Pergamon

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Changes in Macroalgal Communities in the Vicinity of a Mediterranean Sewage Outfall After the Setting Up of a Treatment Plant

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Benthic macroalgal communities of the upper rocky sublittoral were studied in 1995–1996 in the vicinity of the Marseille (Mediterranean, France) sewage outfall, 8 years after the setting up of a wastewater treatment plant and compared to a previous study carried out in 1972–1974. The number of taxa has increased, a clear stational and seasonal gradient of differentiation of the vegetation appeared, and a turf of ephemeral species is taking place of *Corallina elongata* at sites close to the outfall. These changes may be due to a decrease in pollutant load, the discharge of ferric chlorates used in the treatment process. However, the overall change is much less conspicuous than that described for deeper soft bottom communities, in particular the *Cystoseira amantacea* community is not still restored. Biological traits of this species (short distance dispersal) and the nature of most pollutants removed from the effluent (solids and organic matter) may explain this phenomenon. © 2001 Elsevier Science Ltd. All rights reserved.

Mediterranean; wastewater treatment; macroalgae; communities; changes; pollution.

Introduction

Wastewaters emanating from the urban area of Marseille (Mediterranean Sea, France), which represents 1.5 million inhabitants, have been discharged into the sea directly on the shoreline at Cortiou cove since 1896 (Fig. 1). In 1959, waters from two small coastal rivers (the Jarret and Huveaune), polluted by a variety of industries, were added to this discharge, at first only in summer, and subsequently year round since 1980. These industrial and domestic sewages were discharged into the marine environment without treatment for several decades. Changes to both the environment and benthic communities in this area were reported in a number of studies (Bellan-Santini, 1968; Arnoux and Bellan-Santini, 1972; Bellan and Bellan-Santini, 1972; Arnoux *et al.*, 1973; Belsher, 1974, 1979; Bellan *et al.*, 1975; Leung Tack Kit, 1976; Romano, 1979, 1986; Bellan and Bourcier, 1984, 1990). In 1987, the setting up of a primary treatment plant for the whole sewage following a preceding treatment of industrial wastes, led to a significant decrease in the levels of pollution (Table 1). The sewage flowing into the sea is mainly carried westwards along the coast by currents and prevailing winds (Auclair-Dessemon, 1973). This transport process results in a dilution of the polluted waters and the establishment of a pollution gradient.

In this work, benthic macroalgal communities of the upper sublittoral were studied in 1995–1996 after the setting up of the treatment plant. These results were then compared to a previous study carried out in 1972–1974 by Belsher (1979), using identical methods and at the same sites.

Several authors pointed out changes in marine benthic macroalgal communities induced by sewage outfalls into the sea (e.g. Golubic, 1970; Borowitzka, 1972; Belsher, 1974, 1979; Littler and Murray, 1975; Munda, 1980; Murray and Littler, 1984; May, 1985; Tewari and Joshi, 1988; Brown *et al.*, 1990; Fairweather, 1990). In contrast, the changes in these communities, following the setting up of a treatment plant are poorly documented. An attempt was made in the present study to identify a restoration process of upper sublittoral macroalgal

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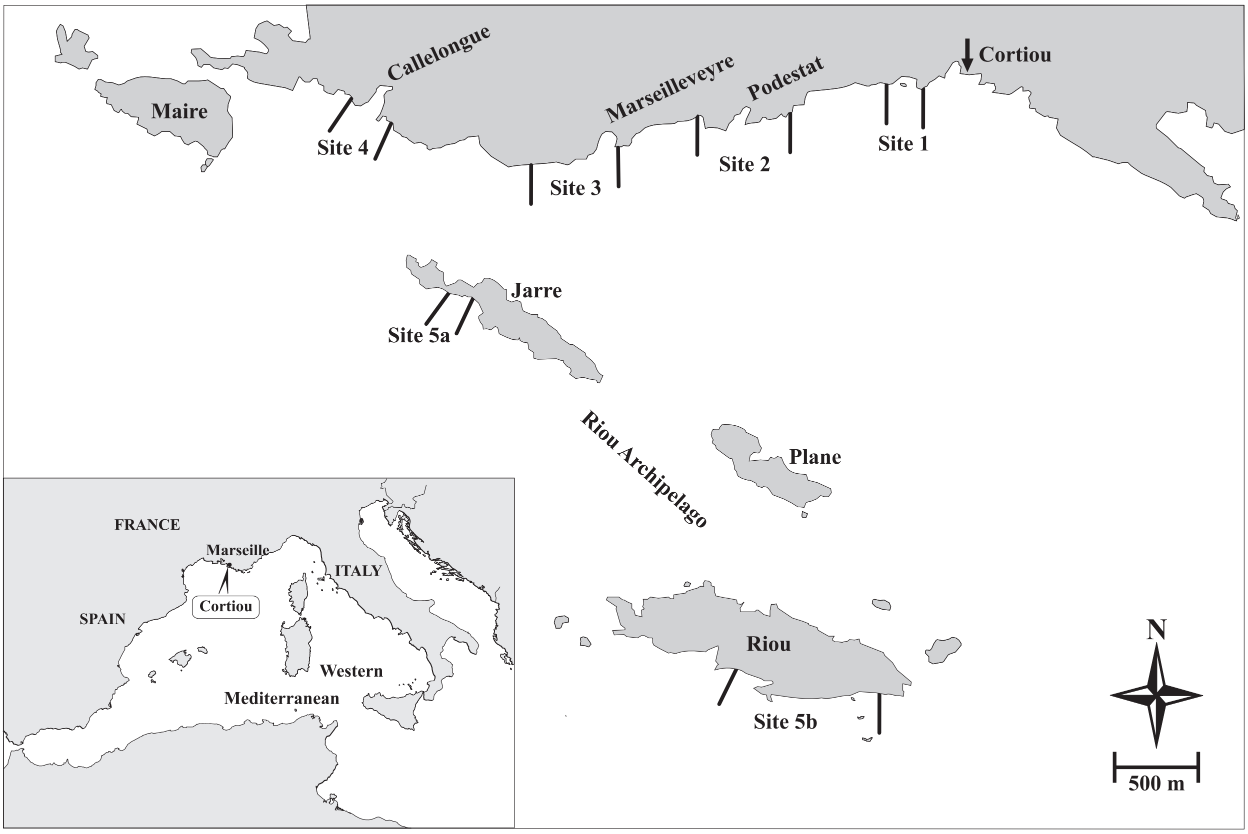

