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The macrofouling on offshore platforms at Ravenna[1]

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Abstract

The fouling which settles on gas platform piles was studied using samples taken in 1993 from the PCWA and ANTARES platforms positioned, at 7 and 10.5 km from the shore respectively and on bottoms at 12 m and 14 m in the Adriatic Sea. For each platform a pile was chosen as representative of the macrofouling found on the whole platform. In March and September 1993 samples were obtained by scraping an area of 600 cm^2 from three or four different aspects (North, East, South, West), at the same depth. Samples were taken at depths of 0.5, 5.5 and 12 m on PCWA and 0.5, 7 and 12 m on ANTARES. Photographs and video recordings taken over the whole length of the chosen pile were used for an additional description of the settlement. On both platforms the macrofouling was characterized by a dominance of mussels from sea surface to a depth of about 10 m. Near the bottom the bivalve *Crassostrea gigas*, barnacles, hydroids and serpulids were more important. The presence of the bryozoan *Schizoporella errata* (present only at ANTARES) and the zoanthid *Epizoanthus arenaceus* (present only at PCWA) were the main differences at this depth. The fouling, or mussel weights, of the two platforms were similar for the two seasons, even though the highest values were registered in September on PCWA (1 m) with 1561.3 g/dm^2, of which 1553 g/dm^2 comprised mussels. A comparison is drawn with a previous fouling experiment (which used one-year panels) carried out in 1975–76. © 1998 Elsevier Science Ltd. All rights reserved.

Keywords: Fouling; Settlement; Biomass; Adriatic Sea.

1. Introduction

It is well known that the accumulation of biological fouling on platform supports not only burdens the structure itself but also increases the surface area exposed to the action of waves, thus threatening the safety of the platform in the event of rough seas. In fact marine fouling on offshore structures can have serious consequences enhancing both the corrosion and stress components of corrosion-fatigue (Edyvean et al., 1988). First the diameter of tubular members of the structure is effectively increased by trapping a layer of water; secondly the surface roughness, and hence the drag coefficient of the members, is increased. It has been calculated that a layer of fouling 150 mm thick increases the loading by 42.5%, the fatigue damage by 62% and decreases the predicted life by 54% (Heaf, 1979 quoted from Edyvean et al., 1988). Thirdly, biological activity can enhance corrosion by providing both an environment and a source of nutrients for sulphate-reducing bacteria (Picken and Grier, 1984; Edyvean et al., 1988). The periodic removal of fouling is, therefore, part of the normal procedure for maintaining these structures. In the Adriatic the massive presence of *Mytilus galloprovincialis*, a commercially profitable species, offers a resource worth exploiting (Relini, 1977). The primary objective of the present study was to describe the fouling present on methane gas extracting platforms off the coast at Ravenna, and also to describe its development in relation to both water depth and distance from the coast. A further aim was to discover whether there had been any changes in the fouling from that observed in a previous study of settlement carried out in 1975–76. During this study asbestos panels immersed at different depths were used to describe settlement periods of main fouling organisms at PCWA and at another platform AGO–A 7 localized 18 km off the coast at Ravenna (Relini et al., 1976; Montanari and Morri, 1977; Relini and Matricardi, 1977; Relini et al., 1977; Relini and Montanari, 1988; Relini et al., 1990). For a review of macrofouling on offshore structures in the Mediterranean Sea, see Relini, 1993 and Relini and Relini, 1994, but comprehensive literature data out of the Adriatic Sea are few.

The PCWA and ANTARES platforms are positioned off the coast at Ravenna, at 7 and 10.5 km from the coast, on a sand-muddy bottom of 12 and 14 m respectively (Fig. 1). The marine environment around the platforms was characterized by extreme eutrophication and water stratification, factors which, during periods when the sea

