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Benthic marine algae of the inlets of the Lagoon of Venice (Northern Adriatic Sea - Italy) concerning environmental conditions

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A study of the benthic algal vegetation in the eulittoral and sublittoral zones was carried out on the hard substrata of the inlets of the Lagoon of Venice (Northern Adriatic). 59 Rhodophyceae, 22 Phaeophyceae and 28 Chlorophyceae were found, a small number in comparison with those of other Mediterranean inlet areas. Total covering of species, biomass and R/P confirm great differences between the shallow and deep algal communities in a change of depth of a few meters. The diversity index is lower than the mean values found in other parts of the Mediterranean.

Key words: Lagoon of Venice, algal communities, species diversity

INTRODUCTION

The benthic algal vegetation living on the hard substrata of the Lagoon of Venice has been insufficiently studied, since attention has mainly focused on the soft substrata of the tidal flats (SCHIFFNER and VATOVA, 1937; SIGHEL, 1938; PIGNATTI, 1962; SOLAZZI *et al.*, 1991; 1991-1994; CURIEL *et al.*, 1995a; *in press*).

Recent studies of the hard substrata of the three inlets of the Lagoon of Venice have revealed changes of the benthic algal vegetation (SFRISO, 1987; CURIEL *et al.*, 1997), due to domestic and industrial pollution (SFRISO *et al.*, 1992).

The progressive decline of seagrass meadows in the last few decades in the central lagoon basin has reduced their role as nurseries for zoobenthos and as protection against bottom erosion and sediment resuspension. Some new algal species, some of which are endemic to other geographical areas (Japan, Korea, China, northern European and American Atlantic coasts) have also recently been reported (RISMONDO *et al.*, 1993; CURIEL *et al.*, 1995 b, 1996 a, b; *in press*).

The aim of the present research is to evaluate the biological and environmental characteristics of the lagoon inlets using both phytosociological methods and some biological indices.

STUDY AREA AND METHODS

The study area (Fig. 1) is located along the breakwaters of the three inlets of the Lagoon of Venice: Lido, Malamocco and Chioggia. The breakwaters are formed of limestone blocks, and were placed there at least 25 years ago. Salinity ranges between 23 and 37 x 10^{-3}, and the mean annual transparency is between 2.2 and 4.5 m (CURIEL *et al.*, 1997). Surveys were carried out in spring and summer of 1995 by snorkeling or scuba-diving in 12 stations between the eulittoral (depth 0.2 m) and sublittoral (depth 7 m) zones. Samples were collected from a 50 x 50 cm surface area, chosen on the basis of a previous study on qualitative minimal area (CURIEL *et al.*, 1997). Samples were preserved in 4% formalin-seawater for later floristic study.

The number of taxa, cover percentages for each taxon, total covering for station (addition of coverage of all taxon for station), R/P index, total biomass (g dry weight m^{-2}) and SHANNON diversity index in accordance with BOUDOURESQUE (1970) were calculated for each station.

On the basis of SECCHI disk data, a depth of 2 m was chosen as the limit for the sublittoral zone, in order to separate it into two parts: upper and lower.

RESULTS

The floristic list revealed a total of 109 taxa, belonging to 97 species, 7 varieties, 1 subspecies and 4 indeterminate species, of which 59 belong to the Rhodophyceae (54.1%), 22 to the Phaeophyceae (20.2%) and 28 to the Chlorophyceae (25.7%).

The mean number of taxa per sample was 38, with higher values on the eulittoral (43) and upper sublittoral (42) and lower ones on the deep sublittoral (34) (Table 1).

