compressa* around the eulittoral/sublittoral junction and the uppermost sublittoral and *C. barbata* lower down the sublittoral. The protein content in representatives of the Dictyotales and in Halopteris scoparia was higher than in the fucoids and again highest in *Dictyopteris membranacea*. Maxima in spring and autumn were observed (Fig.4) in all three species analyzed here.

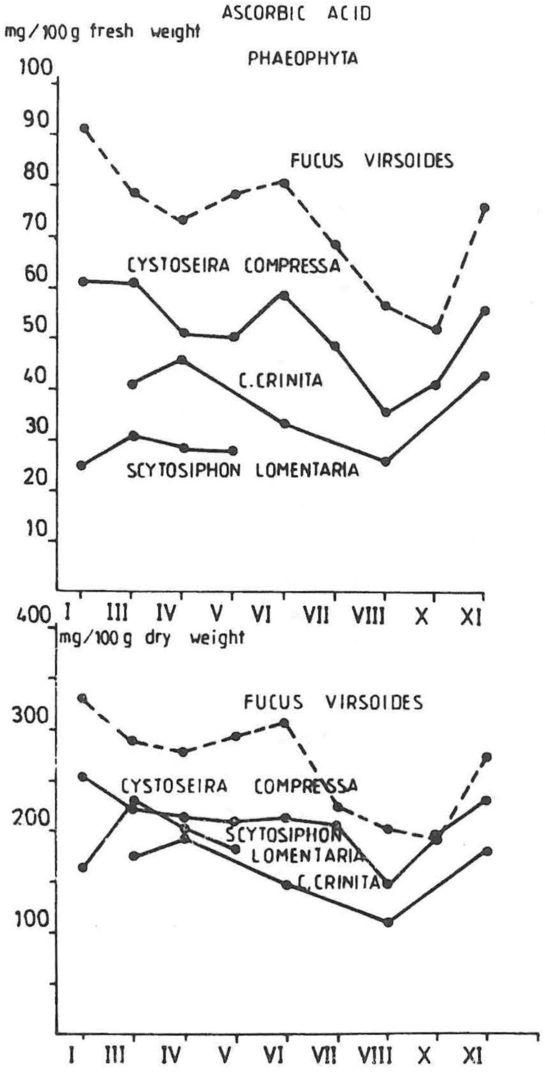

Fig. 5. Ascrobic acid content in brown algae from Piran

The ascorbic acid content in some common brown, red and green algae from this area is presented in Figs. 4 to 8 and is expressed on a fresh weight - and dry weight basis (M u n d a, 1987). Among the fucoids, *Fucus virsoides* had the highest content of ascorbic acid and *Cystoseira crinita* the lowest. The latter species was collected between

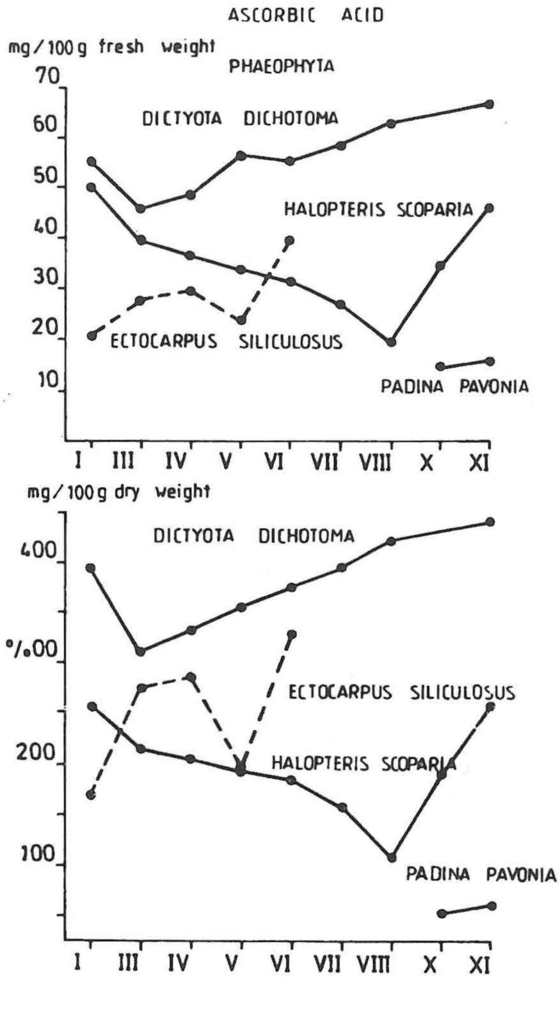

Fig. 6. Ascrobic acid content in brown algae from Piran

3 m and 7 m depth. In *C. compressa* which is found in the uppermost sublittoral or even eulittorally, the ascorbic acid content was lower than in *Fucus virsoides* and higher than in low-level *Cystoseira* species. A correlation between the littoral level and ascorbic acid content in fucoids was hence indicated. In *Fucus virsoides* and *Cystoseira compressa*

