

## Effects of sewage pollution in the structure and dynamics of the community of *Cystoseira mediterranea* (Fucales, Phaeophyceae)\*

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**SUMMARY:** We performed a study on the specific composition, structure, and dynamics of two *Cystoseira mediterranea* communities from the north-western Mediterranean submitted to different degrees of pollution. The structural complexity (species richness, specific distribution, and species and pattern diversity) and biomass production were lower in the polluted site. In this station, opportunistic algae (mainly *Ulva rigida*) bloomed, and *Mesophyllum lichenoides* and some encrusting brown algae increased their cover. Other species (*Jania rubens*, and some Ceramiales) decreased their abundance when compared with the polluted site.

**Key words:** Marine phytoplankton, pollution, community structure, primary production, *Cystoseira mediterranea*. North-Western Mediterranean.

**RESUMEN:** Se ha estudiado la composición, estructura y dinámica de dos comunidades de *Cystoseira mediterranea* del Mediterráneo noroccidental sometidas a distinto grado de contaminación. La complejidad estructural (riqueza específica, distribución específica y diversidad específica y de motivo) y la producción de la comunidad fueron menores en la estación contaminada. En esta localidad se observó también una fuerte proliferación de especies oportunistas (principalmente *Ulva rigida*), y la aparición de algunas especies particularmente resistentes a cambios en los factores ambientales (*Mesophyllum lichenoides* y fofíceas incrustantes). Por otra parte, es remarcable la disminución de la abundancia de la corallinácea *Jania rubens*, así como la de diversos géneros de Ceramiales (*Callithamnion*, *Ceramium* y *Polysiphonia*) en la estación contaminada.

**Palabras clave:** Fitobentos marino, contaminación, estructura de comunidades, producción primaria, *Cystoseira mediterranea*. Mediterráneo noroccidental.

### INTRODUCTION

The increased eutrophication of coastal Mediterranean waters during the last fifty years is negatively affecting the rich diversity of its benthic systems. Typical Mediterranean communities of seaweeds and seagrasses situated close to populated areas have completely disappeared, and have been replaced by some others, qualitatively and structurally simpler, homogenising the submarine landscape (Bellan-Santini, 1966, 1968; Belsher, 1977; Gómez-Garreta and Ribera-Siguan, 1982; Marcot-Coqueugniot *et al.*,

1984; Rodríguez-Prieto *et al.*, 1995). In particular, the upper sublittoral rocky communities dominated by the fucoid *Cystoseira mediterranea* Sauvageau, that are extensively distributed in the high sublittoral of the western Mediterranean (Feldmann, 1937; Boudouresque, 1969; Soto, 1987; Rull-Lluch, 1987; Rull-Lluch and Gómez-Garreta, 1990; Ballesteros, 1988), have disappeared from large areas of its distribution (Pnve/Uicn/Gis Posidonia, 1990), and this has been related to increased pollution (Gómez-Garreta and Ribera-Siguan, 1982; Ballesteros *et al.*, 1984). Nevertheless, no specific studies have been addressed to assess the pollution effects on the structure and the dynamics of this community.

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In this work we compare the *Cystoseira mediterranea* community of two sites subjected to different pollution stress, taking into account the community structure and the annual cycle of biomass production.

## MATERIAL AND METHODS

Samples of the community of *Cystoseira mediterranea* were collected in Palamós (NW Mediterranean, 41°50' N, 3°7' E), at the places known as Punta del Molí (P.M.) and Cala Castell (C.C.). Both sites are oriented S-SW and exposed to a similar hydrodynamism. Whereas P.M. is a well-preserved station, C.C. is affected by an important effluent (between 15000 m<sup>3</sup>/day in winter and a maximum of 33000 m<sup>3</sup>/day in summer) coming from the Sewage Treatment Plant of Palamós and flowing at 200 m from the sampled communities. Streams transport the effluent to the collecting site.

To establish the community structure, samples were taken in March, June and September 1988, and February and June 1989, by scraping off all organisms (Boudouresque, 1971). Samples were composed by 16 subsamples of 7 x 7 cm<sup>2</sup> arranged in a reticulate manner (Ballesteros, 1986), which corresponds to a total area of 784 cm<sup>2</sup>. Each sample was sorted and species abundance was quantified in the laboratory (coverage in cm<sup>2</sup> and biomass in g dm<sup>-2</sup>). Species/abundance matrices were obtained for each sample, with each  $x_{ij}$  representing the coverage (or the biomass) of the species i at the subsample j. Species/area curves and Diversity (Shannon)/area curves were computed from these matrices. Afterwards, the following structural parameters, extensively described in Boudouresque (1971) and Ballesteros (1986) were estimated:

- Total biomass, expressed in g dwt m<sup>-2</sup>
- Total coverage
- Species richness (R): the number of species corresponding to the Calleja point 5·10<sup>-2</sup> in the species/area curves (Ballesteros, 1986)
- Specific distribution (k): value of k defined as:

$$k = e^{-b/a}$$

where a and b correspond to the slope and the ordinate axis intersection in the species/area curve fitted to a semilogarithmic function:

$$y = a \ln x + b$$

where y is the number of species and x the sampled area in cm<sup>2</sup> (Ballesteros, 1986)

- Molinier point 20/5 (Nédélec, 1979): the sampling area at which a 20% increment in sampling area resulted in a 5% increment in species number. It can be considered as a qualitative minimal area
- Species diversity (A): asymptotic value of diversity when the diversity/area is curve fitted to a Michaelis-Menten function:

$$y = \frac{Ax}{B+x}$$

- Pattern diversity (S): surface corresponding to the Calleja point 1.10<sup>-3</sup> in the diversity/area curve fitted to a Michaelis-Menten function. This surface corresponds to the area at which diversity was practically stabilized and is related to the structural minimal area

- Quantitative dominance of each species, expressed in percentage, and computed from the coverage ( $DR_i = (R_i/R_t) \cdot 100$ ) and from the biomass ( $DB_i = (B_i/B_t) \cdot 100$ ), where  $R_i$  and  $B_i$  are the coverage and the biomass of the species i, and  $R_t$  and  $B_t$  are the coverage and the biomass of the sample (Boudouresque, 1971). The mean of these parametres for the sampling period were also calculated.