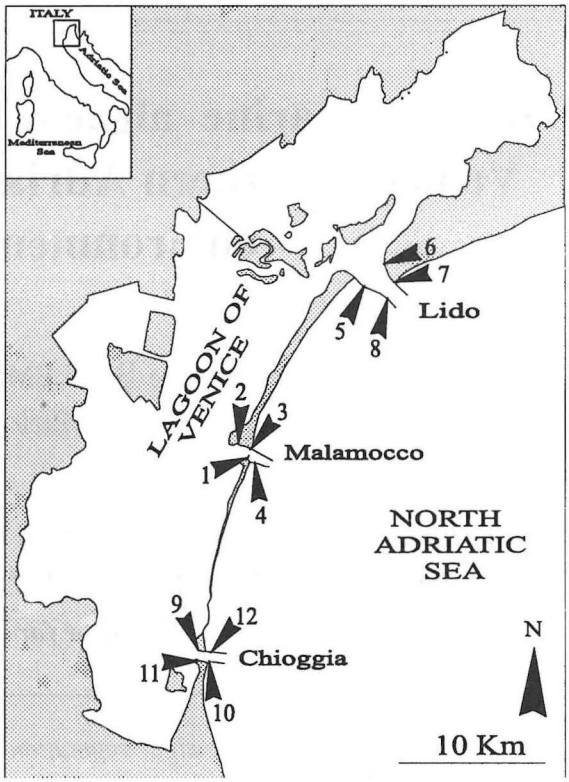

Fig. 1. Map of study area and locations of 12 stations

The mean total covering of all samples was 86.4%, with large differences between the upper and the lower levels; higher values were found in the eulittoral (133.2%) and upper sublittoral levels (119.0%) whereas it was reduced to 49.0% on the lower sublittoral zone. The mean biomass per sample was 105.8 g dry weight m^{-2}. The highest value was found on the upper sublittoral zone (170.4 g dry weight m^{-2}) and the lowest on the lower sublittoral (61.7 g dry weight m^{-2}). Linear regression of the data from the 12 stations showed significant inverse correlations of total covering ($P<0.002$, $R^2=0.61$) and biomass ($P<0.05$, $R^2=0.40$) with depth. The diversity index did not show any change with depth. The mean value per sample was 2.10, with a minimum of 2.0 on the eulittoral zone and a maximum of 2.1 on the upper and lower sublittoral zones. The FELDMANN ratio (R/P) reached a mean value of 7.3 but varied greatly: 4.5 for the eulittoral, 3.9 for the

Table 1. Mean values of the biological indices for total stations and zones

	Total stations	Eulittoral	Upper sublittoral	Lower sublittoral
Depth (m)	-0.2 ÷ -7.0	-0.2 ÷ -0.6	-1.0 ÷ -2.0	-2.2 ÷-7.0
N° taxa	38	43	42.7	34.4
Total covering (%)	86.4	133.2	119.0	49.0
Total biomass (g dry weight m^{-2})	105.8	129.3	170.4	61.7
Diversity index (SHANNON)	2.1	2.0	2.1	2.1
R/P ratio	7.3	4.5	3.9	10.4

upper sublittoral and 10.4 for the lower sublittoral.

The phytosociological units (Fig. 2a) showed considerable frequency of species belonging to the *Rhodymenietalia* MOLINIER 1958 order (22%) and of euryvalent species (28%). These two components, together with the *Ulvetalia* MOLINIER 1958 order (12%), represented 62% of the total algae. Euryvalent species and those belonging to *Ulvetalia* and *Cystoseiretalia* MOLINIER 1958 order did not change frequency along the eulittoral and sublittoral zones, while species belonging to the *Acrochaetietalia* BOUDOURESQUE 1971 and *Rhodymenietalia* orders modified their dominance. *Acrochaetietalia* species were more commonly found on the upper and lower sublittoral zones while *Rhodymenietalia* species became dominant at depth, where the luminous intensity is reduced (Fig. 2b,c and d).

