Long-term changes in sand-bottom macrofauna along the coast of Provence (northwest Mediterranean Sea)

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Abstract – At a time when there is a great deal of talk of the degradation of the coastal environment and of biodiversity being threatened, we felt it would be of interest to sample the macrofauna of five sites at five metres depth in well sorted fine sand at a thirty-year interval (1966–1996), using the same techniques. Four seasonal samplings provided comparative data at each site on the species richness (S), density (N) and biomass (B). The S values are comparable and even on the increase at two stations. Nevertheless, we observed a general tendency towards decline in the relative abundance of the crustacean group. From the quantitative point of view (N and B), the changes observed would appear to result from the impact of clearly identifiable human pressure, such as the diversion of a small coastal river outside the Gulf of Marseilles, or, conversely, the increase of nutrient inputs from the Rhone along the coast of the Camargue. In the latter case, the rate of nutrient inputs was amplified by a climatic factor which contributed to increasing the Rhone's flow rate during the two years preceding the re-sampling of the site in 1996. Apart from these two cases, there would appear to be little significant alteration in the macrofauna, although these fine sand, relatively shallow bottoms are naturally subject to patterns of alternation in the relative dominance of certain zoological groups such as, for example, the prey/predator couple formed by molluscs and echinoderms. © 2000 Ifremer/CNRS/IRD/Éditions scientifiques et médicales Elsevier SAS

Mediterranean / sand-macrofauna / changes / long-term

Résumé – Variations à long terme de la macrofaune de fonds sableux au large des côtes de Provence (Méditerranée nord-occidentale). Alors que l'on parle beaucoup de la dégradation des zones littorales et des atteintes à la biodiversité, il nous a paru intéressant d'échantillonner, à trente ans d'intervalle (1966–1996), avec les mêmes techniques, la macrofaune de cinq sites à une station à cinq mètres de profondeur dans des sables fins bien calibrés. Quatre prélèvements saisonniers ont fourni à chaque site des données de comparaison sur la richesse spécifique (S), la densité (N) et la biomasse (B). Les valeurs de S sont comparables et même en augmentation sensible à deux stations. Toutefois, nous observons une tendance générale à la régression de l'abondance relative du groupe des crustacés. Sur le plan quantitatif (N et B), les modifications observées semblent relever d'effets anthropiques bien identifiés, comme le détournement d'un petit fleuve côtier à l'extérieur du golfe de Marseille, ou à l'inverse, l'accroissement des apports en nutriments par le Rhône sur le rivage de la Camargue, apports encore amplifiés par un facteur climatique qui contribue à l'augmentation du débit du fleuve pendant les deux années précédant le ré-échantillonnage du site en 1996. Mis à part ces deux cas, il n'apparaît pas de modifications significatives de la macrofaune, ces sables fins peu profonds étant naturellement soumis à des alternances dans la dominance relative de certains groupes zoologiques comme par exemple le couple proie/prédateur représenté par les mollusques et les echinodermes. © 2000 Ifremer/CNRS/IRD/Éditions scientifiques et médicales Elsevier SAS

Méditerranée / macrofaune des sables / variations / long-terme

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1. INTRODUCTION

There has been a good deal of pessimistic speculation regarding the future of the Mediterranean seabed, the most sensitive areas being those situated along the coast, which are exposed to the full brunt of human pressure whether direct, such as urbanisation, or indirect such as fluvial inputs fed by catchment areas of greater or lesser surface area and finally atmospheric inputs whose importance has often been underestimated [16]. In addition to this human impact, there are, too, climatic effects that may be very marked in coastal areas and may interact with the human impact. The unfortunate habit of attributing to 'pollution' any alteration observed in the coastal ecosystems has limited the development of more in-depth analyses [12]. Nevertheless, a number of authors have focused their attention on these questions, such as Ziegelmeier [40, 41], Buchanan et al. [7, 8], Beukema [2, 4], Reise [33], Arntz and Rumohr [1], Dauvin and Ibanez [11], Pearson and Barnett [29], Ibanez et al. [14], Beukema et al. [5, 6].

Unfortunately, in many cases surveys are often not sufficiently long-term or relevant in terms of sampling intervals to be useful in this kind of analysis. In this situation, it may prove worthwhile to carry out an occasional comparative study in an area for which earlier data are available, as was done by Pearson et al. [30] and Rosenberg et al. [34], respectively in Swedish and Norwegian waters, on the basis of observations by Petersen [31] made 70 years earlier. The findings derived from this kind of study are of a different order: rather than being focused on population dynamics [10], they are more general and concern, for example, the biodiversity measured on the basis of the species richness and the abundance of individuals or their biomass, or the structure of communities or biocenoses, notably the distribution patterns of zoological groups or trophic groups.

In two previous articles [25, 26], we attempted to assess the patterns of change in the macrofauna of the well sorted fine sand bottoms of the Prado Bay (Gulf of Marseilles) at a time when coastal development work was temporarily suspended.

In the present article, the aim is to extend to regional scale the scope of our observations, on the basis of data collected during the period 1965–1968, the general conclusions of which are reported in Massé [22]. A new sampling programme was therefore carried out from 1996 to 1997 at all the stations and sites previously studied. The interest in this procedure lies in the comparison of sites that have undergone widely varying degrees of human pressure over the past thirty years.

2. MATERIAL AND METHODS

The database used for these comparisons can be found in Massé [18–21], corresponding to studies carried out from 1965 to 1968 at five sites: Bandol, Marseilles-Prado, Verdon, Fos-Saint-Gervais and Camargue-Faraman (*figure 1*). At each site, only one station situated at a depth of 5 m is taken into account as the macrofauna assemblage at this depth was recognized to be the most representative of this sand community [22]. For each station, four seasonal samplings, in spring, summer, autumn and winter, are considered.