For production and dynamics studies, we used the samples sorted for structural studies plus 3 samples of 1600 cm<sup>2</sup> (December 1988, August and November 1989), to complete the annual cycle. The net primary production of the community in each period has been computed as the positive difference of biomass (in g C m<sup>-2</sup>, using dry weight-g C factor conversion of Ballesteros, 1984) between two consecutive samples (Westlake, 1969):

$$P = B_2 - B_1$$

where P was the production at the time t,  $B_1$  was the biomass at the beginning of the period t, and  $B_2$  was the biomass at the end of the period t. The specimens of *Cystoseira mediterranea* were sorted in three compartments (holdfast, stipes and branches). Branch production was estimated assuming linearity between branch biomass and stipes and holdfasts biomass at each sampling period (Ballesteros, 1988). The total production of the community in the sampling period, was computed by adding the positive net productions. Encrusting species of the basal stratum were not considered, because of its difficult biomass estimation.

Surface water samples were collected every 15 days for determination of dissolved nutrients (nitrate and nitrite). Phosphate was also determined but it was always below detection as is usual in shallow Mediterranean waters (Cruzado, 1989). The methodology followed in dissolved nutrient analysis was that recommended in Strickland and Parsons (1968).

Species terminology follows criteria established by Ballesteros (1990).

## RESULTS

In P.M., nitrates and nitrites showed a clear seasonal trend with higher values in autumn and winter, and undetectable values in summer. Nitrates were never higher than 4.2  $\mu\text{M}$ , and nitrites than 1.5  $\mu\text{M}$ . By contrast, in C.C., values were higher all the year round, occasionally peaking in late spring (e.g.  $[\text{NO}_3^-] = 18.7 \mu\text{M}$  in June 1989) (Fig. 1).

Quantified species lists are presented in Tables 1 and 2, the seasonal variation on percentage of coverage and biomass in Table 3, and the quantitative dominance of each strata in table 4. The erect

stratum had a high and similar quantitative importance at the two stations ( $\text{DR}_i = 57\%$  and  $\text{DB}_i = 59\%$  in P.M.;  $\text{DR}_i = 61\%$  and  $\text{DB}_i = 63\%$  in C.C.), and was dominated by *Cystoseira mediterranea*. Epiphytes ( $\text{DR}_i = 25\%$  and  $\text{DB}_i = 15\%$  in P.M.;  $\text{DR}_i = 20\%$  and  $\text{DB}_i = 7\%$  in C.C.) were abundant growing on the stipes (*Jania rubens* and *Titanoderma pustulatum*) or in the branches (*Ceramium rubrum*, *Feldmannia caespitula*, *Herponema valiantei*, *Polysiphonia fruticulosa*, *P. mottei* and several Ectocarpaceae). *Ulva rigida* was quantitatively more abundant in C.C. ( $\text{DR}_i = 15\%$ ) than in P.M. ( $\text{DR}_i = 2\%$ ), whereas *Jania rubens*, was more common in P.M. ( $\text{DR}_i = 15\%$ ) than in C.C. ( $\text{DR}_i = 1\%$ ). Other epiphytes, mainly Ceramiales (*Callithamnion granulatum*, *Callithamnion tetragonum*, *Ceramium ciliatum*, *Ceramium echionotum*, *Polysiphonia fruticulosa* and *Polysiphonia mottei*) were seasonally less abundant at the polluted site (Table 1 and 2). The basal stratum ( $\text{DR}_i = 18\%$  and  $\text{DB}_i = 26\%$  in P.M.;  $\text{DR}_i = 19\%$  and  $\text{DB}_i = 30\%$  in C.C.) developed among and over *Cystoseira* holdfasts and it was dominated by basal crusts and erect talus of *Corallina elongata*, and an encrusting layer made up by *Lithophyllum incrassans*, *Peyssonnelia rosarina* and *Hildenbrandia* sp. In C.C., *Mesophyllum lichenoides* ( $\text{DR}_i = 2\%$ ) and encrusting brown algae ("Aglaozonia" stadia), were also common. Finally, some filter feeders usually occur in the community: *Mytilus galloprovincialis* Lamarck and *Balanus perforatus* Bruguière were attached to the basal stratum or to the holdfasts of *Cystoseira mediterranea*, while the hydrozoan *Aglaophenia kirchenpaueri* Heller grew on its stipes and branches.

The community of *Cystoseira mediterranea* displayed seasonal variations. In P.M. *Cystoseira mediterranea* dominated in spring and the Corallinaceae species of the basal stratum dominated in autumn. The highest values of coverage and biomass were observed in spring (Table 3), corresponding to the development of *Cystoseira mediterranea*, and a secondary maximum was observed in early winter, corresponding to the maximum development of the basal stratum. The lower values were found at late summer. Seasonal variations in C.C. were similar, but values were in average 10–15% lower than in P.M. Differences between the two stations were higher in December 1988 (differences of 43% of % coverage and 30% of biomass). The smallest differences were found in late summer (Table 3).

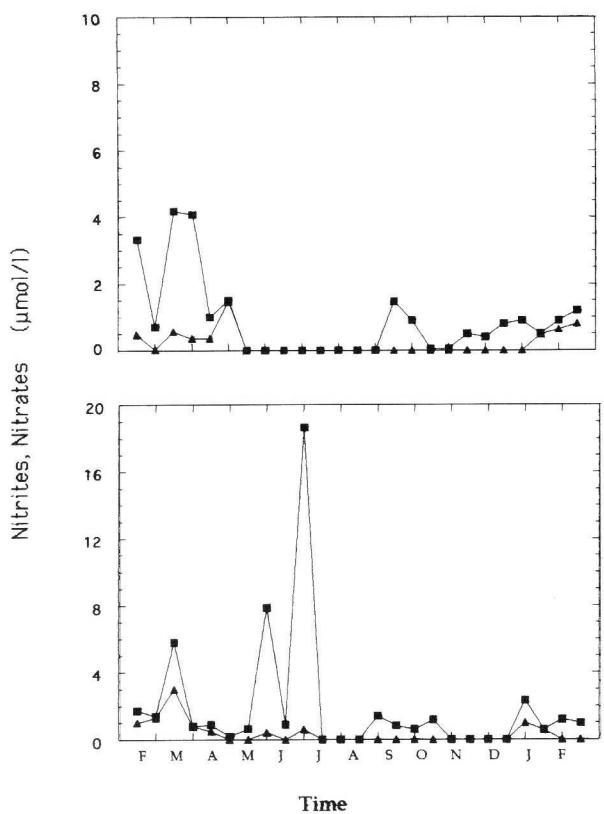


FIG. – 1. Nitrate and nitrite concentrations in surface sea-water from Punta del Molí (above) Cala Castell (below), between February 1989 and January 1990 (every 15 days) (squares: nitrate; triangles: nitrite).