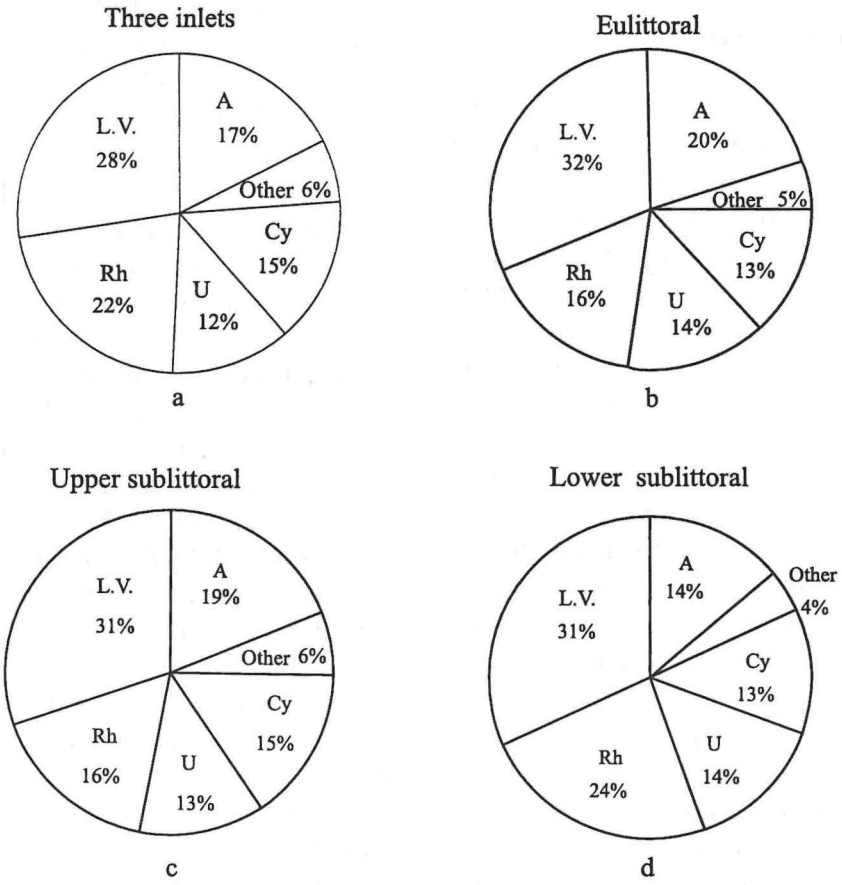

Fig. 2. Percentages of phytosociological units for three inlets (a) and for zone (b, c and d)

Table 2. Photophilic and sciaphilic algae by number and total covering (%) in three zones

	Photophilic algae		Sciaphilic algae		Other algae	
	number	covering	number	covering	number	covering
Eulittoral	60.3	106.7	24.4	20.7	15.3	6.6
Upper sublittoral	61.4	78.6	24.0	32.9	14.6	4.5
Lower sublittoral	49.3	17.8	35.2	28.7	15.5	0.4

Photophilic taxa found on the eulittoral and upper sublittoral zones reached 60.3-61.4% while sciaphilous taxa were reduced to 24.0-24.4% (other taxa 14.6-15.3%) (Table 2). On the lower sublittoral, photophilic taxa were 49.3% and sciaphilous ones 35.2% (other taxa 15.5%). This reduction of photophilic species with depth was more significant when compared with total covering per station, which varied from a mean value of 106.7-78.6% on the first two zones, to 17.8% on the lower sublittoral.

DISCUSSION AND CONCLUSION

The floristic list (in Annex) of the three inlets (109 taxa) is quantitatively comparable to the 100 taxa found by SFRISO (1987) and 105 by PIGNATTI (1962), after revision of the nomenclature. Comparing our data with those of SFRISO (1987), a slight increase in the number of Rhodopohyceae (from 51% to 53.2%) and Phaeophyceae (from 17% to 20.2%) is noticeable, but there is a reduction in Chlorophyceae (from 31% to 26.6%). The floristic list is reduced in comparison with those of other port areas, 184 taxa for Augusta (Sicily) (CORMACI *et al.*, 1985) and 391 for Palermo (GIACCONE *et al.*, 1985). This may be explained by the vicinity of a lagoon environment and to the eutrophic conditions of the Northern Adriatic (DEGOBBIS and GILMARTIN, 1990). The mean number of taxa per sample (38) also appears to be reduced in comparison with the mean number for the Mediterranean ones (40-80) (CORMACI and FURNARI, 1991), especially considering the larger surface area studied here (2500 cm^2) compared with that generally adopted (400-900 cm^2).

Greater numbers of taxa were observed in the eulittoral (43) and upper sublittoral zones (42) and lower numbers in the deep sublittoral one (34), confirming the variation of the environmental conditions in only few meters.

Although the mean diversity index along the bathymetric gradient was lower (2.0-2.1) than the mean values for the Mediterranean (3.2-3.7) (GIACCONE, 1994), it was not as critical as that found in other port areas exposed to human and industrial impact: 1.22 for the Brindisi coastline (CORMACI and FURNARI, 1991), 0.7-1.3 for the Mar Piccolo, Taranto (CECERE *et al.*, 1991), 1.17-1.31 for Augusta and 0.9-2.2 for the Gulf of Marseille (CORMACI *et al.*, 1985).

The annual mean SECCHI disk values ranged between a minimum of 2.2 at low tide (inlet of Lido) and a maximum of 4.5 at high tide (inlet of Malamocco). These water transparency values, converted into Photosynthetically Active Radiation (2.4-12.2% at 5-6 m depth compared to 100% of surface) (CURIEL *et al.*, 1997) show that light intensity is still sufficient for the growth of macroalgae (LÜNING and DRING, 1979), but not for seagrass (DENNISON *et al.*, 1993), which usually colonizes the environment to depths of 3-4 m in the inlet areas of the Lagoon of Venice.