From 1996 to 1997, these stations were again sampled during each of the four seasons using the same technique and following the method of Massé [17]. Each sampling corresponds to a surface area of 0.5 m^2 (5 times 0.1 m^2) and a depth ranging from 25 to 30 cm in the sediment carried out with a suction-sampler by aspiration of the content of a cylinder planted in the sediment. The sample is sieved on a square mesh with a diagonal size of 1 mm.

The sieve residue is fixed with formalin diluted to 10 % and strongly buffered with sodium borate. By carefully sorting of the samples, after colouring with bengal rose, information can be obtained on the number of species, their numerical density and their dry weight or biomass. It should be noted that the criteria for determination are the same as in 1966 in order to provide a basis for comparison of the data regarding the number of species occurring respectively in the 1960s and the 1990s.

Determination of the biomass is based on the dry weight of organic matter obtained after elimination of the digestive tube content, in particular in detritivores, and of the calcium from tests or skeletons of molluscs, echinoderms or crustaceans, using hydrochloric acid diluted to 20 %. The dry weight is obtained by drying for 48 h in an oven at 95 °C and weighing to the nearest mg.

On the basis of the whole set of seasonal data, we have carried out a statistical study aimed at testing the significance of changes occurring after an interval of thirty years for the five sites studied. Because of the lack of data for Fos, for the period 1967–1968, we have included for all the sites only two survey periods. The first focuses on 1966, the second on 1996, each period including a cycle of four seasons. Three-way factorial ANOVA, without replication ($5 \times 4 \times 2$ factorial ANOVA) [9], were made on a table including on the one hand the five sites, and on the other hand the four seasons each consisting, as explained above, of two periods with an interval of thirty years. They take into account successively the number of species, the density of individuals and their biomass. It should be noted that the density data have undergone logarithmic transformation to make the variance independent of the mean and in order to facilitate graphic representation.

Finally, the method of Warwick [37] was applied to the whole set of seasonal observations accumulated over one year. This is the method known as ABC (Abundance, Biomass, Comparison) [38] which consists in establishing a rank-frequency diagram in which the species are ranked by increasing order of dominance, both for their density and for their biomass, with the rank on the X axis on a logarithmic scale, and the accumulated frequencies as percentages on the Y axis.

Granulometric analyses were carried out on a series of cores taken by scuba divers. The desalted and dried samples were analysed with a Mastersizer laser granulometer from Malvern Instruments, in order to detect any possible change in the composition of the stocks of grains, as well as in parameters such as the median or the ranking index.

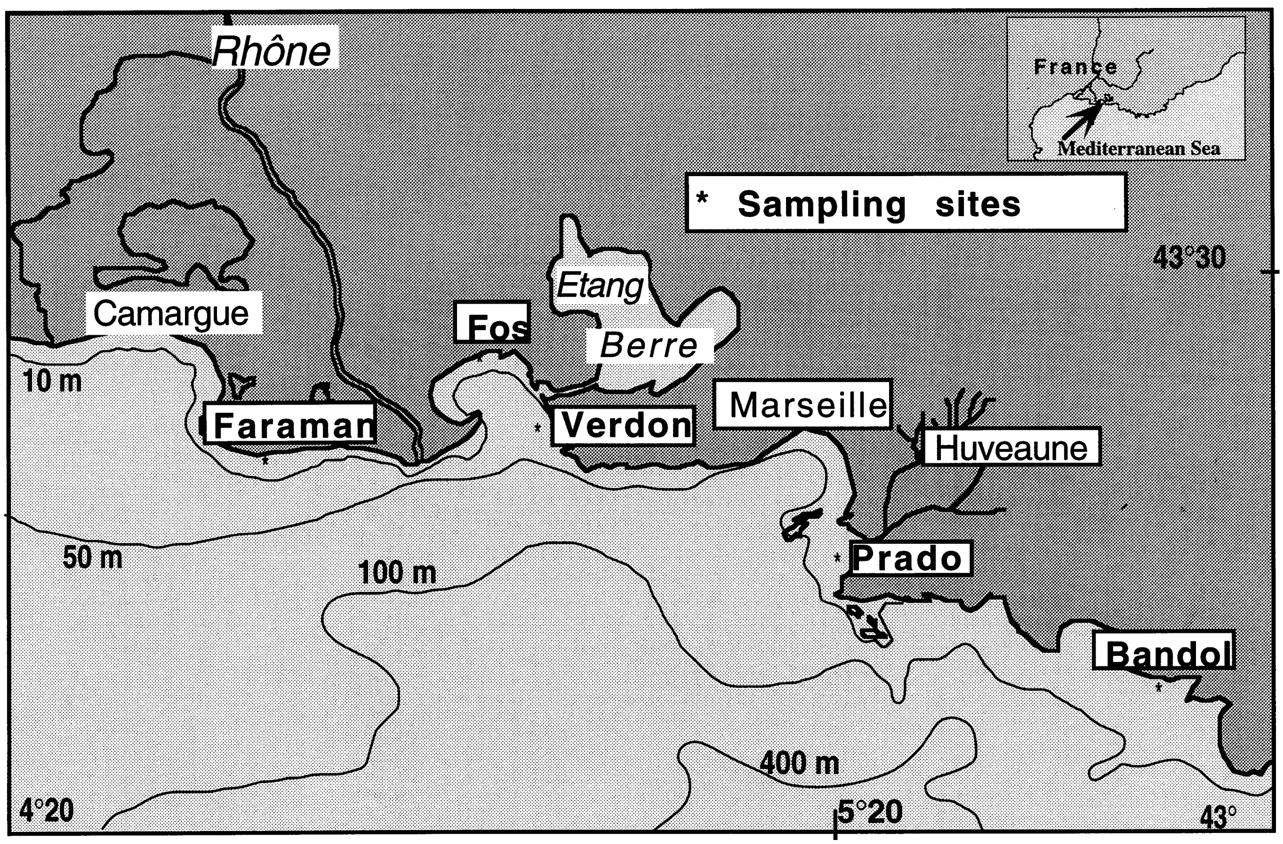

Fig. 1. Location of sampling sites, from east to west: Bandol, Prado, Verdon, Fos and Faraman. Stations at 5 m depth, in well sorted fine sand.