TABLE 1. – Variation in the species composition of the community of *Cystoseira mediterranea* from Punta del Molí during the sampling period. Species abundance is expressed in coverage percentage (up) and g dwt m<sup>-2</sup> (down). Mean quantitative dominance of each species for the sampling period, computed from the coverage (DR<sub>i</sub>) and from the biomass (DB<sub>i</sub>), are also indicated.

Species	1 100388	2 190688	3 160988	4 161288	5 140289	6 240689	7 290889	8 231089	DR <sub>i</sub> DB <sub>i</sub>
<i>Cystoseira mediterranea</i> Sauv.	296.21 1200.5	398.69 1630.4	240.53 870.84	61.13 270.14	143.62 659.48	252.76 1025.1	202.98 855.47	65.19 258.70	57.30 58.54
<i>Jania rubens</i> (L.) Lamour.	84.48 253.20	30.61 99.88	17.33 48.24	138.50 435.40	82.05 235.74	2.28 7.02	31.04 71.08	19.45 62.42	14.75 10.95
<i>Corallina elongata</i> Ell. & Soland.	58.12 267.17	32.77 146.95	2.22 6.94	99.69 428.97	43.65 189.84	31.08 124.17	.16 .71	34.24 158.34	11.52 12.42
<i>Ceramium rubrum</i> (Huds.) C. Ag.	4.01 4.44	11.15 26.10	18.00 28.80	10.17 5.37	5.42 6.47	16.11 19.73	.48 .40	8.00 8.80	2.88 .90
<i>Ulva rigida</i> C. Ag.	.73 .51	.	.11	6.12 6.87	.86 .49	61.67 41.95	3.78 2.83	.31 .05	2.43 .50
<i>Polysiphonia fruticulosa</i> (Wulf.) Spren.	.	53.67 105.84	2.75 4.39	22.17 25.71	.93 .50	.	.01 .02	.	2.10 .87
<i>Lithophyllum incrustans</i> Phil.	4.27 99.79	7.85 204.54	11.74 321.84	.82 22.66	7.94 216.09	3.07 80.04	.48 2.78	8.63 184.10	1.99 11.11
<i>Lithophyllum orbiculatum</i> (Fosl.) Fosl.	.23 .60	1.69 4.83	1.24 2.81	17.62 56.37	6.43 20.39	2.56 5.05	10.84 34.65	.03 .04	1.50 1.24
<i>Feldmannia caespitula</i> (J. Ag.) Knoepff.-Pég.	.	.05 .07	4.73 7.56	.	.	1.76 2.81	17.06 27.30	.	1.00 .43
<i>Gelidium pusillum</i> (Stackh.) Le Jol.	.02 .02	.	.	.15 .48	.08 .13	.01 .01	7.23 11.58	.19 .30	.35 .15
<i>Callithamnion tetragonum</i> (Wither.) Gray	.05 .07	.20 .31	5.83 9.29	.01 .01	2.92 4.68	.01 .01	.	.	.35 .13
<i>Asparagopsis armata</i> Harv.	.	.19 .15	.	.10 .16	.51 .49	.	.	.	.30 .10
<i>Gelidium latifolium</i> (Grev.) Born. & Thur.	1.95 3.12	1.35 2.84	1.20 1.92	1.99 3.50	.19 .36	.55 .90	.74 1.18	.19 .30	.27 .12
<i>Titanoderma pustulatum</i> (Lamour.) Naeg.	.41 6.32	.15 .25	.07 .11	5.24 79.61	1.30 20.22	.03 .05	.06 .10	.19 3.00	.26 1.02
<i>Gigartina acicularis</i> (Roth) Lamour.	.16 .25	.02 .07	.	2.27 3.32	.05 .09	5.23 9.50	.03 .04	.06 .10	.26 .12
<i>Hypnea musciformis</i> (Wulf.) Lamour.	.	.	.	.	.	.	5.76 3.60	.01 .01	.26 .04
' <i>Falkenbergia rufolanosa</i> ' (Harv.) Schmitz stadt.	.26 .41	1.74 1.30	.11 .18	1.66 1.87	1.60 2.28	.50 .67	.04 .06	.66 1.06	.25 .08
<i>Ceramium ciliatum</i> (Ell.) Ducl.	.08 .12	.01 .01	.02 .02	.01 .02	.11 .17	7.22 11.46	.02 .03	.01 .02	.24 .11
<i>Callithamnion granulatum</i> (Ducl.) C. Ag.	.01 .01	4.02 6.60	.08 .12	.64 1.06	2.88 4.07	.04 .06	.	.06 .10	.24 .09
<i>Polysiphonia mottei</i> Lauret	.	.	4.50 7.20	.30 .48	.	.	.07 .11	.03 .05	.19 .07
<i>Hildenbrandia</i> sp. Nardo	.10 .16	.46 1.47	.06 .11	.80 2.56	2.32 7.12	.45 1.29	.09 .15	.03 .04	.16 .11
<i>Sphaerelaria cirrosa</i> (Roth) C. Ag.	.	.08 .12	.01 .01	.67 .51	.06 .10	.05 .07	.11 .18	.98 1.56	.12 .04