Total covering of species, biomass and R/P ratio confirm the diversity between upper and lower algal communities. On the lower sublittoral zone, total covering and biomass were found to be reduced, while the R/P ratio was elevated, due to the reduced occurrence of Phaeophyceae. Its mean value for the inlets of the Lagoon of Venice (7.3) was comparable

Table 3. Total number of taxa and mean value of biological indices for inlet

	Malamocco	Lido	Chioggia
Total taxa	82	71	65
Rhodophyceae	46 (56.0%)	48 (67.5%)	40 (61.5%)
Phaeophyceae	18 (22.0%)	6 (8.5%)	7 (10.8%)
Chlorophyceae	18 (22.0%)	17 (24.0%)	18 (27.7%)
N° taxa per sampling	42	38	34
Total covering (%)	70.3	122.5	66.4
Total biomass (g dry weight m^{-2})	58.5	161.7	97.1
Diversity index (SHANNON)	2.3	1.9	2.0
R/P ratio	5.2	7.4	9.2

with that found in Augusta (8.32), along the Brindisi coastline (8.45) and in the Marseilles area (7.3) where human and industrial impacts are heavy (CORMACI *et al.*, 1985, CORMACI and FURNARI 1991). Reduced depth penetration of macroalgae as an indicator of eutrophication has been demonstrated in localities where previous data exist (KAUTSKY *et al.*, 1986; RUENESS and FREDRIKSEN, 1991).

The algal vegetation of the inlets is characterized by species belonging to the order *Rhodymenietalia*, *Ulvetalia* and euryvalent species (62%). The low frequency of the *Cystoseiretalia* order further confirms severe degradation, especially in the lower sublittoral (SORTINO *et al.*, 1991). *Cystoseira barbata* C. AGARDH, a characteristic species of the *Cystoseiretum barbatae* PIGNATTI 1962 association, once abundant on hard substrata of Venice lagoon (SCHIFFNER and VATOVA, 1937; PIGNATTI, 1962), it is now reduced to some little relict areas outside our sampling stations. *Dictyopteris polypodioides* (D.C.) LAMOUROUX, an alga believed by SFRISO (1987) to have disappeared, was found at one station in a monospecific colony in the inlet of Lido. The considerable frequency of the taxa belonging to the *Rhodymenietalia* order in lower sites denotes increasing water turbidity.

The division into ecological groups, photophilic and sciaphilic, especially as regards their total covering, shows how the photophilic component is drastically reduced at a depth of only 7 m.

The total number of taxa (82) and the mean number per sample at the Malamocco inlet indicate higher specific diversity in comparison with the Lido and Chioggia (Table 3); the ratio among Chlorophyceae, Rhodophyceae and Phaeophyceae is more well-balanced and the more frequent occurrence of the latter reduces the R/P ratio (5.2) (Table 3). In Malamocco, total covering and biomass are reduced, due to the less frequent occurrence of *Ulva rigida* C. AGARDH and the absence of newly introduced *Sargassum muticum* (YENDO) FENSHOLT or *Dictyopteris polypodioides*, which are found in Chioggia and Lido.

Evaluation of biological indices and the phytosociological study showed altered environmental conditions connected with low water transparency, which has also reduced the occurrence of seagrasses such as *Cymodocea nodosa* (UCRIA) ASCHERSON, *Zostera marina* L. and *Zostera noltii* HORNMANN on the soft substrata.

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Bentoske morske alge na ulazima u venecijansku lagunu (sjeverni Jadran - Italija) u odnosu na okolinu

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SAŽETAK

Istraživanje vegetacije bentoskih algi u eulitoralnoj i sublitoralnoj zoni je obavljeno na čvrstom supstratu na ulazima u venecijansku lagunu. Nađeno je 59 vrsta razreda Rhodophyceae, 22 vrste razreda Phaeophyceae i 28 vrsta razreda Chlorophyceae, što je mali broj u odnosu na ostala područja Mediterana. Ukupna pokrovnost vrsta, biomasa i R/P kvocijent ukazuje na velike razlike između zajednica plitkih i dubljih voda s promjenom dubine od nekoliko metara. Indeks različitosti je manji od srednjih vrijednosti u drugim dijelovima Mediterana.