Fig. 1 Location of study area and sites. For the site 5, 5a was sampled in 1972–1974 and 5b in 1972–1974 and 1995–1996.

communities in a zone where pollution has been reduced.

Materials and Methods

Five sites were studied: four sites (1, 2, 3, 4) were established along the coast, at incremental distances from the outfall, and an additional site (5) was selected as a reference due to its lack of exposure to the polluted plume (Fig. 1).

Sampling was performed both during the cold season (winter–spring) and during the warm season (summer–autumn). All sampling was carried out in the upper sublittoral zone (0.25–0.45 m below the limit between the midlittoral and sublittoral; see Pérès and Picard, 1964), under exposed conditions and on gently slopping rocks (20° on average) exhibiting a southern exposure. For each sample, the whole assemblage was collected from a 20 × 20 cm surface, using a hammer and a chisel. Samples, kept in seawater and formalin, were sorted in laboratory for both taxa identification and cover estimates. Cover values (r) for each algal taxa were expressed as a percentage and only those taxa presenting a cover value equal to or higher than 1% were retained.

Significance differences in the means of total algal cover and number of taxa at each site between the two studies were evaluated by a Mann–Whitney U-test.

Ordination of both 1972–1974 and 1995–1996 data by a Correspondence Analysis (Benzécri, 1973; Hugh and Gauch, 1982; Greenacre, 1984; Digby and Kempton, 1987) was used to describe community changes in space and time and to identify the possible parameters

TABLE 1

Changes in composition of effluent discharged before (1978, winter and summer) and after (1995–1996) the setting up of the Marseille treatment plant.[a]

	Discharge (m^3 d^{-1})	pH	TSS (kg d^{-1})	COD (kg d^{-1})	BOD5 (kg d^{-1})	Hydro-carbons (kg d^{-1})	N (kg d^{-1})	P–PO_4 (kg d^{-1})	Pb (kg d^{-1})	Cd (kg d^{-1})	Cu (kg d^{-1})	Zn (kg d^{-1})	Hg (kg d^{-1})	Fe (kg d^{-1})
1978 W	319 387	7.6	49 434	118 618	56 566	920	12 334	5095	16.6	3.3	16.6	29.9	0.2	33
1978 S	801 415	7.8	60 000	131 518	60 313	1187	14 793	5707	40.7	7.6	40.7	56.5	1.2	141
1995	248 336	7.8	7780	69 650	30 500	80	9390	1010	1.4	0.1	11.0	12.6	0.1	191
1996	261 850	7.7	8590	68 440	30 020	100	10 290	1070	1.5	1.2	14.9	26.2	0.2	240

[a] Information provided by the municipal authority for sanitation.

TABLE 2A

Cover in percent of taxa according to sites and study periods (1972–1974).[a]

Taxa	Code	1972–1974																			
		Site 1					Site 2								Site 3				Site 4	Site 5	
	Sample No.	1Bc1	1Bw1	1Bw2	1Bw3	1Bw4	2Bc1	2Bc2	2Bc3	2Bw1	2Bw2	2Bw3	2Bw4	2Bw5	3Bc1	3Bc2	3Bc3	3Bc4	4Bw1	5Bw1	5Bw2
Acrochaetium spp.	Asp	–	–	1	1	5	–	–	–	–	–	5	1	–	4	–	–	–	–	–	–
Aglaothamnion caudatum	Aca	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
'Aglaozonia parvula'	Apa	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	–
Amphiroa cryptarthrodia	Acr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Antithamnion cruciatum	Acu	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	5
Antithamnionella elegans	Ael	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aphanocladia stichidiosa	Ast	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	20	2
Asparagopsis armata	Aar	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Boergeseniella fruticulosa	Bfr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Bryopsis duplex	Bdu	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Bryopsis feldmanii	Bfe	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	10	–	1	1
Bryopsis muscosa	Bmu	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Callithamniae indet.	Cal	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Callithamnion granulatum	Cgr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	–
Callithamnion tetragonum	Cte	–	–	–	1	–	–	–	–	–	–	8	–	–	–	–	–	3	1	–	–
Ceramium ciliatum	Cci	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ceramium diaphanum	Cdi	–	–	–	–	–	–	–	–	–	–	–	4	–	–	–	–	–	–	–	–
Ceramium echionotum	Cec	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–
Ceramium flaccidum	Cfl	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	15	5
Ceramium secundatum	Cse	2		5	5	1	1	1	1	2	2	2	10		4	2	2	5	1	10	15
Ceramium siliquosum	Csi	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	1	1	4	5	5
Ceramium tenerrimum	Cte	–	–	5	2	–	–	–	–	–	–	–	5	–	5	1	2	–	–	2	–
Chaetomorpha mediterranea	Cme	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Chondracanthus acicularis	Cac	–	–	–	–	–	–	–	–	–	–	–	–	–	4	2	2	–	–	–	–
Chilionema sp.	Csp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cladophora albida	Cab	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cladophora hutchinsiae	Chu	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cladophora laetevirens	Cla	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cladophora pellucida	Cpe	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Cladophora sp.	Csc	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Codium fragile	Cfr	–	–	–	–	–	–	–	–	–	–	–	–	15	–	–	–	–	–	–	–
Colpomenia sinuosa	Csn	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–
Corallina elongata	Cel	80	100	100	90	50	100	85	100	100	90	85	100	100	100	100	100	100	100	3	–
Crustose Corallinaceae	Cen	–	–	–	–	–	–	–	–	–	–	–	–	–	13	42	30	17	15	25	14
Crouania ischiana	Cis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cystoseira amentacea var.stricta	Cam	5	–	–	5	–	–	15	–	–	–	5	–	–	–	–	–	15	–	90	90
Cystoseira compressa	Cco	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dasya sp.	Dsp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Derbesia tenuissima	Dte		–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Dictyota dichotoma	Ddi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ectocarpus siliculosus	Esi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6
Enteromorpha flexuosa	Efl	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