<i>Peyssonnelia rosa-marina</i> Boudour. & Den.	.	.	2.65	.01	.	.22	.	.	.11
			31.84	.01	.	2.11	.	.	.31
<i>Gastroclonium clavatum</i> (Rothp.) Ardis.	.20	.01	.15	.71	.84	1.21	.04	.01	.11
	.32	.01	.24	1.20	1.34	1.82	.06	.02	.05
<i>Callithamniae</i> unidentified	3.29	.	.	.01	.05	.01	.01	.	.11
	5.26	.	.	.01	.08	.01	.01	.	.05
<i>Aglaozonia melanoidea'</i> Schousb. ex Sauv. <i>stadium</i>	.85	.	.68	.	.	1.62	.	.	.10
	1.99	.	1.94	.	.	6.41	.	.	.09
<i>Herponema valiantei</i> (Born. ex Sauv.) Hamel	1.20	.35	.	.16	1.20	.32	.	.	.10
	1.92	.56	.	.25	1.92	.50	.	.	.04
<i>Laurencia pinnatifida</i> (Huds.) Lamour.	.	1.77	.02	.27	.42	.	.64	.01	.10
	.	2.92	.02	.33	.26	.	.30	.01	.03
<i>Cladophora pellucida</i> (Huds.) Kütz.	.04	.05	.14	.88	.12	1.05	.31	.02	.09
	.06	.07	.23	1.13	.19	1.69	.50	.03	.04
<i>Cystoseira compressa</i> (Esp.) Gerl. & Niz.	.	.	.05	.13	.	.	.	.91	.09
	.	.	.07	.64	.	.	.	1.45	.03
<i>Ceramium strictum</i> Harv.	.05	.10	.35	.59	.09	.21	.42	.04	.07
	.07	.16	.56	.90	.14	.33	.67	.06	.03
<i>Ceramium echionotum</i> J. Ag.	.	.	.	1.97	.01	.	.01	.	.07
	.	.	.	3.15	.01	.	.02	.	.03
<i>Lomentaria clavellosa</i> Erceg.	.06	.	.98	.11	.22	.	.	.03	.06
	.09	.	1.56	.17	.35	.	.	.05	.02
' <i>Aglaozonia parvula'</i> (Grev.) Zanard. <i>stadium</i>	.51	.	.11	.	.46	.08	.	.01	.04
	.78	.	.18	.	1.10	.23	.	.01	.02
<i>Ectocarpus siliculosus</i> var. <i>confervoides</i> (Roth) Kjellm.	.01	.	.	1.00	.02	.	.	.	.03
	.01	.	.	1.60	.01	.	.	.	.01
<i>Corallina granifera</i> Ell. & Soland.	.73	.	.	.	.08	.	.	.	.02
	1.46	.	.	.	.24	.	.	.	.01
<i>Melobesia membranacea</i> (Esp.) Lamour.	.01	.29	.	.01	.13	.	.	.	.01
	.01	3.48	.	.01	1.83	.	.	.	.04
<i>Lithophyllum lichenoides</i> Phil.	.	.08	.	.	.	.	.	.	.
	.	1.20	.	.	.	.	.	.	.01
<i>Titanoderma corallinae</i> (Cr. & Cr.) Woelk., Chamb. & Silv.	.	.	.	.	.08	.	.	.	.
	.	.	.	.	1.20	.	.	.	.01

**Other species with biomass always lower than 1 g dwt m<sup>-2</sup>:** *Acrochaete viridis* (Reink.) Niels. (7,8); *Acrosorium uncinatum* var. *venulosum* (Zanard.) Kylin (6); *Antithamnion cruciatum* (C.Ag.) Näg. (1,3,5); *Antithamnion heterocladium* Funk (4); *Antithamnionella elegans* (Berthol.) Pr. & John (3,5); *Aphanocladia stichidiosa* (Funk) Ardré (1,2,5,6,7); *Audouinella crassipes* (Börg.) Garb. (2,5); *Audouinella daviesii* (Dillw.) Woelk. (2,3); *Audouinella leptoneura* (Rosenv.) Garb. (8); *Audouinella secundata* (Kylin) Dixon (4); *Audouinella* sp. Bory (1,2,4,5,6,7,8); *Bryopsis duplex* De Not. (4,5); *Bryopsis* sp. Lamour. (1,2,4,5,6,8); *Callithamniella tingitana* (Schousb. ex Born.) J. Feldmann (3,4); *Callithamnion byssoides* Ar. ex Harv. in Hook. (4,5,8); *Callithamnion cymbosum* (Smith) Lyngb. (1); *Ceramiaceae* unidentified (2,5,6,7); *Ceramium giacconei* (Web.) Cor. & Fur. (4,5); *Ceramium* sp. Roth (1,5,7); *Chondria boryana* (De Not.) De Toni (2); *Choreonema thuretii* (Born.) Schmitz (2,6,7); *Chroodactylon ornatum* (C. Ag.) Bass. (1,2,3,4,6,7); *Cladophora albida* (Huds.) Kütz. (3); *Cladophora sericea* (Huds.) Kütz. (6,7); *Cladophora* sp. Kütz. (1,2,5,6,7,8); *Colpomenia peregrina* Sauv. (6); *Colpomenia sinuosa* (Mert. ex Roth) Derb. & Sol. in Castag. (4,8); *Corallinaceae* unidentified (1,2,5,6,7,8); *Crouania attenuata* (C. Ag.) J. Ag. (1,2,3,4,5,6,7,8); *Champiaceae* unidentified (2); *Dasya corymbifera* J. Ag. (1,2,4,5,6,7,8); *Dasya hutchinsiae* Harv. in Hook. (1,2,4,5,6,7,8); *Dasya* sp. C. Ag. (1,5,8); *Delesseriaceae* unidentified (1); *Derbesia tenuissima* (De Not.) Cr. & Cr. (3); *Dictyota dichotoma* (Huds.) Lamour. (4), *Dictyota dichotoma* var. *intricata* (C. Ag.) Grev. (7); *Ectocarpaceae* unidentified (1,2,4,5,7,8); *Enteromorpha compressa* (L.) Grev. (1,4,6,7,8); *Enteromorpha ramulosa* (Smith) Hook. (7,8); *Erythrocladia subintegra* Rosenv. (2,4,6,8); *Erythrotrichia carnea* (Dillw.) J. Ag. (1,2,3,4,5,6,7,8); *Erythrotrichia investiens* (Zanard.) Born. (8); *Erythrotrichia* sp. Aresch. (6,7,8); *Feldmannia globifera* (Kütz.) Hamel (3,6,7); *Fosliella farinosa* (Lamour.) Howe (1,3,4,5,6,7,8); *Gelidiella* sp. J. Feldm. & Hamel (1,4,5); *Grateloupia filicina* (Lamour.) C. Ag. (3,4,5,6,8); *Griffithsia* sp. C. Ag. (4); *Halopteris filicina* (Gratel.) Kütz. (2,5,6,7); 'Halicystis parvula' Schmitz stadium (6,8); *Herposiphonia tenella* (C. Ag.) Ambr. (1,3,4,5,6,7,8); *Herposiphonia tenella* var. *secunda* (C. Ag.) Hollenb. (1,2,3,4,5,7,8); *Heterosiphonia crispedia* (C. Ag.) Wynn. (6); *Hydroclathrus clathratus* (Bory) Howe (5); *Laurencia obtusa* (Huds.) Lamour. (1,4,5); *Lithophyllum lichenoides* Phil. (2); *Mesophyllum lichenoides* (Ell.) Lem. (2); *Nithophyllum punctatum* (Stackh.) Grev. (1); *Pilinia rimosa* Kütz. (1); *Plocamium cartilagineum* (L.) Dixon (2,4,7,8); *Polysiphonia serularioides* (Gratel.) J. Ag. (5); *Polysiphonia* sp. Grev. (1,4,7,8); *Porphyra leucosticta* Thür. in Le Jol. (4); *Porphyra* sp. C. Ag. (1,4,5); *Pseudochlorodesmis furcellata* (Zanard.) Börges. (1,3,6); *Pterocladia melanoides* (Schousb. ex Born) Daw. (2,3); *Pterothamnion crispum* (Ducl.) Näg. (4,5,8); *Ptilothamnion pluma* (Dillw.) Thür. in Le Jol. (5); *Rhodophylloides divaricata* (Stackh.) Papenf. (1,7); *Rissoella verruculosa* (Bertol.) J. Ag. (1); *Sphacelaria* sp. Lyngb. (1,5,7,8); *Stylonema alsidii* (Zanard) Drew (1,2,3,4,5,6,7,8); *Stylonema cornut-cervi* Reinsch (1,2,4,5,6,7,8); *Ulvella lens* Cr. & Cr. (3,4); *Vickersia baccata* (J. Ag.) Kars. emend. Börge. (1,2,4,8); *Wrangelia penicillata* C. Ag. (4).