Table I. Average year values observed.[a]

Station	(5 m)	1966-67	1967-68	1996-97
Bandol				
	S	48	60	59
	N	900	1160	1674
	B	4	4	5
Prado				
	S	36	49	43
	N	6612	14250	1616
	B	10	15	1
Verdon				
	S	39	58	66
	N	735	2031	1219
	B	6	3	6
Fos				
	S	42		89
	N	845		2739
	B	14		13
Faraman				
	S	39	55	46
	N	1109	2061	5766
	B	24	11	48

[a] S = number of species per sample (0.5 m^2), N = number per m^2, B = biomass per m^2 (dry weight).

3. RESULTS

Major granulometric differences in the sediments were not noted at any of the five sites, between the two survey periods. The bottom consists of well sorted fine sand of which 70 to 90 % of the grains are fine to very fine sand, with the addition of two small stocks (5 to 20 %) of medium sand and silt.

Table I summarises the overall results showing two annual means in the 1966–1968 period and one in the 1996–1997 period observed at the stations of the five sites studied. Of the five stations, two stand apart because of their exposure to major anthropic perturbations. These are the Prado and Fos sites. Prado Bay was the site of major development works (construction of breakwaters, embanking and the diversion of a coastal river, the Huveaune) described in detail by Massé [25]. In addition to occasional effects linked to the work itself, the site is subject to the permanent impact of the diversion of the Huveaune to the city of Marseilles' sewage treatment plant. This results in lasting alterations linked to the interruption of inputs of fresh water, except during periods of heavy rain when the absorbtion capacity of the sewage treatment plant is exceeded and the Huveaune is restored to its role of small coastal river. This resulted in a marked drop in the values for density of individuals and their biomass at this site [26].

In the Gulf of Fos, perturbations in the Anse de Saint Gervais began in 1965 with the digging of a ship canal and of harbour basins in addition to the construction of the Saint Gervais marina with breakwaters and embankments. This development work explains the absence of observations for the period 1967–1968. In contrast to the Prado site, we may consider that the impact of human pressure was of a temporary nature, directly linked to the progress of the work, apart from a certain heterogeneity of the seabed resulting from the mixing of sediments under the impact of dredging and the transportation of waste matter by barges [35]. In 1996, biomass and density were back to the previous level.

The three other sites have not a priori suffered any major anthropic impact.

If we compare the patterns of change in the relative importance of the taxonomic groups, both from the point of view of individual density and that of biomass, marked differences are apparent between stations and between survey periods (*table II*).

At Bandol, the relative numerical and biomass abundances of molluscs showed an increase and the reverse for the crustaceans. There was a small decrease in the relative weight dominance of the echinoderms.

At Prado, the relative density of the polychaetes decreased whereas that of the molluscs increased. The strong contribution of the 'others' group corresponds to the presence of the species *Phoronis psammophyla* during the two survey periods, although the mean density values were substantially lower in 1996–1997. A similar pattern may be observed for the biomass. It should be noted that the high biomass of the echinoderms in 1996–1997 is an artefact, since it is linked to the collection of a single starfish which represents a high weight compared to the low total biomass values.

At Verdon, the numerical dominance of the crustaceans was lower in 1996–1997, whereas that of the polychaetes was higher. The pattern of biomass dominance was above all influenced by the abundance of the species *Sipunculus nudus* in the 'others' group, whereas the decline of the large *Echinocardium corda-*

tum resulted in a drop in the relative importance of the echinoderms.

At Fos, the numerical dominance of the polychaetes was higher in 1996–1997 whereas that of the molluscs and crustaceans was lower. This difference is not reflected in the biomass dominance. Nevertheless, an increase under the 'others' heading should be noted, which once again was caused by the occurrence of *Sipunculus nudus*.

At Faraman, an increase in the numerical dominance of the Polychaeta and echinoderms is apparent, and is mirrored in the biomass dominance. These increases due to the species *Owenia fusiformis* and *Acrocnida brachiata*, whereas the participation of the molluscs declines, especially in terms of weight.

In general, the only clear pattern, for the whole set of stations, is that of a relative decline in the numerical dominance of the crustaceans. For the other zoological groups, only the usual variations for this type of surface biotope are observed, in particular with regard to the prey/predator couple formed by molluscs and echinoderms (Faraman, *table II*).

With regard to the number of species, on the basis of the results of the ANOVA (*table III*), the difference between the values for the mean number of species observed by site and by period may be considered as significant, whereas the seasonal differences are not. *Figure 2* shows that two stations were in particular responsible for this difference occurring after a lapse of thirty years. These are the stations at Verdon and in particular Fos, where a marked increase in species diversity is apparent.

With regard to numbers of individuals, *table IV* presents the results of the ANOVA. A weak interaction ($P < 0.05$) between the factors Stations and Survey periods is observed. Otherwise, the Season factor is not significant, whereas the Stations and Survey periods factors are, but weakly. *Figure 3* shows the origin of the differences between mean numbers. On the one hand, there was the strong decline in the mean density observed at the Prado station during the second sampling period, and on the other hand, the strong increase in the density of individuals at the Faraman station during the second survey period. It should be noted that for the three other stations (Bandol, Verdon and Fos) the density values were higher in the 1990s.