TABLE 2A (CONTINUED)

Taxa	Code	1972–1974																			
		Site 1					Site 2								Site 3				Site 4	Site 5	
	Sample No.	1Bc1	1Bw1	1Bw2	1Bw3	1Bw4	2Bc1	2Bc2	2Bc3	2Bw1	2Bw2	2Bw3	2Bw4	2Bw5	3Bc1	3Bc2	3Bc3	3Bc4	4Bw1	5Bw1	5Bw2
Enteromorpha jugoslavica	Eju	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Enteromorpha prolifera	Epr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Enteromorpha sp.	Esp	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Erythrocladia grisea	Egr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Erythrocladia irregularis	Eir	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Erythrocladia sp.	Esp	–	–	–	–	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Erythropeltis discigera	Edi	3	–	–	–	–	–	–	–	–	–	–	–	–	1	5	20	10	15	–	–
Erythrotrichia carnea	Eca	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Erythrotrichia investiens?	Ein	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Erythrotrichia obscura	Eob	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	5	–	10	–	–
Erythrotrichia spp.	Ese	–	–	15	–	–	–	–	–	10	–	–	–	1	–	–	–	–	–	–	–
'*Falkenbergia rufolanosa*'	Fru	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	15	3
Feldmannia caespitula	Fca	1	20	10	–	2	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
Feldmannia irregularis	Fir	–	–	5	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–
Fosliella lejolisii	Fle	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Gastroclonium clavatum	Gcl	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–
Gelidium latifolium	Gla	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Grateloupia filicina	Gfi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4
Gymnogongrus crenulatus	Gcr	1	–	–	1	–	–	–	–	–	–	–	–	–	5	–	2	–	–		
Gymnothamnion elegans	Gel	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Haliptilon virgatum	Hvi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Herposiphonia tenella	Hte	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hincksia granulosa	Hgr	–	–	–	5	–	–	–	–	–	3	5	–	–	–	–	–	–	–	–	–
Hincksia mitchelliae	Hmi	–	–	–	–	–	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–
Hincksia sp.	Hsp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Jania sp.	Jsp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Kuckuckia spinosa	Ksp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lithophyllum incrustans	Lin	–	5	5	3	–	–	–	2	15	5	5	25	–	–	6	5	20	6	2	–
Lithophyllum lichenoides	Lli	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–
Lomentaria articulata	Lar	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lomentaria clavellosa	Lcl	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
Mesospora macrocarpa	Mma	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Myriogramme sp.	Msp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	–
Osmundea ramosissima	Ora	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Petalonia fascia	Pfa	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Peyssonnelia armorica	Par	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Plocamium cartilagineum	Pca	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	5
Polysiphonia atlantica	Pat	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Polysiphonia harveyi	Pha	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Polysiphonia sp1	Psp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Polysiphonia sp2	Pse	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Porphyra leucosticta	Ple	2	–	–	1	–	1	2	–	–	–	–	–	–	–	–	–	–	–	–	–

Porphyrostromium boryanum	Pbo	5	30	20	15	–	4	7	5	–	6	4	–	–	–	–	–	5	–	–	–
Porphyrostromium ciliare	Pci	–	–	–	5	–	–	–	–	–	5	1	–	1	5	–	–	–	–	–	–
Pseudochlorodesmis furcellata	Pfu	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	5
Pseudolithoderma adriaticum	Pad	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pterocladiella capillacea	Pcp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
Pterocladiella melanoidea	Pme	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ralfsia verrucosa	Rve	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rhodymenia ardissonei	Rar	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sahlingia subintegra	Ssu	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	5	–	–
Seirospora sp.	Ssp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Spermothamnion repens	Sre	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Sphacelaria cirrosa	Sci	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
Stylonema alsidii	Sal	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ulva rigida	Uri	1	–	–	1	1	–	3	–	–	1	–	–	–	1	–	3	–	–	–	–
Valonia utricularis	Vut	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
	Total cover	101	155	166	145	73	106	119	108	127	114	120	147	120	142	159	175	188	157	213	174
	Taxa number	10	4	9	17	8	4	8	4	4	9	10	7	6	9	8	13	11	9	19	20

[a] All taxa are listed in alphabetical order. Samples are numbered according to the site (1, 2, 3, 4 and 5), the study period (B: before, i.e. 1972–1974; A: after, i.e. 1995–1996, the setting up of the treatment plant), the season (c: cold season, w: warm season) and the running number.

involved. For each study, hierarchical classification analysis allowed floristic differences to be identified (taxonomic composition and abundance) between sites. Each clustering was done in two stages: first a correspondence analysis was performed, and then a hierarchical classification was carried out taking as input the sample coordinates for the first three axes of the correspondence analysis (see Roux, 1985). The hierarchical classification was the agglomerative Ward's method based on Euclidean distance, computed from the factorial coordinates. All statistical analyses were carried out using the Statistica software, Statsoft, 1997®.