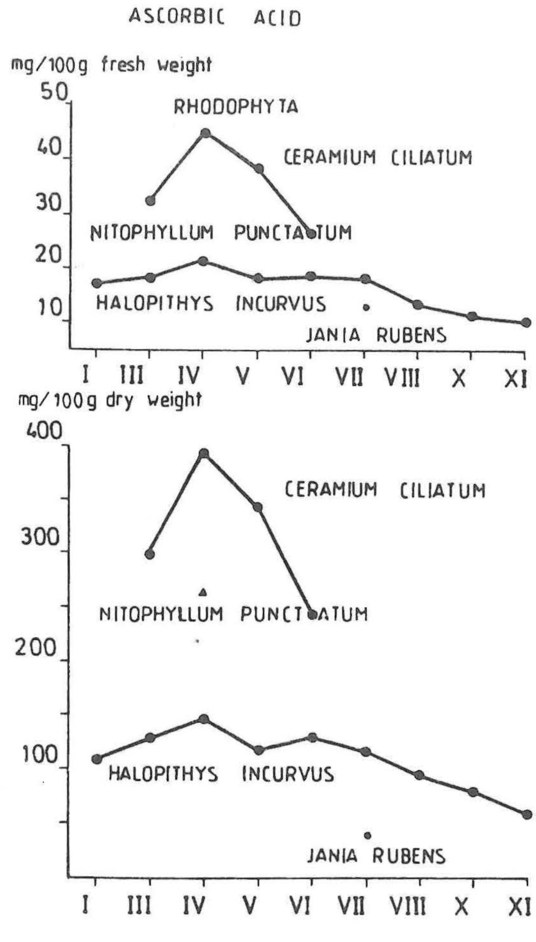

Fig. 7. Ascrobic acid content in red algae from Piran

maxima in ascorbic acid content were found in winter and in June, while in *C. crinita* a spring maximum was indicated. The spring annual *Scytosiphon lomentaria* had its maximum in ascorbic acid content in March, during the height of its vegetative period.

In *Dictyota dichotoma* and *Halopteris scoparia*, which are outstanding in the biomass of slightly polluted habitats, the ascorbic acid content was lower than in the fucoids. In *Dictyota* a gradual increase in ascorbic acid content was found after a minimum in March, whereas *Halopteris scoparia* exhibited a pronounced summer minimum. In *Padina pavonica* which was tested only in autumn, the ascorbic acid content was low. In *Ectocarpus siliculosus* a spring maximum was observed and after a decline in May a subsequent increase in June, when a new generation appeared.

Among the red algae (Fig. 7) the seasonal course in ascorbic acid content was followed in the perennial *Halopythis incurvus* and in the seasonal *Ceramium ciliatum*. Ascorbic acid content was rather low in *Halopythis* with inconspicuous seasonal variations. A decline from spring towards autumn was indicated. In *Ceramium ciliatum* the maximum ascorbic acid content in April coincided with the height of its vegetative period.

Among the green algae (Fig. 8) *Ulva rigida* and mixed samples of diverse *Enteromorpha* species were analyzed. Maxima and minima in ascorbic acid content obviously reflected the appearance and disappearance of subsequent generations.