Finally, with regard to the biomass values, *table V* gives the ANOVA results. We note the weak interaction between the factors Stations and Years (at the threshold of 0.07); however, the difference between stations is highly significant (at the threshold of 0.001). *Figure 4* shows these differences graphically; they concern respectively the increase in the mean biomass at the Faraman station during the second sampling period and the decline of that of the Prado station. It should also be noted that the Fos and Faraman stations already had a high biomass during

Table II. Main taxonomic group stocks.[a]

	1965–1968		1996–1997	
	N %	B %	N %	B %
Bandol				
Polychaetes	38.1	46.8	44.6	44.7
Molluscs	7.8	12.1	35.9	32.1
Crustaceans	39.9	4.1	14.4	1.7
Echinoderms	1.1	20.2	1.9	14.4
Others	13.1	16.8	3.2	7.1
Prado				
Polychaetes	40.4	57.5	24.4	15.1
Molluscs	3.0	19.7	27.3	39.9
Crustaceans	7.2	1.5	2.7	2.1
Echinoderms	0	1.5	0.2	20.5
Others	49.5	19.9	45.5	22.4
Verdon				
Polychaetes	28.9	34.2	42.6	17.3
Molluscs	14.8	15.8	20.8	11.0
Crustaceans	54.2	6.6	26.7	2.0
Echinoderms	1.7	29.7	5.8	8.7
Others	0.3	13.8	4.0	61.0
Fos				
Polychaetes	34.0	31.9	56.2	32.7
Molluscs	31.4	49.8	18.6	43.4
Crustaceans	32.1	7.9	16.1	1.8
Echinoderms	2.1	8.3	3.5	2.1
Others	0.4	2.0	5.0	20.0
Faraman				
Polychaetes	31.4	8.1	41.0	21.2
Molluscs	26.8	62.7	17.8	16.5
Crustaceans	35.7	2.8	27.1	1.1
Echinoderms	2.4	4.0	13.9	60.4
Others	3.7	22.5	0.2	0.8

[a] As percentage of density N % and biomass B % for the five sampling sites (Bandol, Prado, Verdon, Fos and Faraman) respectively during the years 1965–1968 and 1996–1997.

Table III. Results of ANOVA performed on S values.[a]

Source of variation	SS	Df	MS	F	p
Stations (A)	3439.65	4	859.9125	11.27	< 0.001
Seasons (B)	414.275	3	138.0917	1.81	NS
Years (C)	3940.225	1	3940.225	51.66	< 0.001
(A × B)	744.35	12	62.0292	< 1	NS
(A × C)	2437.65	4	609.4125	7.99	< 0.01
(B × C)	238.475	3	79.4917	1.04	NS
(A × B × C)	915.15	12	76.2625		
Σ	12129.775	39			

[a] A = stations sampled in five sites, B = samples made at four seasons, C = two sampling programmes at a thirty year interval, A × B interaction between factor A and B, A × C interaction between factors A and C, B × C interaction between factor B and C, A × B × C interactions between the three factors.

the first survey period, compared to the three other stations.

The rank-frequency diagrams relative to the density and the biomass were used according to the procedure proposed by Warwick [37] for all the stations and periods considered, taking into acount an annual cycle based on four seasons. According to this author, from the respective position of biomass and density curves, we could have an idea on the level of stress experienced by the community. When K-dominance curve for biomass lies above that for density, the community would be unpolluted, and grossly polluted when the density curve lies above the biomass curve. When the two K-dominance curves overlap, the community would be moderately polluted.

At Bandol (*figure 5A*), on the basis of the theoretical curves describing the three stages of the communities (non-perturbed, moderately perturbed and severely perturbed), it might seem that after an improvement in 1968, the situation in 1996 is roughly comparable to that of 1966 corresponding to a moderately perturbed stage. At Prado (*figure 5B*), a certain consistency is apparent in the appearance of the diagrams corresponding to the characteristics of a relatively perturbed environment. At Verdon (*figure 5C*), there is an inversion in the position of the curves, the values corresponding to the biomass moving well above those for the density in 1996, after an intermediary situation in 1968. At Fos (*figure 5D*), the same pattern is apparent in 1996. At Faraman (*figure 5E*), a progression towards a non-perturbed type of community becomes evident in 1996, as the biomass curve was far above the abundance one.

4. DISCUSSION

The subtidal character of well-sorted fine sand bottoms in the Mediterranean means that they are protected from the thermal impact of severe winters; the winter temperature in the open sea rarely falls below 10 °C on these bottoms, which represents a perfectly acceptable temperature for most of the species that have a wide geographical range in the temperate Atlantic area. This is in strong contrast with the conditions observed in the intertidal zone [2, 6, 7] and

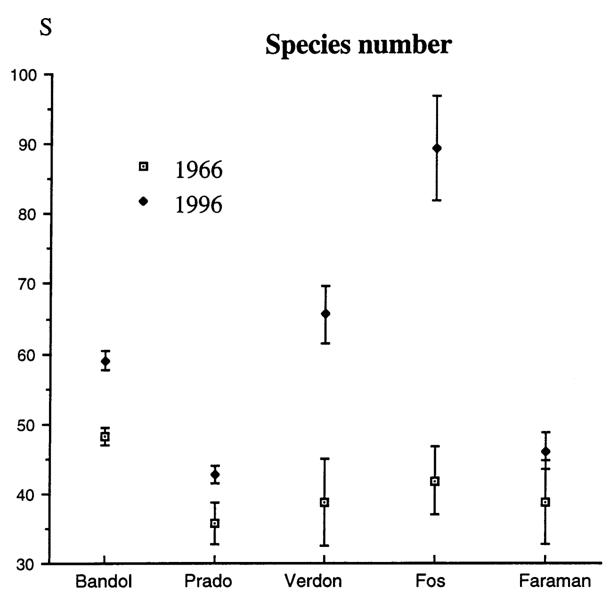

Fig. 2. Fluctuations of species number (S) per sample (0.5 m^{-2}), between 1966 and 1996, respectively at Bandol, Prado, Verdon, Fos and Faraman. C.I. confidence intervals ($t_{95}.S/\sqrt{n}$) calculated from seasonal observations.