Results

57 and 80 taxa were recorded from the 1972–1974 and 1995–1996 samples, respectively, ($r \geq 1\%$), with 38 taxa in common (Tables 2a and b). More than half of the taxa recorded in 1995–1996 were not observed in the 1972–1974 samples. Only six of them (*Antithamnionella elegans*, *Boergeseniella fruticulosa*, *Bryopsis muscosa*, *Ceramium ciliatum*, *Enteromorpha flexuosa*, *Osmundea ramosissima*) had an important cover ($r \geq 25\%$ in at least one sample). All the 19 taxa only observed in the first study had a moderate cover ($r \leq 8\%$).

An increase in the number of dominant taxa ($r \geq 25\%$ in at least one sample) from 5 to 17 occurred between the 1972–1974 and 1995–1996 studies. Among the taxa having the highest cover, *Corallina elongata* is recorded in all samples from both studies, with the exception one sample from 1972 to 1974 (5Bw2, Table 2a).

Number of taxa and total algal cover

In the first study (1972–1974), the lowest mean number of taxa (6.4) and algal cover (120.1%) were recorded in site 2 and the highest in site 5 (20.0 and 193.5%, Fig. 2). In the second study (1995–1996), the minimum and maximum values were recorded in sites 3 and 2 (12.5 and 107.0%, respectively), and in site 5 (27.0 and 290.5%).

For the five study sites, the number of taxa was significantly different between 1972–1974 and 1995–1996 in sites 1 ($p < 0.05$), 2 ($p < 0.01$) and 5 ($p < 0.05$). The total algal cover did not differ significantly between the two studies ($p > 0.05$).

Ordination

The structure observed along the axes 1 and 2 represents 28.4% of the correspondence analysis total inertia (eigenvalue of 0.67 and 0.48, respectively). The 1972–1974 samples are clearly distributed into two distinct groups according to only one factor: one group containing the reference samples and the other the remaining samples (Fig. 3a). In 1995–1996, samples show a more complex distribution with the occurrence of a second factor. On the first axis, samples from site 5 (reference site) from both studies are opposed to all the others, with the exception of those recorded in 1995–

TABLE 2B

Cover in percent of taxa according to sites and study periods (1995–1996).