ANNEX

Floristic list: Units abbreviations: A = *Acrochaetietalia* BOUDOURESQUE 1971; Cy = *Cystoseiretalia* MOLINIER 1958; L.V. = Eurivalent species; U = *Ulvetalia* MOLINIER 1958; *Rhodymenietalia* BOUDOURESQUE 1971; Other = species of other syntaxa.

	RHODOPHYCEAE
L.V.	*Aglaothamnion* sp.
L.V.	*Antithamnion cruciatum* (C. AGARDH) NAEGELI var. *cruciatum*
L.V.	*Antithamnion cruciatum* (C. AGARDH) NAEGELI var. *radicans*
L.V.	*Antithamnion pectinatum* (MONTAGNE) BRAUNER
L.V.	*Antithamnionella spirographidis* (SCHIFFNER) WOLLASTON
A	*Audouinella daviesii* (DILLWYN) WOELKERLING
A	*Audouinella* sp.
A	*Bangia atropurpurea* (ROTH) C. AGARDH
Cy	*Bonnemaisonia hamifera* HARIOT
Rh	*Callithamnion corymbosum* (SMITH) LYNGBYE
A	*Ceramium ciliatum* (ELLIS) DUCLUZEAU
L.V.	*Ceramium diaphanum* (LIGHTFOOT) ROTH
Cy	*Ceramium gaditanum* (CLEMENTE) CREMADES
A	*Ceramium rubrum* auctorum
Rh	*Chondria capillaris* (WITHERING) C. AGARDH
U	*Chondria coerulescens* (J.AGARDH) FALKENBERG
Cy	*Chondria dasyphylla* (WOODWARD) C. AGARDH
U	*Chondrocanthus acicularis* (ROTH) FREDERICQ
Rh	*Compsothamnion thuyoides* (SMITH) NAEGELI
U	*Corallina officinalis* LINNAEUS
Rh	*Cryptonemia lomation* (BERTOLINI) J. AGARDH
L.V.	*Dasya corymbifera* J.AGARDH
L.V.	*Dasya hutchinsiae* HARVEY in W. J. HOOKER
L.V.	*Erythrocladia irregularis* ROSENVINGE
L.V.	*Erythrotrichia carnea* (DILLWYN) J.AGARDH
A	*Gastroclonium clavatum* (ROTH) ARDISSONE
A	*Gastroclonium reflexum* (CHAUVIN) KUETZING
Cy	*Gelidium pusillum* (STACKHOUSE) LE JOLIS
L.V.	*Gracilaria bursa-pastoris* (GMELIN) SILVA
L.V.	*Gracilaria verrucosa* (HUDSON) PAPENFUSS
Rh	*Grateloupia dichotoma* J.AGARDH
U	*Grateloupia doryphora* (MONTAGNE) HOWE
Rh	*Grateloupia filicina* (LAMOROUX) C. AGARDH
L.V.	*Gymnogongrus griffithsiae* (TURNER) MARTIUS
Rh	*Halymenia floresia* (CLEMENTE) C. AGARDH
Rh	*Hydrolithon farinosum* (LAMOUROUX) PENROSE *et* CHAMBERLAIN
Rh	*Lomentaria chylocladiella* FUNK
Rh	*Lomentaria clavaeformis* ERCEGOVIĆ
Rh	*Lomentaria clavellosa* (TURNER) GAILLON
Rh	*Monosporus pedicellatus* (J. E. SMITH) SOLIER *in* CASTAGNE
U	*Nitophyllum punctatum* (STACKHOUSE) GREVILLE
Rh	*Peyssonnelia* sp.

Rh	*Pleonosporium borreri* (SMITH) NAEGELI *ex* HAUCK
U	*Polysiphonia breviarticulata* (C. AGARDH) ZANARDINI
L.V.	*Polysiphonia denudata* (DILLWYN) GREVILLE *ex* HARVEY
Rh	*Polysiphonia elongata* HARVEY *in* W. J. HOOKER
L.V.	*Polysiphonia elongella* HARVEY
A	*Porphyra leucosticta* THURET *in* LE JOLIS
Rh	*Pterothamnion crispum* (DUCLUZEAU) NAEGELI
Rh	*Pterothamnion plumula* (ELLIS) NAEGELI
Rh	*Radicilingua reptans* (ZANARDINI) PAPENFUSS
Rh	*Radicilingua thysanorhizans* (HOLMES) PAPENFUSS
Rh	*Rhodophyllis divaricata* (STACKHOUSE) PAPENFUSS
Rh	*Rhodymenia ardissonei* J. FELDMANN
L.V.	*Stylonema alsidii* (ZANARDINI) DREW
L.V.	*Spermothamnion repens* (DILLWYN) ROSENVINGE
L.V.	*Spermothamnion strictum* (C. AGARDH) ARDISSONE
L.V.	*Titanoderma pustulatum* (LAMOROUX) FOSLIE