Table IV. Results of ANOVA performed on density values (LnN).[a]

Source of variation	SS	Df	MS	F	P
Stations (A)	6.73	4	1.68	3.36	0.046
Seasons (B)	0.11	3	0.04	0.08	NS
Years (C)	3.71	1	3.71	7.42	0.019
(A × B)	3.31	12	0.27	0.54	NS
(A × C)	8.52	4	2.13	4.26	0.022
(B × C)	0.72	3	0.24	0.48	NS
(A × B × C)	6.02	12	0.50		
Σ	29.02	39			

[a] A = stations sampled in five sites, B = samples made at four seasons, C = two sampling programmes at a thirty year interval, A × B interaction between factor A and B, A × C interaction between factors A and C, B × C interaction between factor B and C, A × B × C interactions between the three factors.

even in the subtidal zone in northern regions [1, 7, 34, 40, 41].

Detailed analysis of the seasonal data provides confirmation of the reality of certain general findings. The species richness, for example, appears to be relatively stable at three of the five stations studied, Bandol, Prado and Faraman, whereas the Verdon and Fos stations showed a higher mean number of species during the second survey period. The null hypothesis (equality of mean values for the species richness) is ruled out both in the comparison between stations, all data taken together, and in the comparison between survey periods.

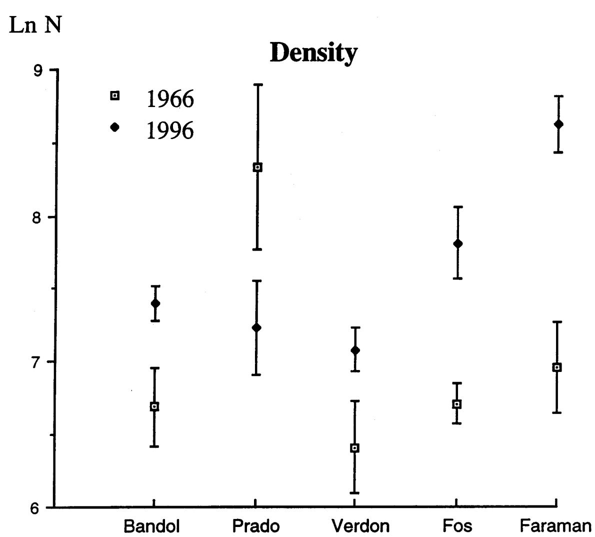

Fig. 3. Fluctuations of densities (Ln N per m^{-2}), between 1966 and 1996, respectively at Bandol, Prado, Verdon, Fos and Faraman. C.I. confidence intervals ($t_{95}.S/\sqrt{n}$) calculated from seasonal observations.

At the Fos station, it might well be that this is linked to anthropogenic perturbations, in particular the construction of Saint Gervais harbour. As a result of the extensive dredging and transportation of sediment, the bottom has become a veritable mosaic favouring a greater richness of species. Although the samples were always taken in well-sorted fine sand (median 113.5 µm, composition: 2 % clay, 10 % silt, 47 % very fine sand, 35 % fine sand, 5 % medium sand, 2 % coarse sand), there was a contamination by proximity, in particular of species with an affinity for fine particles.

At the Verdon station, the increase in the number of species in 1996 is smaller than at Fos station. This station was not exposed to the direct impact of human action, and there is no obvious explanation for this state of affairs, except possibly the decline in the density of *Echinocardium cordatum* that in 1966 exerted strong predatory pressure on the temporary meiofauna and thus controlled the recruitment of certain species [20].

The numbers of individuals often show wide variations in these coastal waters [22], which induced us to apply a logarithmic transformation to the data. *Figure 3* shows clearly that the interaction between the factors Stations and Survey Year is due to Station 2 (Prado) where the density decreases significantly, whereas it increases at all the other stations, in particular Camargue-Faraman station under the direct influence of the Rhone waters.

With regard to the biomass, the observed values are significantly different both for the sites and for the survey periods (*figure 4*).

This may be explained on the one hand by the strong decline in numbers and biomass at the Prado station between the first and second periods, and on the other hand by the increase in the density at the Faraman station, in 1996 (*figure 4*). There is no need to reiterate our comments on the impoverishment of the Prado station where the diversion of the Huveaune coastal river is the principal cause [26]. For the Faraman station in the Camargue, already considered as the richest in 1966 (*figure 4*), the increase in density and biomass would appear to be directly

Table V. Results of ANOVA performed on biomass values (B g·m^2).[a]

Source of variation	SS	Df	MS	F	p
Stations (A)	5570.504	4	1392.626	14.65	< 0.001
Seasons (B)	298.714	3	99.571	1.05	NS
Years (C)	100.806	1	100.806	1.06	NS
(A × B)	735.474	12	61.289	0.64	NS
(A × C)	1168.11	4	292.027	3.07	≠ 0.07
(B × C)	244.752	3	81.584	0.86	NS
(A × B × C)	1140.696	12	95.058		
Σ	9259.057	39			

[a] A = stations sampled in five sites, B = samples made at four seasons, C = two sampling programmes at a thirty year interval, A × B interaction between factor A and B, A × C interaction between factors A and C, B × C interaction between factor B and C, A × B × C interactions between the three factors.

linked to the Rhone inputs, with regard to the mean flow rates on the one hand, and to the nutrient concentrations on the other. With regard to the mean flow rates of the Rhone recorded at Beaucaire, we have taken into account the two years preceding the survey periods (*table VI*).

The years 1994 and 1995 were marked by heavy spates that contributed to the increase in both dissolved and particulate inputs [32]. Regarding nutrient inputs, there is no data for such a long period. However, Moutin et al. [28] suggest that over the last two decades there has been a strong increase in nutrients, estimated at 50 % for mean annual concentrations of nitrates, that constitute the bulk of the river's nitrogen inputs, or an annual input, for the period 1994–1995, ranging between 92.3 and 96.1 kt·a^{-1}. This suggests a probable increase in the food supply available for the filter-feeders and the suspension-feeders: mollusc (*Pharus legumen*), ophiuran (*Acrocnida brachiata*) and polychaete (*Owenia fusiformis*) and consequently an increase in recruitments that account for most of the numbers and biomass in 1996–1997.