Taxa	Code	1995–1996																													
		Site 1						Site 2						Site 3						Site 4						Site 5					
	Sample No.	1A c1	1Ac2	1Ac3	1Aw1	1Aw2	1Aw3	2Ac1	2Ac2	2Ac3	2Aw1	2Aw2	2Aw3	3Ac1	3Ac2	3Ac3	3Aw1	3Aw2	3Aw3	4Ac1	4Ac2	4Ac3	4Aw1	4Aw2	4Aw3	5Ac1	5Ac2	5Ac3	5Aw1	5Aw2	5Aw3
Acrochaetium spp.	Asp	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aglaothamnion caudatum	Aca	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	11	–	–	1	–	–
'Aglaozonia parvula'	Apa	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6	–	–	–	–	8	–	6	–	–
Amphiroa cryptarthrodia	Acr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	2	2	2
Antithamnion cruciatum	Acu	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	7	10	1	1	2
Antithamnionella elegans	Ael	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	–	–	3	2	6	4	4	11	17	29	33	18	5	4
Aphanocladia stichidiosa	Ast	2	2	–	–	–	–	–	1	–	–	–	1	1	1	1	–	–	–	–	–	–	–	1	–	6	5	4	–	–	10
Asparagopsis armata	Aar	–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	8	3	–	–	–
Boergeseniella fruticulosa	Bfr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	50	5	8	–	2
Bryopsis duplex	Bdu	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Bryopsis feldmanii	Bfe	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	–	8	–	–	–	–	–	–
Bryopsis muscosa	Bmu	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	43	34	12	–	–	–	20	45	25	7	3	4
Callithamniae indet	Cal	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Callithamnion granulatum	Cgr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	2	–	–	–	4	3	5	4	1	–
Callithamnion tetragonum	Cte	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ceramium ciliatum	Cci	30	2	3	–	–	–	1	–	–	–	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ceramium diaphanum	Cdi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ceramium echionotum	Cec	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ceramium flaccidum	Cfl	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	3	9	7	10	4	4
Ceramium secundatum	Cse	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	18	10	16	10	16	5	50	90	25	22	12	9
Ceramium siliquosum	Csi	–	4	4	–	–					1	1		–	–	–	–	–	–	–	–	1	5	4	3	1	2	2	4	1	2
Ceramium tenerrimum	Cte	1	1	1	30	53	39	5	4	4	43	9	72	–	3	–	–	–	–	6	7	3	18	29	68	–	–	–	–	–	–
Chaetomorpha mediterranea	Cme	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Chondracanthus acicularis	Cac	–	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Chilionema sp.	Csp	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	1	3	–	–	–	–	–	–	–	–	–	–	–	–
Cladophora albida	Cab	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cladophora hutchinsiae	Chu	18	10	–	–	–		–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	1	1	1	–	–	–
Cladophora laetevirens	Cla	–	–	–	–	–	2	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cladophora pellucida	Cpe	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cladophora sp.	Csc	–	–	2	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
Codium fragile	Cfr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Colpomenia sinuosa	Csn	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Corallina elongata	Cel	43	26	12	20	21	13	90	26	80	26	28	34	100	80	80	100	100	100	63	81	30	24	38	30	2	8	25	11	5	7
Crustose Corallinaceae	Cen	–	3	12	6	7	13	–	1	3	7	6	8	2	2	7	7	4	6	4	5	3	12	3	8	39	25	42	34	36	18
Crouania ischiana	Cis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–
Cystoseira amentacea var.stricta	Cam	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	47	13	40	49	31	30	40	26	2	33	18	25
Cystoseira compressa	Cco	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	4
Dasya sp.	Dsp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Derbesia tenuissima	Dte	2	6	9	3	5	9	1	–	–	10	6	2	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–
Dictyota dichotoma	Ddi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	14	–	–	2
Ectocarpus siliculosus	Esi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–
Enteromorpha flexuosa	Efl	–	–	–	22	40	63	6	–	–	2	3	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Enteromorpha jugoslavica	Eju	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Enteromorpha prolifera	Epr	3	4	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Enteromorpha sp.	Esp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Erythrocladia grisea	Egr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–		–	–	–
Erythrocladia irregularis	Eir	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	3	3	1	–	–	–	–	–	–	–	–	–	–	–	–
Erythrocladia sp.	Esp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Erythropeltis discigera	Edi	–	–	–	–	1	–	–	8	3	–	–	–	8	4	1	4	7	8	1	–	1	–	–	–	–	–	–	–	–	–
Erythrotrichia carnea	Eca	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	4	1	–	–	–	–	–	–	–	–	–	–	–	–
Erythrotrichia investiens?	Ein	–	–	3	3	1	–	–	–	–	–	–	–	–	–	3	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–
Erythrotrichia obscura	Eob	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Erythrotrichia spp.	Ese	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
'Falkenbergia rufolanosa'	Fru	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	17	9	9	29	11	21
Feldmannia caespitula	Fca	21	6	9	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Feldmannia irregularis	Fir	2	–	–	1	2	2	2	–	–	3	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	2	–
Fosliella lejolisii	Fle	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gastroclonium clavatum	Gcl	12	3	–	23	2	–	–	–	–	2	–	3	13	15	5	–	3	1	–	–	–	–	–	–	2	1	1	–	6	–
Gelidium latifolium	Gla	13	–	3	–	–	–	–	–	–	–	–	–	–	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Grateloupia filicina	Gfi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	2	–	2
Gymnogongrus crenulatus	Gcr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–	2	–	6	–	–	–	2	2
Gymnothamnion elegans	Gel	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Haliptilon virgatum	Hvi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
Herposiphonia tenella	Hte	–	–	–	–	1	2	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	2	4	6	12	6	15
Hincksia granulosa	Hgr	–	4	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hincksia mitchelliae	Hmi	–	3	3	–	1	4	–	–	–	4	1	1	–	4	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hincksia sp.	Hsp	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Jania sp.	Jsp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	–	–	–	1	–	–	–	–	3
Kuckuckia spinosa	Ksp	10	–	–	–	1	–	–	–	–	–	1	–	–	4	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lithophyllum incrustans	Lin	35	9	7	1	3	1	2	1	8	2	1	8	3	17	14	2	1	5	24	40	18	8	3	11	–	–	20	3	–	2
Lithophyllum lichenoides	Lli	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Lomentaria articulata	Lar	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10	20	–	8	3	17
Lomentaria clavellosa	Lcl	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mesospora macrocarpa	Mma	–	–	–	1	–	4	–	–	–	1	–	–	–	–	–	1	–	3	–	–	–	–	–	–	–	–	–	–	–	–
Myriogramme sp.	Msp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Osmundea ramosissima	Ora	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	21	34	40	14	10	38
Petalonia fascia	Pfa	–	2	2	–	–	–	–	–	1	–	–	–	–	–	1		–	–	3	3	–	–	–	–	–	–	–	–	–	–
Peyssonnelia armorica	Par	4	1	4	–	1	1	–	–	–	–		–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Plocamium cartilagineum	Pca	–																		–	–	–	–	–	–	–	–	–	–	–	–
Polysiphonia atlantica	Pat	–	–	–	1	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	2	3	6	–	–	–	–	–	–	–
Polysiphonia harveyi	Pha	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	1	3	–
Polysiphonia sp1	Psp	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	–	–	–	–
Polysiphonia sp2	Pse	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–
Porphyra leucosticta	Ple	–	2	5	–	–	–	17	10	5	–	–	–	3	5	4	–	–	–	66	50	35	–	–	–	18	3	12	–	–	–
Porphyrostromium boryanum	Pbo	12	2	3	–	–	–	10	8		–	–	–	80	55	40	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Porphyrostromium ciliare	Pci	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–	2	–	5	–	–	–	–	–	–	–	–	–	–	–	–
Pseudochlorodesmis furcellata	Pfu	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	1	–	–	8	2	9	4	12
Pseudolithoderma adriaticum	Pad	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	2	–	–	–	–	–	1	–	–	–	–	–	–	–
Pterocladiella capillacea	Pcp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pterocladiella melanoidea	Pme	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	5	–	1	–	–	–	–	–	–	–	2	–	–	–	6

TABLE 2B (CONTINUED)