DISCUSSION AND CONCLUSIONS

The benthic algal vegetation of the North Adriatic shelf is exposed to a combination of environmental stresses, such as the input of sewage, industrial discharges and agriculture drainage. The greater part of these pollutants is carried into the area by the Po River (M a r c h e t t i *et al.*,1989). The increased eutrophication has profoundly changed the benthic algal vegetation in terms of biomass, floristic diversity and leading algal associations (M u n d a , 1980a,b; 1982). The main characteristic feature of recent North Adriatic vegetation is a reduction of fucoid populations, which were replaced by seasonal annual in the eulittoral and by diverse populations of perennial and seasonal species in the sublittoral (*Dictyota dichotoma, Dictyopteris membranacea, Padina pavonica, Halopteris scoparia, Halopythis incurvus, Ulva rigida, Enteromorpha* species, *Scytosiphon lomentaria*). Lack of competition with fucoids gave, however, opportunity for the development of other populations throughout the sublittoral levels. In spite of these pollution-induced changes, *Cystoseira* species still represent the major part of algal biomass in the northern Adriatic. It is concentrated between 1 m and 3 m depth in the Gulf of Trieste, around Piran, and to lower levels around Rovinj. *Cystoseira compressa* and *C. barbata* are common in the upper sublittoral. Around Rovinj, *C. adriatica* Sauv. was also frequent at this level and was usually densely overgrown by *Jania rubens* L.. *C. spicata* Erc. (*C. stricta* Sauv. v. *spicata*(Erc.)Giaccone) is beside *C. barbata* the most frequent North Adriatic *Cystoseira* species. It was found over a wide range of exposure conditions at Rovinj (M u n d a , 1979; 1982) but was rare around Piran. Among just mentioned species both *C. spicata* and *C. barbata* exhibit the highest average biomass (average maxima of 5200 and 5600 g m^{-2}). North Adriatic

Cystoseira species have their maximum biomass in June, during the most vigorous growth and fruiting (M u n d a , 1972; 1979; 1990). *C. crinita* and *C. corniculata* form

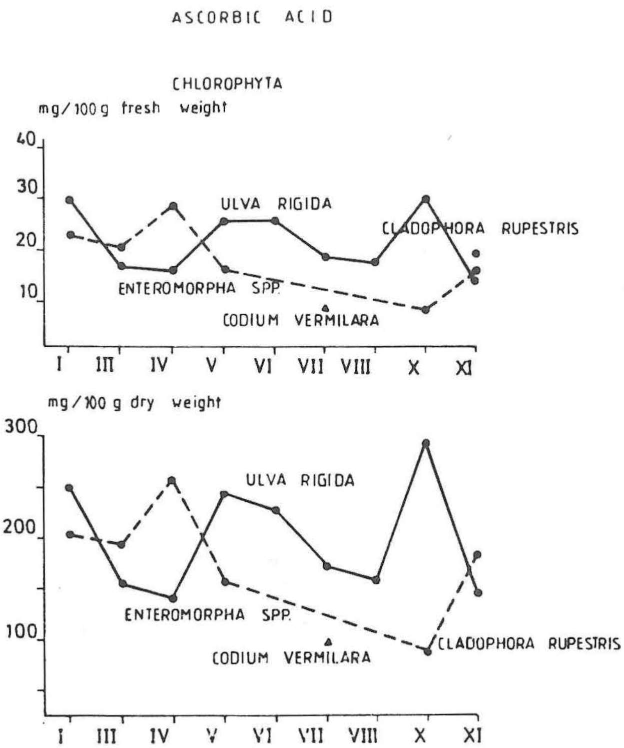

Fig. 8. Ascrobic acid content in green algae from Piran

scattered stands in the lower sublittoral, with a lower biomass and inconspicuous seasonal variations. Notable fresh-weight biomass values were found also for some other brown algae, which form continuous populations between the fucoid stands, such as *Dictyota dichotoma* and *Halopteris scoparia* (average maximum biomass values 1500 and 2100 g m^{-2} respectively). *Dictyopteris membranacea* and *Padina pavonica* occurred scattered in small patches, but the average biomass measured within their individual stands was relatively high (1750 and 900 g m^{-2}).

The spring annual *Scytosiphon lomentaria* covered wide surfaces around the eulittoral/sublittoral junction and in the uppermost sublittoral. Its average biomass ranged from 210 to 2700 g m^{-2}.

Among red algae, which became rare in the polluted North Adriatic basin, only the perennial *Halopythis incurvus* and *Corallina officinalis* formed rather extensive populations, the first one between 1 m and 3 m depth and the second in the upper sublittoral. Average biomass values ranged from 300 to 2600 g m^{-2} for *Halopythis* and from 340 to 1600 g m^{-2} for *Corallina*. Pure populations of seasonal red algae occurred only in patches, though the fresh weight biomass within these small, scattered populations could be notable. The average fresh weight biomass of the spring annual *Ceramium diaphanum* ranged from 100 to 1600 g m^{-2} and that of the summer annual *Laurencia obtusa* from 150 to 1900 g m^{-2}. High-level red algae, which form locally turf-like mats (*Catenella caespitosa, Gelidium pusillum*) exhibited low biomass values. Green algae, which became prolific in polluted sites had a rather high biomass, as e.g. *Ulva rigida* with average values from 300 to 3400 g m^{-2} and *Enteromorpha* species from 280 to 4300 g m^{-2}.