In the absence of long-term survey data, care must be taken with regard to the interpretation of data obtained over a long time-interval. Pearson et al. [30] and Rosenberg et al. [34], for example, propose, on the basis of qualitative arguments in particular, that the increase in the eutrophication of the Danish and Swedish waters explains the alterations in the benthic communities at an interval of seventy years, whereas Tunberg and Nelson [36] suggest climatic factors, the North Atlantic Oscillations (NAO), whose fluctuations within a period of seven to eight years coincided with those of the macrobenthos (abundance and biomass). Under the typically Mediterranean conditions of our stations, we are a far way from the conditions found in the Kattegat or Skagerrak, to the extent that our bays are in direct contact with an open oligotrophic sea characterized by a high degree of hydrological instability linked to the absence of strong tides and to the preponderant influence of the dominant winds [27]. Under these conditions, the

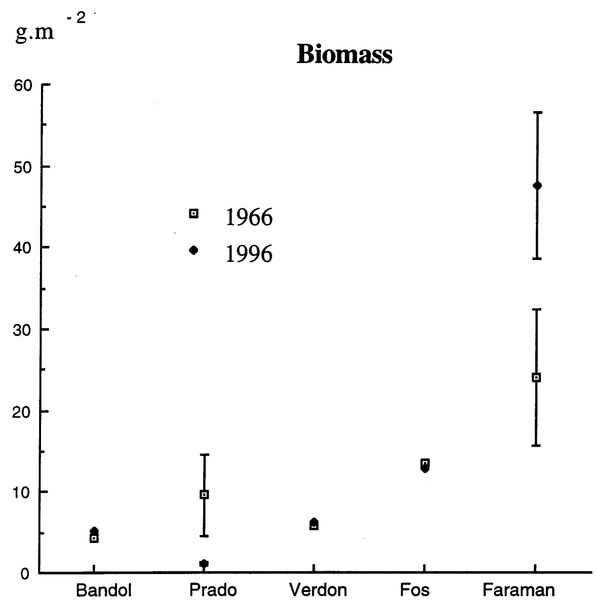

Fig. 4. Fluctuations of biomasses (dry weight, g·m^{-2}), between 1966 and 1996, respectively at Bandol, Prado, Verdon, Fos and Faraman. C.I. confidence intervals ($t_{95}.S/\sqrt{n}$) calculated from seasonal observations. Error bars have been omitted when CI values were small (< 0.2) (Prado, 1996) or small and overlapping (Bandol, Verdon, Fos).