Taxa	Code	1995–1996																													
		Site 1						Site 2						Site 3						Site 4						Site 5					
	Sample No.	1A cl	1Ac2	1Ac3	1Aw1	1Aw2	1Aw3	2Ac1	2Ac2	2Ac3	2Aw1	2Aw2	2Aw3	3Ac1	3Ac2	3Ac3	3Aw1	3Aw2	3Aw3	4Ac1	4Ac2	4Ac3	4Aw1	4Aw2	4Aw3	5Ac1	5Ac2	5Ac3	5Aw1	5Aw2	5Aw3
Ralfsia verrucosa	Rve	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	–	–	–
Rhodymenia ardissonei	Rar	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	10
Sahlingia subintegra	Ssu	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	–	–	–
Seirospora sp.	Ssp	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	3	–	–	–	–
Spermothamnion repens	Sre	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sphacelaria cirrosa	Sci	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	2	3	5
Stylonema alsidii	Sal	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Ulva rigida	Uri	33	30	13	22	22	15	3	–	–	4	2	2	2	3	1	–	1	–	–	–	1	–	–	–	–	1	–	–	–	–
Valonia utricularis	Vut	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	15	30	–	46	33	12
	Total cover	241	131	106	149	174	181	148	61	111	108	67	147	215	221	166	124	126	138	280	247	182	141	141	176	299	436	297	290	176	245
	Taxa number	16	21	20	15	18	19	13	9	11	13	16	15	10	17	15	8	10	14	13	12	18	11	14	10	25	27	25	26	27	30

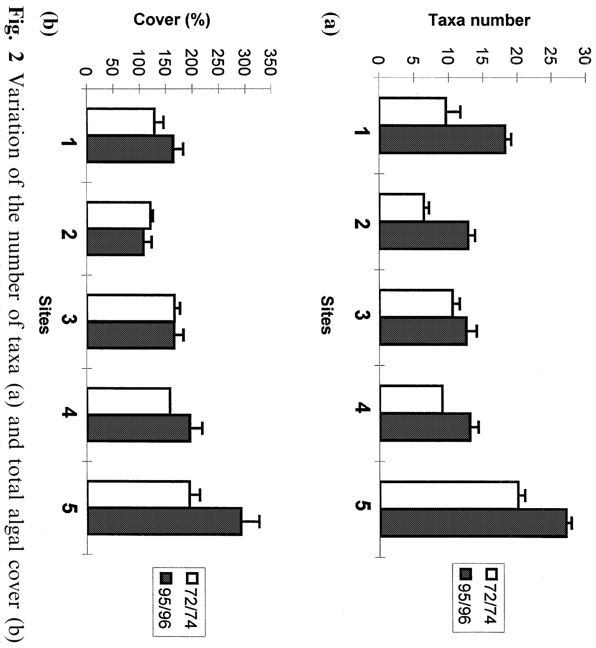

Fig. 2 Variation of the number of taxa (a) and total algal cover (b) according to the outfall distance. Bars show standard error of mean.

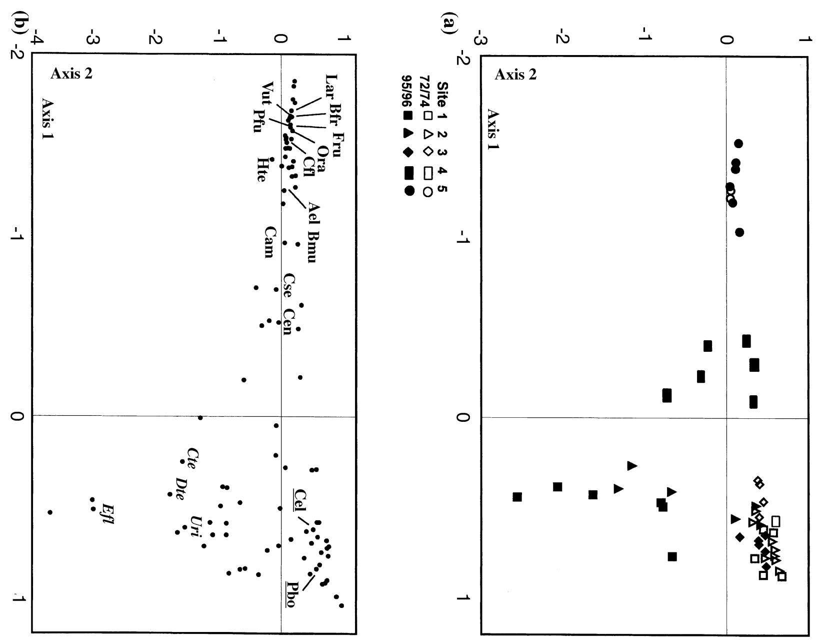

Fig. 3 Ordination plot for the two first axes of correspondence analysis of the two study periods samples (a) and taxa (b). In b, only major contributors to the inertia explained by the two first axes are mentioned: normal for axis 1, italique for axis 2, underlined for axis 1 and 2.

1996 from site 4. These samples exhibit an intermediate position, close to the origin, on the reference samples side. On the second axis, the 1995–1996 samples from site 1 and warm season samples from site 2 are opposed to all the other samples from both studies. 1995–1996 samples from site 4 are divided around the origin into two seasonal groups: a cold season (positive side) and a warm season group (negative side).

In the same plan, the taxa distribution shows the transition from the *C. elongata* community, along axis 1, to a *Cystoseira amentacea* community from the reference site on one hand and on the other, along the axis 2, to an assemblage dominated by the ephemeral species from the zone close to the outfall (Fig. 3b). Taking into account taxa with the highest contribution to the inertia explained by the two first axes, *C. amentacea*, *O. ramosissima*, *Valonia utricularis*, *Falkenbergia rufolanosa* are opposed on axis 1 to *C. elongata* and *Porphyrostromium boryanum*. Along axis 2, *C. elongata* and *P. boryanum* are opposed to *E. flexuosa*, *C. tenerrimum*, *Ulva rigida* and *Derbesia tenuissima*.