TABLE 2. – Variation in the species composition of the community of *Cystoseira mediterranea* from Cala Castell during the sampling period. Species abundance is expressed in coverage percentage (up) and g dwt m<sup>-2</sup> (down). Mean quantitative dominance of each species for the sampling period, computed from the coverage (DR<sub>i</sub>) and from the biomass (DB<sub>i</sub>), are also indicated.

Species	1	2	3	4	5	6	7	8	DR <sub>i</sub> DB <sub>i</sub>
	030388	200688	150988	171288	140289	300689	280889	011189	
<i>Cystoseira mediterranea</i> Sauv.	211.17 899.11	387.18 1488.89	230.98 969.74	56.27 218.14	124.92 499.38	296.50 1182.52	240.83 940.53	37.57 168.46	60.13 62.24
<i>Ulva rigida</i> C. Ag.	62.45 30.19	9.86 8.64	36.66 27.13	25.70 14.18	178.59 144.60	2.85 4.72	19.23 9.27	24.31 15.64	14.98 2.85
<i>Corallina elongata</i> Ell. & Soland.	37.81 162.61	18.16 88.45	12.08 54.54	97.52 416.96	13.27 60.86	9.45 42.62	.01 .01	24.39 117.13	11.12 12.06
<i>Lithophyllum incrustans</i> Phil.	6.78 186.24	.14 3.04	6.05 159.60	6.59 182.56	6.88 186.38	2.36 53.87	1.84 45.30	7.73 121.03	2.01 11.52
<i>Ceramium rubrum</i> (Huds.) C. ag.	20.09 27.22	6.74 10.70	.	5.22 4.30	2.89 2.12	4.26 5.26	.04 .07	.	1.45 .46
<i>Gelidium latifolium</i> (Grev.) Born. & Thur.	1.80 2.88	.01 .01	1.35 2.85	.16 .21	7.03 10.01	.42 .39	5.96 9.49	8.25 15.70	1.44 .67
<i>Jania rubens</i> (L.) Lamour.	4.14 13.96	3.32 8.38	7.19 22.86	3.69 10.24	.22 .70	2.78 7.27	.58 1.87	4.28 12.04	1.28 .92
<i>Mesophyllum lichenoides</i> (Ell.) Lem.	.	2.03 32.88	11.93 152.43	.	15.80 254.04	2.72 30.17	.65 10.73	.61 4.82	1.24 4.74
<i>Gigartina acicularis</i> (Roth) Lamour.	.08 .12	.01 .01	.21 .34	.71 .85	5.75 9.19	.05 .08	.48 .77	7.02 15.08	.94 .50
<i>Colpomenia sinuosa</i> (Mert. ex Roth) Derb. & Sol. in Castag.	0.1 0.1	.	.	.09 .15	.	.01 .01	.	8.17 .79	.79 .02
<i>Cystoseira compressa</i> (Esp.) Gerl. & Niz.	4.80 7.68	.	.53 1.88	.04 .06	.	.	1.60 2.76	4.05 6.08	.65 .27
<i>Titanoderma pustulatum</i> (Cr. & Cr.) Woelk., Chamb. & Silv.	.51 5.46	.23 .36	1.51 19.70	6.51 84.80	.31 2.65	.19 .30	.58 9.33	1.26 20.01	.63 1.98
<i>Lithophyllum orbiculatum</i> (Fosl.) Fosl.	0.1 0.1	3.66 9.22	1.78 5.65	1.84 5.79	1.83 5.86	4.85 15.12	.13 .33	.04 .06	.53 .40
' <i>Aglaozonia parvula</i> ' (Grev.) Zanard. <i>stadium</i>	.05 .08	.	.23 .37	.41 .26	7.27 6.65	.	.	.59 1.70	.33 .12
<i>Polysiphonia fruticulosa</i> (Wulf.) Spren.	.04 .06	7.48 11.96	.	.18 .14	.10 .16	.05 .08	.	.	.22 .09
<i>Cladophora pellucida</i> (Huds.) Kütz.	.02 .02	.01 .01	.31 .50	.03 .04	.32 .52	2.24 3.58	1.80 2.89	.01 .01	.19 .08
<i>Ceramium strictum</i> Harv.	.05 .08	.08 .12	.23 .37	2.01 1.95	1.18 1.77	.05 .07	.25 .40	.03 .04	.19 .06
<i>Herponema valiantei</i> (Born. ex Sauv.) Hamel	2.09 3.35	.	.75 1.20	.16 .25	1.20 1.92	.28 .44	.	.16 .25	.18 .08
<i>Ectocarpus siliculosus</i> var. <i>confervoides</i> (Roth) Kjellm.	.79 1.26	.	.03 .05	1.31 2.10	.36 .58	.	.	.	.12 .05
<i>Feldmannia caespitula</i> (J. Ag.) Knoepff.-Pég.	.	.01 .01	.	.	.	2.00 3.19	.92 1.47	.	.12 .05