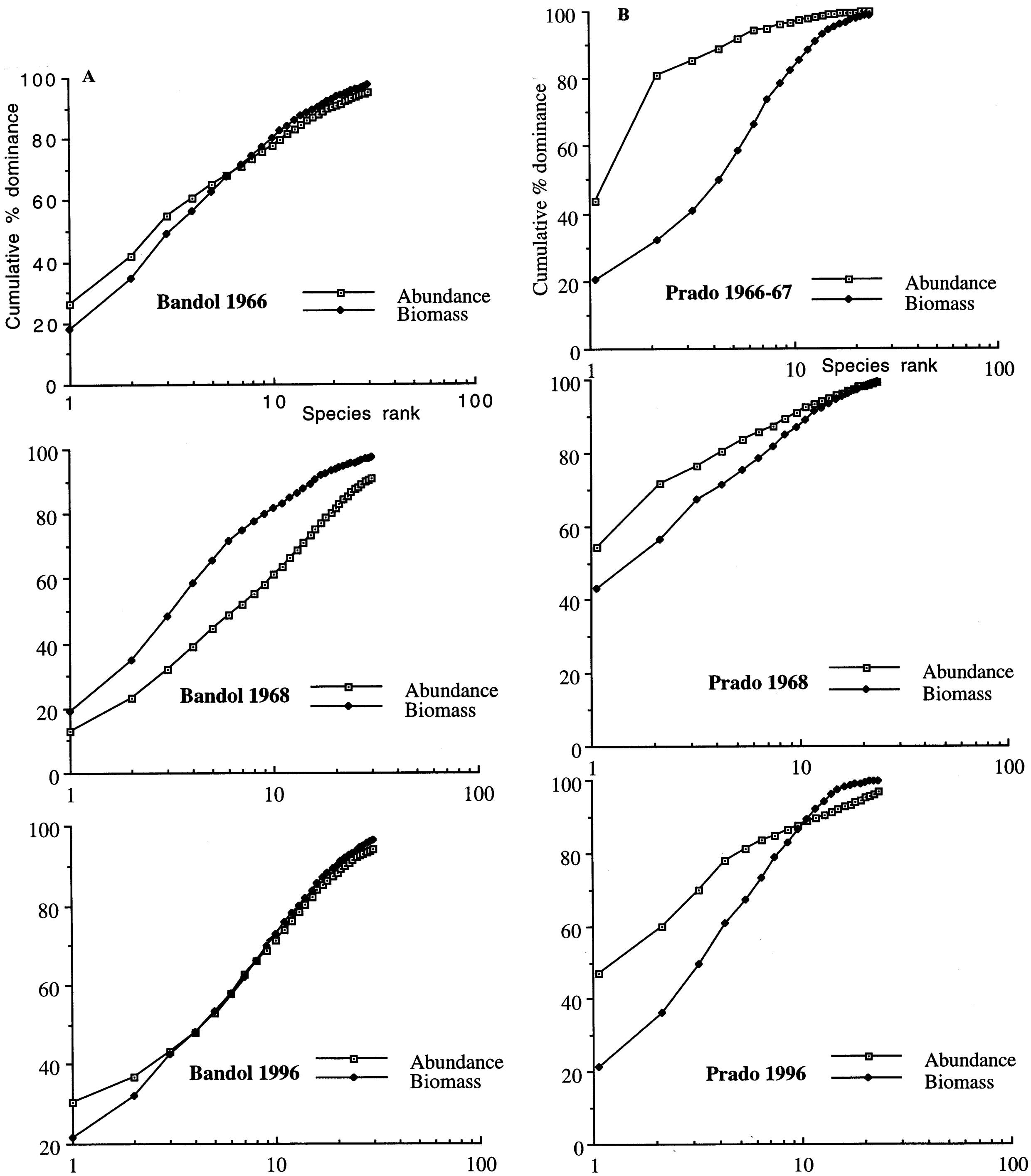

Fig. 5. Combined K-dominance curves for species abundance (squares) and species biomass (diamonds), A: Bandol, B: Prado, C: Verdon, D: Fos, E: Faraman. Species ranked on the X axis on a logarithmic scale, cumulated frequencies as percentage on the Y axis.

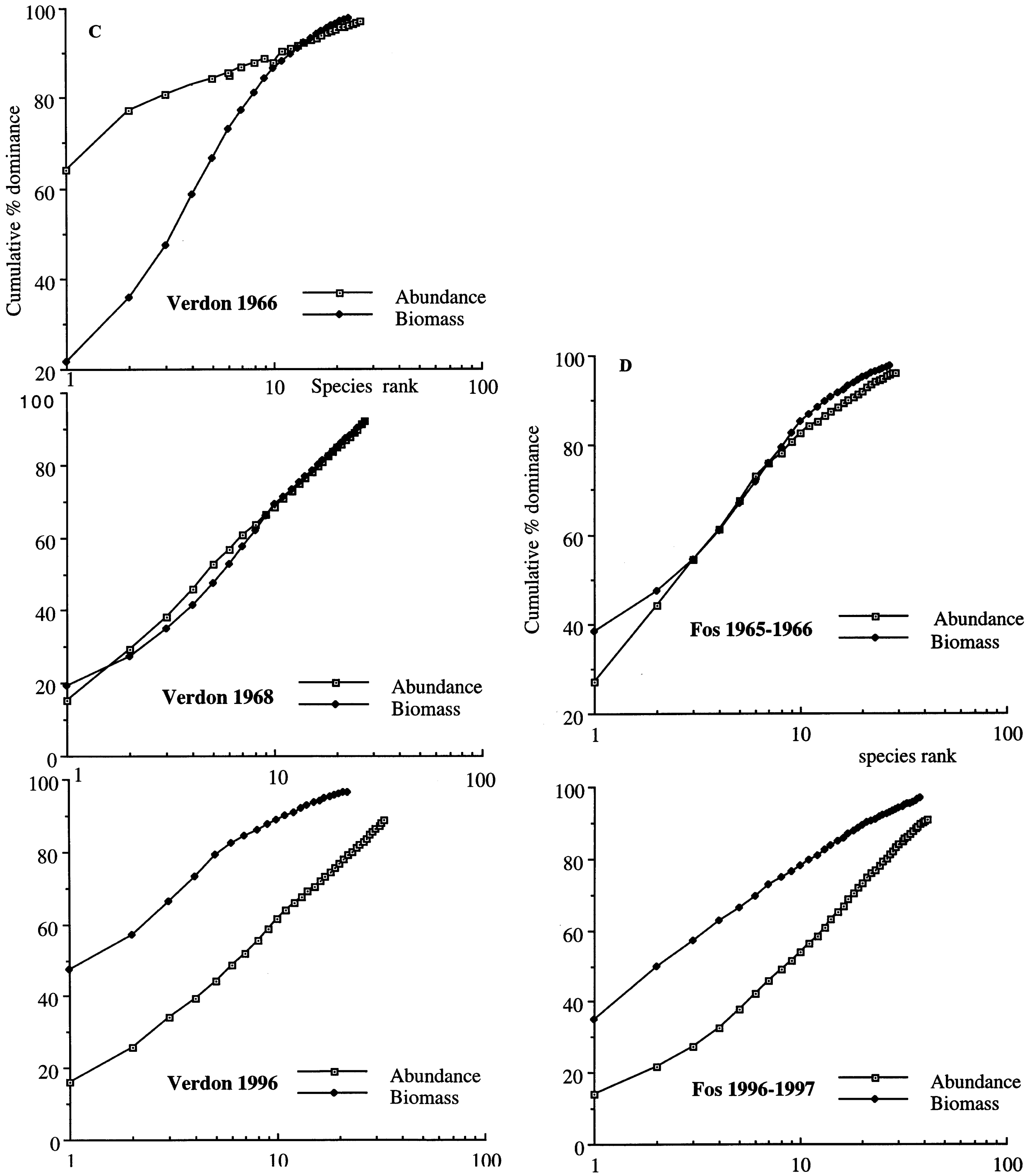

Fig. 5. (*Continued*)