Classification

For the 1972–1974 study, the dendrogram separates two groups, which expresses the clear difference between samples (Fig. 4a, before). Group *a* gathers the reference samples (site 5) dominated by *C. amentacea*. Group *b* is made up of all the other samples recorded at different distances from the outfall (sites 1, 2, 3, 4). All of these are strongly dominated by *C. elongata*.

Samples recorded in 1995–1996 are distributed into three main groups (Fig. 4b, after). Group A is made up of all the samples from site 5 (reference site). These samples are dominated by *C. amentacea*, *C. secundatum*, *O. ramosissima* and *V. utricularis*. Group B gathers samples from sites 2 (cold season), 3 and 4. This large group is characterized by the dominance of *C. elongata* and is differentiated into two subgroups. Subgroup B1 corresponds to the samples from site 4, splitted in warm and cold season groups. This site is the most distant from the outfall along the coastline (Fig. 1). In these samples, *C. amentacea* had important covers whereas this species is absent in sites 1, 2 and 3. *Porphyra leucosticta* and *B. muscosa* during the cold season and *C. tenerrimum* during the warm season also had important covers in these samples. Subgroup B2 is composed of: (i) the cold season samples from site 3 and (ii) warm season samples from site 3 with the cold season samples from site 2. This group of samples is strongly dominated by *C. elongata*. Another taxa, *P. boryanum,* is also dominant, in site 3 during the cold season. Group C is made up of all the samples from site 1 and the warm season samples from site 2. Samples of this group are characterized by the dominance of small turf-forming algae: *C. tenerrimum*, *E. flexuosa* in warm season (subgroup C1) and *U. rigida* in cold season (subgroup C2).

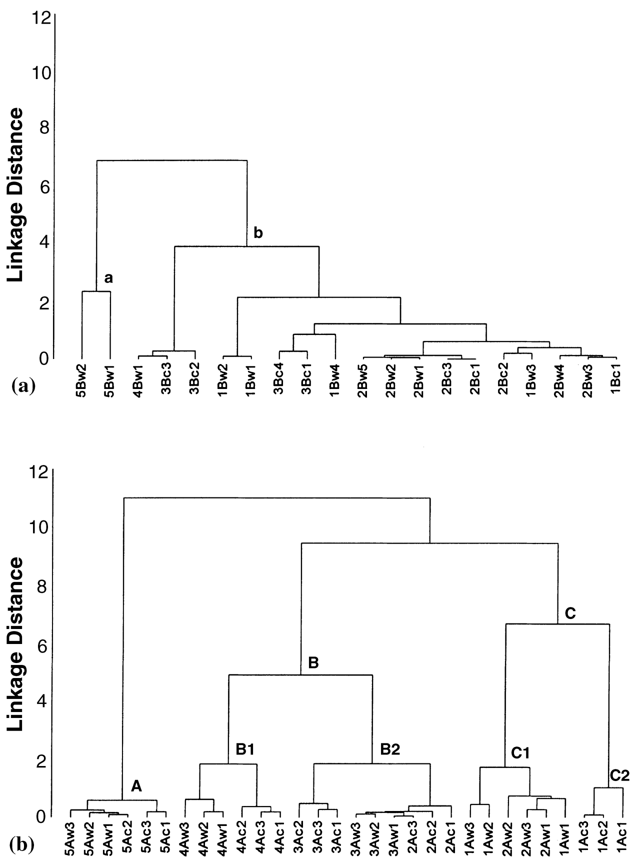

Fig. 4 Tree diagram of all samples for (a) 1972–1974 (before) and (b) 1995–1996 (after). Cluster analysis uses Ward's method and Euclidean distance.

Discussion and Conclusion

Studies on benthic macroalgal communities subjected to domestic and/or industrial wastewaters show similar results to those obtained in the two studies presented in this paper: a decrease in species richness, a reduction in community stratification with the disappearance of large perennial algae, the dominance of the genus *Corallina* in the polluted zones and the development close to the outfalls of turf-forming algae, which are very tolerant and have a short life cycle (Golubic, 1970; Borowitzka, 1972; Littler and Murray, 1975; Belsher, 1979; Wilkinson and Tittley, 1979; Munda, 1980, 1993; Murray and Littler, 1984; May, 1985; Hoffmann *et al.*, 1988; Tewari and Joshi, 1988; Brown *et al.*, 1990; Giaccone, 1991, 1993; Kautsky, 1992; Lopez-Rodriguez and Perez-Cirera, 1994; Gorostiaga and Diez, 1996; Diez *et al.*, 1999). Although the processes leading to macroalgal communities degradation when subjected to pollution are well known, those following an improvement in the sewage outfall quality have been less studied. Only few studies have described the recovery processes following a decrease and/or a treatment of pollution. These processes involve the recolonization of sites where macroalgae have disappeared (Hardy *et al.*, 1993), a significant increase in the taxa number (Bokn *et al.*, 1996), an increase in algal cover and a greater complexity in community stratification (Gorostiaga and Diez, 1996).