Recent investigations around Piran, described in the above chapters, revealed that biomass of the total populations was lowest in the eulittoral in sites depleted of fucoids. Seasonal maxima were found in spring. In relatively undisturbed localities, where the perennial *Fucus virsoides* persisted, its biomass was highest in June (average seasonal maximum 2850 g m^{-2}).

The highest biomass of the entire populations was found between 1 m and 3 m depths, ranging from 360 to 6000 g m^{-2} during the seasons. It was again lower at 7 m, where crustose floristic elements prevail and seasonal variations are less conspicuous. It is noteworthy that the seasonal maxima in fresh weight biomass were found in spring in the uppermost sublittoral, and in May/June at 3 m and 7 m depth. Spring maxima in the eulittoral and in the uppermost sublittoral are due to the appearance of diverse spring annuals, mainly representatives of the order Ceramiales.

The chemical composition of individual species of benthic algae from the northern Adriatic was investigated in connection with biomass studies as well as with the aim of their evaluation as raw material for different purposes (in food- and pharmaceutical industry, as animal fodder and as manure). Previous (M u n d a , 1962; 1974; 1988) and recent studies of the protein content in the Adriatic seaweeds have revealed, that it would be sufficient for eventual additional human and animal nutrition. Fucoid algae revealed protein maxima during different seasons, as e.g. *Fucus virsoides* in June, *Cystoseira compressa* in March and *C. barbata* in winter. Representatives of the Dictyotales had a higher protein content than the Fucales and exhibited spring and autumn maxima. A high protein content was likewise found in *Scytosiphon lomentaria*. It was in general higher in red than in brown algae and again highest in *Porphyra leucosticta* and the high-level species *Catenella caespitosa*. It was observed that the protein content in benthic algae increases under stress conditions, such as lowered salinity and pollution impact. Extremely high protein values were found in green algae from polluted sites (M u n d a ,1988). In connection with the interest for exploitation of some species, their total amino acid pool was also determined (M u n d a and G u b e n š e k , 1986). Results indicated some differences in the overall proportions of the individual amino acids in brown, red and green algae. In all the brown algae investigated glutamic acid was the main constituent. Glutamic and aspartic acid, together with their amides, are present in high amounts in all the taxonomic groups. The amino acid which was next highest is alanine. There is a general similarity in the amino acid composition of the brown algae, but notable variations among taxa of red algae. In *Porphyra leucosticta* alanine was the major constituent, arginine in *Catenella caespitosa* and proline in *Alsidium corallinum* C.Ag. In *Polysiphonia* species aspartic acid was higher than glutamic acid. The Adriatic species of benthic algae investigated exhibit, however, an amino acid content which would make them suitable in human and animal nutrition. Essential amino acids are present in sufficient amounts.

As a further aspect of potential utilization of North Adriatic algae their ascorbic acid (M u n d a , 1987) content was determined. The highest concentrations of this vitamin were found in *Fucus virsoides* and lowest in *Cystoseira crinita*, as far as fucoids are concerned. Values found for *C. compressa* were intermediate between the two species. Regarding the position of these fucoids on the littoral slopes a decrease of ascorbic acid content with depth was indicated. Maxima were found in June for the two high-level fucoids and in April for *C. crinita*. An increase of ascorbic acid towards winter was indicated in all the fucoid species investigated. High concentration of ascorbic acid was found in *Dictyota dichotoma*, whereas it was rather low in the perennial red alga *Halopythis incurvus*. It was again higher in the spring annual *Ceramium ciliatum*. In green algae irregular variations of a rather low ascorbic acid content were observed probably connected with the appearance and disappearance of succeeding generations.

Previous and more recent studies on the alginic acid content in the Adriatic brown algae (M u n d a , 1964; 1973; 1990) revealed a rather high content in fucoid species, ranging from approx. 18 to 25 % of dry weight. Nevertheless, the Adriatic brown algae are inappropriate as alginic acid raw material because of low viscosity of the isolated products.

On the basis of all the data collected around Rovinj and Piran some suggestions for potential commercialization of North Adriatic algae could be given.

Fucus virsoides could be exploited on a small scale in relatively unpolluted habitats, where it forms continuous belts. The best sampling would be in June, when maxima in biomass, protein-and ascorbic acid content coincide. It could be used in human nutrition and as animal fodder. A similar commercialization could be suggested for Adriatic *Cystoseira* species, especially for those from the upper sublittoral. The best sampling time would be in June, when their biomass is at its maximum. Seasonal maxima in protein content were found during different seasons, as e.g. for *Cystoseira compressa* in March and *C. barbata* in winter, while the ascorbic acid content was highest in June. Low-level *Cystoseira* species would be less suitable for small-scale exploitation because of their scattered stands in the sublittoral. Seasonal variations in biomass and chemical composition were less pronounced than in fucoids from the upper water levels.