PHAEOPHYCEAE

Other	*Asperococcus compressus* GRIFFITHS *ex* HOOKER
Other	*Asperococcus fistulosus* (HUDSON) HOOKER
Cy	*Dictyopteris polypodioides* (D.C.) LAMOUROUX
Cy	*Dictyota dichotoma* var. *intricata* (C.AGARDH) GREVILLE
Cy	*Dictyota linearis* (C. AGARDH) GREVILLE
Cy	*Ectocarpus siliculosus* var. *arcta* (DILLWYN) GALLARDO
Cy	*Ectocarpus siliculosus* var. *dasycarpus* (KUCKUCK) GALLARDO
Cy	*Ectocarpus siliculosus* var. *pygmaeus* (J. ARESCHOUG) GALLARDO
Cy	*Ectocarpus siliculosus* var. *siliculosus* (DILLWYN) LYNGBYE
L.V.	*Hincksia granulosa* (SMITH) SILVA
L.V.	*Hincksia ovata* (KJELLMAN) SILVA
L.V.	*Hincksia sandriana* (ZANARDINI) SILVA
Other	*Kuckuckia spinosa* (KUETZING) KUCKUCK
A	*Petalonia fascia* (O.F.MUELLER) KUETZING
Other	*Pilayella littoralis* (LINNAEUS) KJELLMAN
Cy	*Pseudolithoderma adriaticum* (HAUCK) VERLAQUE
L.V.	*Punctaria latifolia* GREVILLE
Cy	*Sargassum muticum* (YENDO) FENSHOLT
A	*Scytosiphon dotyi* WYNNE
A	*Scytosiphon lomentaria* (LYNGB.) LINK
Cy	*Sphacelaria cirrosa* (ROTH) C. AGARDH
Other	*Stictyosiphon adriaticus* KUETZING

CHLOROPHYCEAE

L.V.	*Blidingia marginata* (J. AGARDH) P. DANGEARD
L.V.	*Blidingia minima* (NAEGELI *ex* KUETZING) KYLIN
A	*Bryopsis adriatica* (J. AGARDH) MENEGHINI
Cy	*Bryopsis disticha* (J. AGARDH) KUETZING
A	*Bryopsis plumosa* (HUDSON) C. AGARDH
A	*Bryopsis* sp.
A	*Chaetomorpha aerea* (DILLWYN) KUETZING
A	*Chaetomorpha linum* (O.F. MUELLER) KUETZING
L.V.	*Cladophora albida* (NEES) KUETZING

U	*Cladophora coelothrix* KUETZING
A	*Cladophora dalmatica* KUETZING
Cy	*Cladophora hutchinsiae* (DILLWYN) KUETZING
A	*Cladophora laetevirens* (DILLWYN) KUETZING
Rh	*Cladophora lehmanniana* (LINDENBERG) KUETZING
U	*Cladophora rupestris* (LINNAEUS) KUETZING
U	*Cladophora sericea* (HUDSON) KUETZING
L.V.	*Cladophora vagabunda* (LINNAEUS) VAN DEN HOEK
L.V.	*Codium fragile* subsp. *tomentosoides* (VAN GOOR) P.C. SILVA
Rh	*Derbesia tenuissima* (DE NOTARIS) P.L. *et* H.M.CROUAN
A	*Enteromorpha compressa* (LINNAEUS) LINK
U	*Enteromorpha intestinalis* (LINNAEUS) NEES
U	*Enteromorpha linza* (LINNAEUS) J. AGARDH
U	*Enteromorpha prolifera* (MUELLER) J. AGARDH
L.V.	*Entocladia viridis* V. REINKE
Rh	*Pedobesia lamourouxii* (J.AGARDH) J.FELDMANN *et al.*
Other	*Rhizoclonium tortuosum* (DILLWYN) KUETZING
U	*Ulva rigida* C. AGARDH
Other	*Ulvaria oxysperma* (KUETZING) BLIDING
L.V.	*Ulvella lens* P.L. *et* H.M. CROUAN