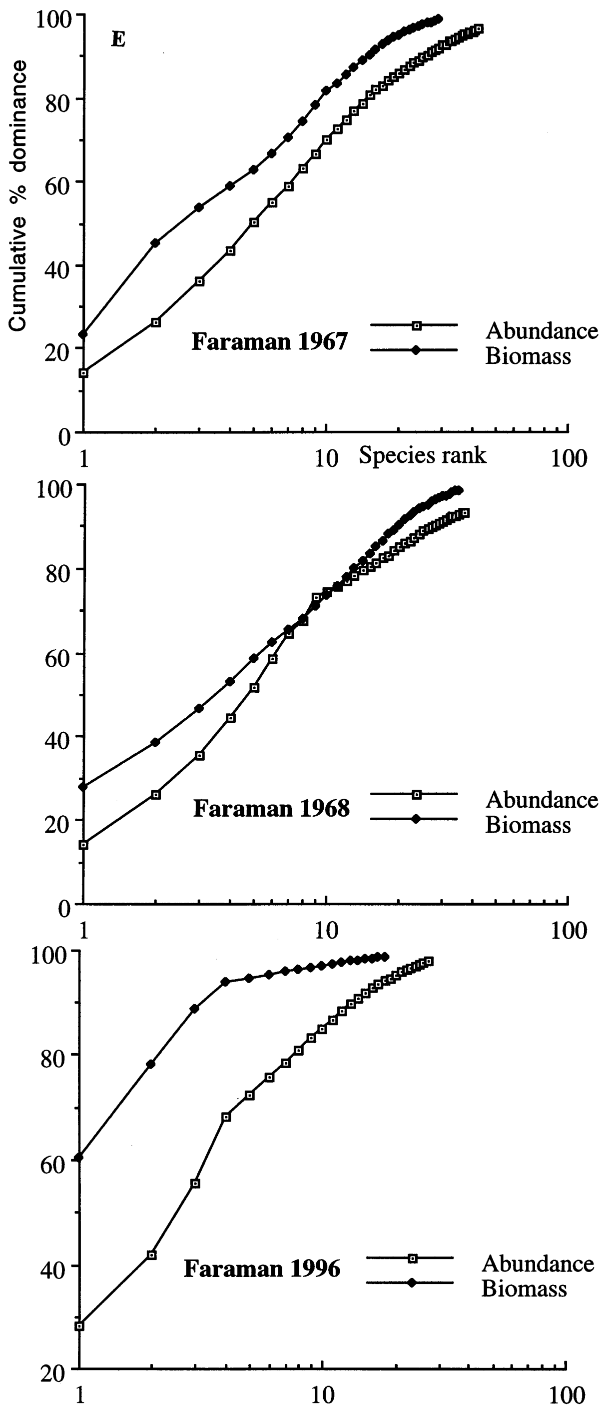

Fig. 5. (*Continued*)

Table VI. Fluctuations of Rhone river flow rates.[a]

Years	Flow ($m^3 \cdot s^{-1}$)
1964	1255
1965	1854
1994	2179
1995	2122

[a] During the two years preceding the sampling periods respectively 1966–1967 and 1996–1997.

capacity for dispersal of continental inputs towards the open sea is considerable, thus limiting the likelihood of excessive enrichment. Nevertheless, the macrofauna of the coastal zone studied here seems to react strongly to these continental inputs, as is demonstrated in reverse by the observations made respectively in the Gulf of Marseilles (Prado), [26] and off the Camargue (Faraman, *figures 3* and *4*).

From the qualitative point of view, there is no major change in the lists of dominant species by site observed in 1966 [22]. While the number of species has tended to increase in 1996, at all the stations (*figure 2*), it is above all the Fos and Verdon stations that are concerned. Nevertheless, there is no increase comparable to that observed by Kröncke [15] on the Dogger Bank which justifies the hypothesis of a certain eutrophication of the area. Still, comparison of this author's ABC curves with ours might give grounds for thinking that the biological perturbations are more severe in the fine sands of the coast of Provence than in those of the Dogger Bank, where rank-frequency curves for biomass are almost always well above those for abundance. In our study, overlaps are frequent at all the sites, according to the period in question. Sometimes, as at the Prado station, there is even an inversion, with the abundance curve above that of biomass. If we do not take into account the period 1996, the sites at Verdon, Fos and Faraman show figures comparable to those of the Dogger Bank. The significance of these comparisons is a little limited in that in the Mediterranean, the mean weight of individuals of the macrofauna is in general lower than in the northern seas [23, 24]. These small specimens are thus in danger of being assimilated wrongly to opportunistic species with a short life span. In addition, the relative position of the curves of abundance and biomass is strongly conditioned by the occurrence of large specimens (e.g. *Sipunculus nudus* at Verdon, *S. nudus* and *Cardium tuberculatum* at Fos) whose contribution to the biomass is all the more disproportional in that the mean biomass values are low [24]. It is only at Faraman that a relative balance is observed, with the abundance of the ophiuran *Acrocnida brachiata* and the polychaete *Owenia fusiformis* influencing the high biomass values equally.

Beukema [3] had already shown that in the intertidal zone, the application of this ABC method was difficult because of the high density of two small species. This author recommended basing all interpretation on long-term surveys, as was done by Ibanez and Dauvin [13]. In the present study, surveys of this kind are not available, and our purpose was simply to detect any possible major alteration in the composition of the macrobenthic fauna over a thirty-year interval. Warwick and Clarke [39] have drawn attention to the care that should be taken when using their method when the macrobenthos is not dominated by the class Polychaeta, as has often been observed at our stations.

To conclude, examination of the ABC curves does not provide justification for either an improvement or a decline in the macrofaunal communities in 1996. Rather, examination of the lists of dominant species suggests, reassuringly, that these infralittoral fine sand communities of the coasts of Provence have remained relatively stable over the thirty-year period.

5. CONCLUSIONS

Re-sampling of five stations in well sorted fine sand on the coast of Provence, after an interval of thirty years, has provided a basis for determining the patterns of change of the macrofauna. From the qualitative (species richness) point of view, no decline in the mean number of species occurring over an annual survey cycle taking into account the four seasons was observed. At two stations (Fos and Verdon), there was even a marked increase in the species richness.

Concerning the respective representation of the different zoological groups, a general trend towards a decline in the abundance of the crustaceans is apparent.

From the quantitative point of view, the changes observed resulted either from the impact of well identified human actions, such as the deviation of a coastal river in Prado bay, or from the increase in the nutrient input from the Rhone at Faraman, an area that is under the direct influence of the river's coastal plume. The combined effect of these phenomenona with a climatic factor, resulting in an increase in the Rhone's flow rate during the period preceding re-sampling of the site in 1996, should be noted.

Otherwise, there do not appear to be any significant alterations; these shallow water communities are in any case subject to considerable fluctuations and alternation in the relative dominance of certain groups, such as, for example, the prey/predator couple formed by molluscs and echinoderms.

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