Representatives of the Dictyotales (*Dictyota dichotoma*, *Dictyopteris membranacea*, *Padina pavonica*) along with *Halopteris scoparia* could be harvested throughout the year on a small scale as additional food and for pharmaceutical purposes. These species exhibit spring and autumn maxima in protein content, higher than in the fucoids, and two maxima in ascorbic acid content. Representatives of the Dictyotales contain phloroglucin along with other antibacterial and antifungal substances (M o r e a u *et al.*, 1984). Fungicidal substances were found also in *Halopteris scoparia* and other representatives of the Sphacelariales. Small-scale harvesting during spring could be suggested for the seasonal species *Scytosiphon lomentaria*, which is especially prolific in polluted sites. Both biomass and protein content were increased for this species in heavily polluted habitats. A maximum in ascorbic acid was found during the peak of its vegetative period. Fungicidal and antitumor substances have been found in the extracts of this species (M a y e r and P a n i c k , 1984).

Red algae are relatively rare in the polluted northern Adriatic. In spite of a rather high floristic diversity, their biomass is low. They form scattered stands or occur epiphytic in single specimens. Representatives of the Ceramiales and *Polysiphonia* species were also found interwoven into turf-like mats of *Corallina officinalis* or *Gelidium pusillum* in the uppermost sublittoral. Red algae have a high protein content and wide applicability in pharmacy and medicine (M i c h a n e k , 1979). In the northern Adriatic small-scale harvesting would only be possible for *Halopythis incurvus*, which contains bromphenol with antibiotic activity, *Alsidium corallinum* containing vermifugal substances and *Corallina officinalis*, which contains both antimicrobial and vermifugal substances. *Ceramium diaphanum* is known for its antibiotic activity. It forms pure populations in tide pools and in the uppermost sublittoral of undisturbed areas in spring and is replaced by *Laurencia obtusa* in summer. The latter species has a high protein content and contains substances with antimicrobial activity (e.g. laurentine, lauren).

Green algae develop prolific populations in polluted habitats. Their protein content increases with pollution. Recommendations for exploitation of *Ulva rigida* and mixed stands of diverse *Enteromorpha* species could be made. They could be used as a human food supplement or animal fodder.

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RESURSI ALGI U ZAGAĐENIM PODRUČJIMA SJEVERNOG JADRANA (OKOLICA PIRANA)

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KRATKI SADRŽAJ

1.- Resursi algi u zagađenim područjima sjevernog Jadrana prikazani su kroz vlažnu težinu (biomasu) i karakterističnim primjerima zonacije. Vodilo se računa naročito o vodećim asocijacijama algi na lokalitetima izloženim utjecaju otpadnih voda.

2.- Uslijed djelovanja jakog zagađenja fukoidna naselja smanjena su ili odsutna, a njihova je biomasa opala. Eulitoralna fukoidna vrsta *Fucus virsoides* bila je uglavnom odsutna i zamijenjena drugim efemernim sezonskim vrstama. Sublitoralne sastojine *Cystoseira* reducirane su i isprekidane ili nadomještene naseljima algi *Dictyota dichotoma, Halopteris scoparia, Halopythis incurvus* i *Padina pavonica*. Tijekom proljeća naselja vrsta *Ulva rigida* i *Scytosiphon lomentaria* bila su vrlo obimna na zagađenim lokalitetima.

3.- Vlažna težina algi u istraživanom području kretala se od 40 do 6000 g m^{-2}. Sezonski maksimum biomase u eulitoralu i na dubini od 1 m zabilježen je u rano proljeće, a na 3 i 7 m dubine u lipnju. Maksimum biomase nije se uvijek vremenski podudarao s najvećom florističkom raznolikošću.

4.- Broj vrsta na različitim dubinama prikazan je uzduž nekih karakterističnih transekata sa glavnim pojasevima alga.

5.- Istraživan je kemijski sastav nekih vrsta, kao sadržaj proteina i askorbinske kiseline. Izneseni su i podaci o sadržaju alginske kiseline.

6.- Dane su i neke sugestije o mogućnosti korištenja pojedinih vrsta u ljudskoj i životinjskoj prehrani, a naznačene su i najpovoljnije sezone i lokaliteti za sakupljanje sirovog materijala.