'Falkenbergia rufolanosa' (Harv.) Schmitz	1.41	.23	.10	.01	.78	.04	.03	.33	.12
stadium	2.20	.37	.16	.03	.76	.06	.04	.04	.03
<i>Peyssonnelia rosa-marina</i> Boudour. & Den.	.	.	2.19	.	.05	.28	.	.	.10
	.	.	27.89	.	.07	3.52	.	.	.27
<i>Hildenbrandia</i> sp. Nardo	.16	.18	.26	.05	.70	.48	.46	.01	.09
	.50	.29	.68	.13	1.96	1.06	1.37	.01	.06
'Aglaozonia melanoidea' Schousb. ex Sauv.	.01	.	.94	.62	.27	.02	.15	.	.09
stadium	.01	.	2.63	.74	.35	.02	.43	.	.04
<i>Aphanocladia stichidiosa</i> (Funk) Ardré	.08	.15	.32	.68	.15	.	.03	.	.07
	.13	.24	.51	.43	.23	.	.04	.	.02
<i>Enteromorpha compressa</i> (L.) Grev.	.	.01	.01	.93	.12	.32	.	.01	.07
	.	.01	.02	.78	.12	.36	.	.02	.02
<i>Gastroclonium clavatum</i> (Rothp.) Ardiss.	.01	.02	.05	.88	.22	.11	.02	.04	.07
	.01	.02	.08	.77	.61	.17	.03	.06	.02
<i>Grateloupia filicina</i> (Lamour.) C. Ag.	.	.02	.26	.	.01	1.49	.	.	.07
	.	.02	.37	.	.01	2.34	.	.	.02
<i>Gelidium pusillum</i> (Stackh.) Le Jol.	.	.	.26	.10	1.31	.01	.	.	.06
	.	.	.42	.17	2.09	.01	.	.	.03
<i>Sphacelaria cirrosa</i> (Roth) C. Ag.	.02	.19	.07	.	.	.07	.72	.15	.06
	.04	.30	.11	.	.	.10	1.15	.24	.02
<i>Ceramium ciliatum</i> (Ell.) Ducl.	.02	.01	.	.77	.02	.08	.09	.01	.05
	.04	.01	.	.54	.04	.13	1.35	.01	.03
<i>Corallina granifera</i> Ell. & Soland.	.	.	.	.48	.	.	.	.	.03
	.	.	.	2.83	.	.	.	.	.04
<i>Gelidiella</i> sp. J. Feldm. & Hamel	.	.	.	.	.	.96	.	.	.03
	.	.	.	.	.	1.52	.	.	.01
<i>Melobesia membranacea</i> (Esp.) Lamour.	.	.23	.	.09	.01	.04	.	.	.01
	.	2.52	.	1.50	.01	.06	.	.	.04
<i>Corallinaceae</i> unidentified	.	.	.16	.03	.	.	.01	.06	.01
	.	.	1.70	.05	.	.	.01	1.00	.04

**Other species with biomass always lower than 1 g dwt m<sup>-2</sup>:** *Acrochaete viridis* (Reink.) Niels. (3,4,5,7,8); *Antithamnion cruciatum* (C. Ag.) Näg. (1); *Antithamnion heterocladium* Funk (1); *Apoglossum ruscifolium* (Turn.) J. Ag. (5); *Asparagopsis armata* Harv. (2); *Audouinella crassipes* Garb. (7); *Audouinella davyseii* (Dillw.) Woelk. (1,2,3,4); *Audouinella secundata* (Kylin) Dixon (1); *Audouinella* sp. Bory (1,5,7); *Bryopsis duplex* De Not. (3,4,5,7); *Bryopsis plumosa* (Huds.) C. Ag. (4,5); *Bryopsis* sp. Lamour. (4,6,7,8); *Callithamniaceae* unidentified (3,5); *Callithamniella tingitana* (Schousb. ex Born) G. Feldm. (1,4); *Callithamnion byssoides* Arnott ex Harv. in Hook. (4); *Callithamnion granulatum* (Duel.) C. Ag. (5,6); *Callithamnion tetragonum* (Wither.) Gray (2,4); *Ceramiaceae* unidentified (5); *Ceramium echinotum* J. Ag. (5); *Ceramium* sp. Roth (6); *Chaetomorpha aerea* (Dillw.) Kütz. (7); *Chondria boryana* (De Not.) De Toni (2,3,6); *Choreonema thuretii* (Born.) Schmitz (8); *Chroodactylon ornatum* (C. Ag.) Bass. (3,7); *Cladophora albida* (Huds.) Kütz. (1,4,7); *Cladophora coelothrix* Kütz. (2,6); *Cladophora dalmatica* Kütz. (3); *Cladophora* sp. Kütz. (3,5,6,7,8); *Crouania attenuata* (C. Ag.) J. Ag. (1,2,6); *Dasya corymbifera* J. Ag. (1,2,3,4,5,7); *Dasya hutchinsiae* Harv. in Hook. (1,2,6,7,8); *Dasya* sp. C. Ag. (1,5,7); *Delesseriaceae* unidentified (5); *Dictyopteris membranacea* (Stackh.) Batt. (5); *Ectocarpaceae* unidentified (4,5,8); *Enteromorpha multiramosa* Blid. (4); *Enteromorpha ramosa* (Smith) Hook (1,2,3,4,5,7,8); *Erythrocladia subintegra* Rosenv. (2,4,5); *Erythrotrichia carnea* (Dillw.) J. Ag. (1,2,3,4,5,6,7,8); *Erythrotrichia* sp. Aresch. (4,8); *Feldmannia globifera* (Kütz.) Hamel (8); *Fosliella farinosa* (Lamour.) Howe (1,3,4,5,6,7,8); *Griffithsia* sp. C. Ag. (5); *Halopteris filicina* (Gratel.) Kütz. (6,7); *Halopteris scoparia* (L.) Sauv. (6); '*Halicystis parvula*' Schmitz stadium (1,3,4,5,6,8); *Herposiphonia tenella* (C. Ag.) Ambr. (1,3,4,7,8); *Herposiphonia tenella* var. *secunda* (C. Ag.) Hollenb. (1,2,4,5,6,7,8); *Heterosiphonia crispella* (C. Ag.) Wynn. (4); *Hydroclathrus clathratus* (Bory) Howe (8); *Hypnea musciformis* (Wulf.) Lamour. (5,8); *Jania longifurca* Zanard. (5); *Laurencia obtusa* (Huds.) Lamour. (6); *Laurencia pinnatifida* (Huds.) Lamour. (1,2,4,6,8); *Lomentaria clavellosa* Erceg. (1,2,4,5,7,8); *Nithophyllum punctatum* (Stackh.) Grev. (8); *Padina pavonica* (L.) Thivy (8); *Plocamium cartilagineum* (L.) Dixon (1,2,4,5); *Polysiphonia mottei* Lauret (1,2,5); *Polysiphonia sertularioides* (Gratel.) J. Ag. (2); *Polysiphonia* sp. Grev. (4,5,6,8); *Porphyra leucosticta* Thur. in Le Jol. (1); *Porphyra* sp. C. Ag. (5); *Pseudochlorodesmis furcellata* (Zanard.) Börges. (4); *Pterocladia melanoidea* (Schousb. ex Born.) Daw. (1,2,4); *Pterosiphonia spinifera* (Kütz.) Falk. (5); *Pterothamnion plumula* var. *bebpii* (Reinsch) J. Feldm. (4); *Rhodophyllis divaricata* (Stackh.) Papenf. (6); *Rissoella verruculosa* (Bertol.) J. Ag. (5); *Sphacelaria* sp. Lyngb. (4,5,7,8); *Stylocladia alsidii* (Zanard.) Drew (1,2,3,4,5,6,7,8); *Stylocladia cornu-cervi* Reinsch (1,3,4,5,6,7,8); *Ulvella lens* Cr. & Cr. (2,3); *Vickmania baccata* (J. Ag.) Kars. emend Börges. (2,6,8).