In the present study, despite the insufficient number of samples for certain sites in the 1972–1974 study, results obtained are clear enough to allow a global comparison of the assemblages recorded and of their distribution in the study area during both studies. Since 1972–1974, the upper sublittoral vegetation of the study area has become more diversified. In the first study, only two communities dominated the study area: (i) a *C. elongata* community which was uniform over the entire polluted zone (sites 1, 2, 3, 4), without clear delimitations according to Belsher (1979), and (ii) a *C. amentacea* community located in the reference site (site 5), similar to communities described in non polluted Mediterranean environments (Molinier, 1960; Boudouresque, 1971; Verlaque, 1987; Ballesteros, 1988). Results of the second study show a more complex differentiation of the vegetation in the study area. Along the coast, according to the distance from the outfall and sampling season, the former *C. elongata* community (i) has been partially replaced, near the outfall in site 1 and in site 2 by a turf of ephemeral algae: *C. tenerrimum*, *E. flexuosa*, and *U. rigida*; (ii) remains dominant in site 3 and in site 2; (iii) forms a mixed community with the large perennial Fucophycae *C. amentacea* in site 4. In the reference site, the richest *C. amentacea* community is similar to that described in the 1972–1974 study.

Therefore, in addition to an increase in the number of taxa, changes in the vegetation between 1972–1974 and 1995–1996 concern the polluted zone, with the presence in 1995–1996 of a stational and seasonal differentiation of the vegetation. These changes concern mainly the closest (sites 1 and 2) and most distant site 4 from the outfall. For the former (sites 1 and 2), a decline in the *C. elongata* community which was abundant in 1972–1974 and the replacement of this community by turf-forming algae that are opportunistic and/or common to polluted environments (Boudouresque, 1984) occurred. The limited data available for site 4 in the 1972–1974 study unfortunately do not allow any further conclusions concerning its evolution to be drawn.

The changes observed between 1972–1974 and 1995–1996 in studied area can be linked to the treatment of the effluent discharged into the sea. The effluent treatment, with the reduction of an important part of the discharged pollution, may have led to the expression of a stational and, to some extent, seasonal differentiation within the vegetation in 1995–1996. The affinities shown between warm season samples from site 2 and all samples from site 1 are consistent with the warm season increase of pollution (annual peak of load and low dilution). The lack of differentiation observed in 1972–1974 may thus have been due to the too heavy pollution occurring in this area.

The decline of *C. elongata* can be explained in part by the change in the nature of the discharged effluent. The occurrence of a decrease or not in *Corallina* near outfalls seems to be linked to the intensity and nature of the discharged pollution, as has been suggested by certain authors (May, 1985; Diez *et al.*, 1999). The physico-chemical treatment carried out by the Marseille treatment plant includes the enrichment of the effluent by ferric chlorates (4–5 t/day). The polluting load flowing into the sea, with increase of iron load, has been then modified since 1987 (Lardic, 1990). This change may involve, in the two sites close to the outfall, the development of more competitive opportunistic species under these new environmental conditions.

Despite the changes in the upper sublittoral macroalgal communities described here since the setting up of a treatment plant, these communities appear still far from being restored. In contrast, Bellan *et al.* (1999) have described a marked recovery process for soft-bottom macrobenthic communities in the same study area, and this even at a rather short distance from the outfall. The comparatively slow recovery of algal communities could be related to the egg dispersal strategy of the large perennial alga *C. amentacea*. Female gametes and zygotes are rather large in the genus *Cystoseira*, measuring up to 180 μm in diameter (Guern, 1963, 1964). According to Lüning (1990), eggs of most large perennial algae are adapted for rapid sinking. In *Sargassum muticum*, a brown algae belonging to the same family as *Cystoseira*, and for which egg diameter is similar to that of *Cystoseira* species (Norton and Fetter, 1981), eggs have a dispersal range of as little as 3 m in the intertidal region (Critchley, 1981). Though this distance can increase significantly with water movement (Norton and Fetter, 1981; Deysher and Norton, 1982) and varies according to substratum roughness and species, it is clear that recolonization by *C. amentacea* depends on the proximity of parent individuals. Before the setting up of the treatment plant, this very pollution-sensitive species was eliminated from most of the Marseille coastline, including the study area (Bellan-Santini, 1966, 1968; Arnoux and Bellan-Santini, 1972). For such a species, a period of 8 years may be too short to allow recolonization. In addition, *C. amentacea* acts as an ecosystem engineer (see Lawton, 1994): a number of algal species are epiphytic on its stems and branches or depend upon light reduction in its understory. As a result, the absence of *C. amentacea* may explain the rather poor algal restoration observed following the decrease in pollution levels, and the contrasting recovery of the soft-bottom communities. Another possible explanation for the contrasting restoration processes between shallow sublittoral algal communities and deeper soft-bottom macrobenthic communities may be that, quantitatively, most of the removed pollutants are solids and organic matter (Bellan *et al.*, 1999; Table 1). The major portion of these pollutants quickly sinks after having been discharged into the sea. Their removal can thus be logically expected to allow rapid restoration of soft-bottom communities. Conversely, a large part of the remaining pollutants, and the desalinated water plume, flow near the sea surface, such that their impact on shallow communities may remain rather high.

In conclusion, benthic macroalgal communities located in the vicinity of the Marseille sewage outfall are currently different from those described before the setting up of the treatment plant. However, the overall change is far from being comparable to a clear recovery process. Causes of the changes may include a decrease in pollutant load and an increase in iron load. The reason behind the limited extent of the changes observed as compared to deeper soft-bottom communities may be linked to the biological traits of *C. amentacea*, the dominant species in reference communities, and the nature of most pollutants removed from the effluent, i.e. organic matter and solids. On the basis of the low vertical range of the studied communities (# 1 m), the extent of observed changes does not seem sufficient to induce any effect to the marine environment or coastal ecosystem. However, studies in that direction may be initiated for a global understanding of the impact of the wastewater treatment.

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