TABLE 3. – Seasonal variation in percentage coverage and biomass (g dwt m<sup>-2</sup>) in Punta del Molí and in Cala Castell.

Punta del Molí			Cala Castell		
Date	Coverage	Biomass	Date	Coverage	Biomass
100388	459	1851	030388	357	1345
190688	548	2241	200688	451	1672
160988	317	1349	150988	317	1455
161288	378	1356	171288	214	953
140289	309	1381	140289	373	1196
240689	391	1345	300689	337	1361
290889	283	1015	280889	277	1041
231089	140	682	011189	130	501

TABLE 4. – Percentage of quantitative dominance, computed from the coverage ( $DR_i$ ) and from the biomass ( $DB_i$ ) of the different strata at the two stations.

stratum	Punta del Molí		Cala Castell	
	DRi	DBi	DRi	DBi
erect	57.4	58.6	60.8	62.5
basal	17.1	26.0	18.5	30.7
epiphytes	25.5	15.4	20.7	6.8

TABLE 5. – Seasonal variation in species richness (R), specific distribution (k), Molinier point 20/5 (M20/5) (in cm<sup>2</sup>), and specific diversity and pattern diversity computed from coverage values ( $A_c$  and  $S_c$ ). Correlation coefficients between experimental and adjusted curves fitted by a Michaelis-Menten function are also indicated.

date	R	k	M20/5	$A_c$	$S_c$	$r^2_c$
<b>Punta del Molí</b>						
100388	44	19.8	760	1.64	109.6	0.943
190688	34	20.3	777	1.52	101.7	0.786
160988	31	10.6	406	1.60	122.9	0.882
140289	48	23.4	895	2.38	181.8	0.694
240689	38	17.3	661	1.96	161.8	0.828
mean	39	18.3	700	1.82	135.6	
<b>Cala Castell</b>						
030388	35	17.6	672	1.87	134.9	0.940
200688	35	15.2	584	0.87	85.7	0.840
150988	33	8.7	332	1.65	123.4	0.654
140289	45	23.0	880	2.06	141.9	0.822
300689	38	15.6	599	1.01	101.1	0.892
mean	37	16.0	613	1.49	117.4	

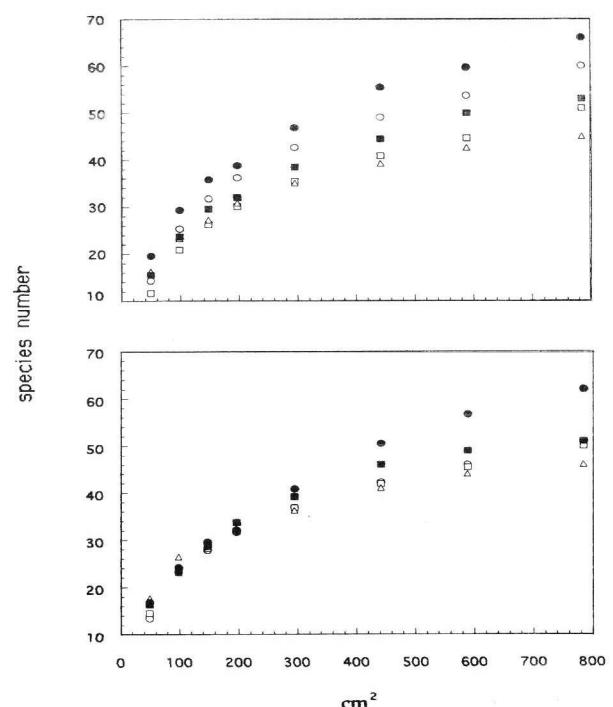


FIG. 2. – Species/area curves in *Cystoseira mediterranea* community from Punta del Molí (up) and Cala Castell (down). Different samples are figured with different symbols: 0388: white circles; 0688: white squares; 0988: white triangles; 0289: black circles; 0689: black squares.

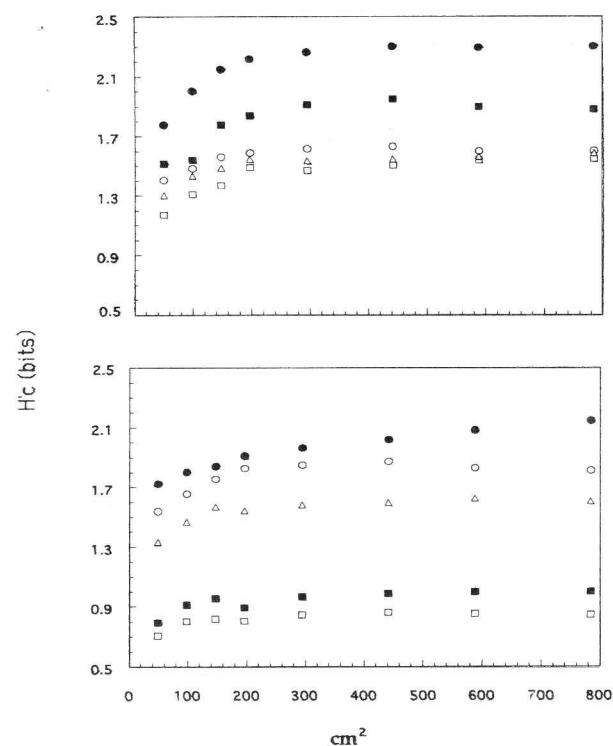


FIG. 3. – Diversity (computed from coverage values)/area curves in Punta del Molí (up) and in Cala Castell (down). Different samples are figured with different symbols: 0388: white circles; 0688: white squares; 0988: white triangles; 0289: black circles; 0689: black squares.

Species richness was always similar in the two stations except in winter, when it was higher in P.M. (44 and 48 species *versus* 35 and 45 species in C.C.). Estimates of specific distribution were higher all through the year in P.M. and this was reflected in a higher minimal qualitative area (Molinier point M20/5) (Table 5) (Fig. 2). Specific diversity and pattern diversity, computed for the coverage, were, in average, higher in P.M. than in C.C., and the stronger differences corresponded to spring 1989 (48 % of Ac and 38 % in Sc), and spring 1988 (43 % of Ac and 16% in Sc) (Table 4) (Fig. 3).

Production was highest in spring but growth was maintained from early winter until July. The production of the community of *Cystoseira mediterranea* was 12 % higher in P.M. ( $493 \text{ g C m}^{-2}$ ) than in C.C. ( $435 \text{ g C m}^{-2}$ ) (Table 6).

TABLE 6. – Production values in  $\text{g C m}^{-2}$  and Pday for the community of *Cystoseira mediterranea* of the two stations at the different sampling periods. Time (t) and biomass ( $B_2$ ,  $B_1$ ) are also indicated.

	t(day)	$B_2$	$B_1$	P	$P_{\text{day}}$
<b>Punta del Molí</b>					
100388 - 190688	100	605	302	303	3.03
200688 - 160988	88	286	605		
170988 - 161288	89	264	286		
171288 - 140289	59	246	264		
150289 - 240689	129	435	246	190	1.47
250689 - 290889	65	331	435		
300889 - 231089	54	103	331		
<b>Cala Castell</b>					
030388 - 200688	109	475	247	229	2.10
210688 - 150988	86	320	457		
160988 - 171288	91	115	320		
181288 - 140289	58	141	115	26	0.44
150289 - 300689	134	321	141	180	1.35
010789 - 280889	58	285	321		
290889 - 011189	64	110	285		

## DISCUSSION

Dissolved nutrients concentration of the surface sea-water was higher in C.C. than in P.M., due to the constant effluent of the Sewage Treatment Plant of Palamós. Peaks observed in late spring and in summer corresponded with effluents of no-treated sewage in periods of strongly increased tourist population, when the capacity of the Plant is inadequate. The results suggest that these inputs are more frequent than the sampling frequency, and that to asses its real importance it will be necessary to take closer samples.

The increased sewage pollution in C.C. is reflected in some changes of the species composition of the *Cystoseira mediterranea* community, and in a decrease of its structural complexity, biomass and production. These changes are not extremely hard, probably because phytobenthos reacts better to a relatively constant pollution than to a weaker but intermittent pollution (Boudouresque *et al.*, 1981), but they are detectable.

Changes in the species composition are specially related to the great proliferation of *Ulva rigida* in C.C. This opportunistic species (Feldmann, 1937) profits the constant nutrients effluent of C.C. to grow. Similar proliferations of different species of Ulvales have been observed in other nutrient rich systems (i.e. Cotton, 1910; Nars and Aleem, 1948; Grenager, 1957; Den Hartog, 1959; Borowitzka, 1972; Edwards, 1973; Marcot-Coqueugniot *et al.* 1984; Rodríguez-Prieto *et al.*, 1995). The calcareous red crusts of *Mesophyllum lichenoides* and several encrusting brown algae, such as '*Aglaozonia parvula*' or '*Aglaozonia melanoidea*' stadium, considered to be specially resistent to changes in environmental factors (Feldmann, 1937), are specially developed. There is a strong decrease in the dominance of *Jania rubens* (from 15 % to 1 % of DRi), although no sensibility to pollution has been noted before for this species. Other authors have attributed differences in the abundance of *Jania rubens* in the *Cystoseira mediterranea* community to differences in hydrodynamism (Rull Lluch and Gómez-Garreta, 1990). Finally, there is also a decrease on the Dominance of some species of Ceramiales (*Callithamnion*, *Ceramium*, *Polysiphonia*,...).

Changes in the structural complexity of the community of *Cystoseira mediterranea* from the polluted station, C.C., compared to the non-polluted site, P.M., are reflected in a decrease of the species richness, mainly in winter, and a decrease of the specific distribution all the year round. In winter, the species richness is the highest because the small thalli of *Cystoseira mediterranea* prevent competence for light (Ballesteros, 1988), being higher in P.M. than in C.C. In spring, when cover of *C. mediterranea* is the highest, species richness at the two stations becomes similar. The high values of specific distribution from both stations, compared to other communities of the same species (Ballesteros, 1984) reveal a strong patchiness in the community, and the lower values of C.C. compared to P.M. indicate a more homogeneous distribution of epiphytic species.

The lower biomass of the community of *Cystoseira mediterranea* from C.C., compared to P.M., is a typical response to pollution stress (Dawson, 1959, 1965; North, 1964; Copeland, 1966; Widdowson, 1971, Borowitzka, 1972; Littler and Murray, 1975; Niell and Pazó, 1978). By the other hand, the decrease of the diversities values of the polluted sites in comparison with stable ones, has been proved also in other communities affected by environmental stress (Borowitzka, 1972; Niell and Pazó, 1978; Boudouresque *et al.*, 1981; Martin *et al.*, 1993; Rodríguez-Prieto *et al.*, 1995).

Production peaks in spring as it is usual for the upper infralittoral communities (Ballesteros, 1984), but values were lower at the polluted station. *C. mediterranea*, and the usual species of its community, need a stable ambiance to develop to their maximum, and in C.C., these conditions are not attempted. By the other hand, the production of the opportunistic species, as *Ulva rigida*, may be increased at the polluted station, but the methods used are not able to detect short blooms.

In conclusion, structure and dynamics differ between polluted and unpolluted stations. Pollution acts as a physical stress in *Cystoseira mediterranea* communities changing its species composition, diminishing their structural complexity and heterogeneity and altering their production values.

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