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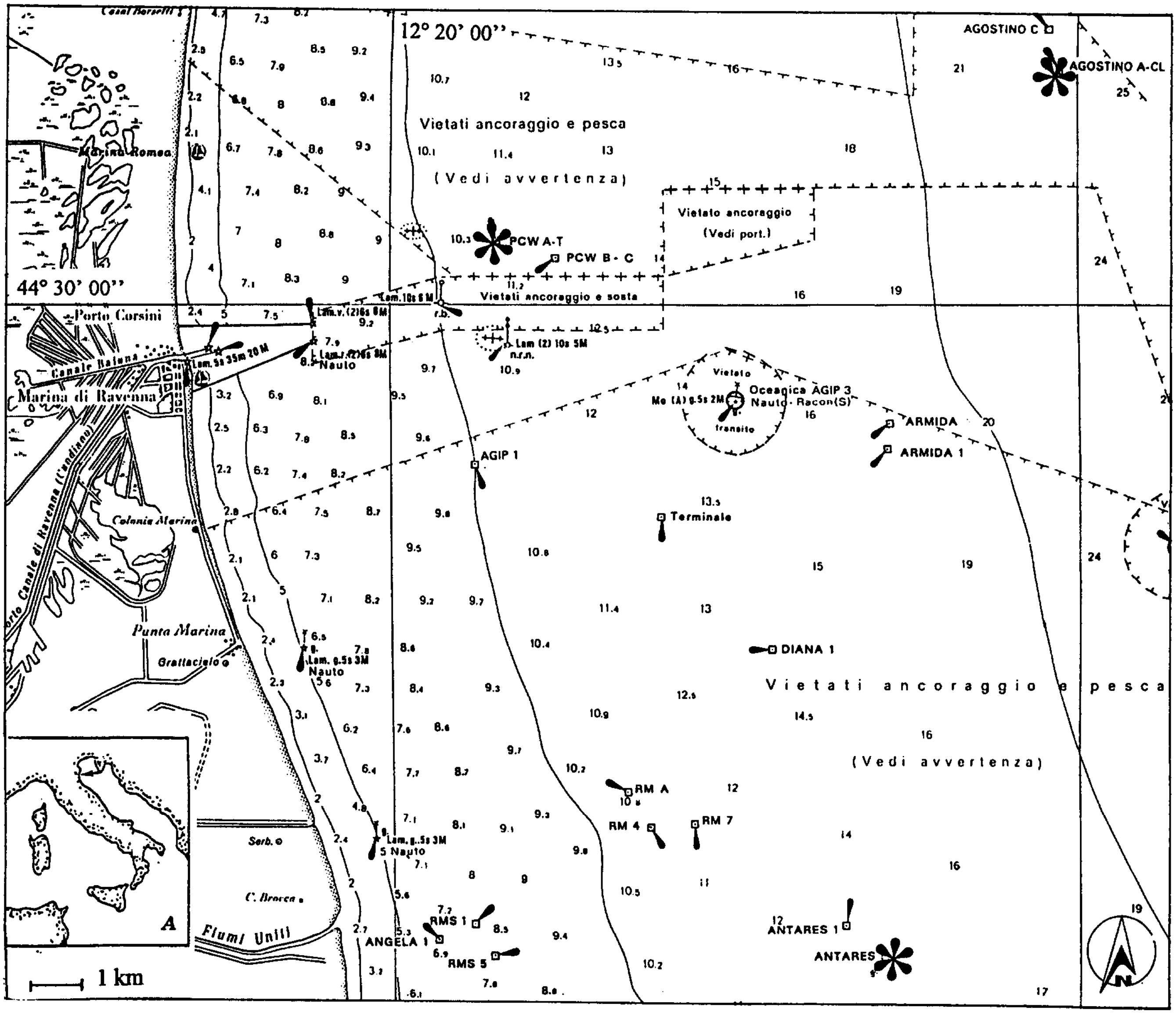


Fig. 1. Location of Ravenna in the North-Eastern part of Italy (A). General view of area under study. * ANTARES, PCWA and AGO–A platforms.

is calm, favour the extraordinary blooms of phytoplankton. The presence of a fresh water surface layer, resulting from the outflow of the River Po, is connected to a multitude of hydrological and metereological factors and is thus extremely variable in time. As documentation of the eutrophication of the waters around the Ravenna platforms, some values obtained monthly, and at different depths, in 1975–76 are reported and, for purposes of comparison, other values obtained at Crotone, where the waters are oligotrophic, are also given (Table 1).

2. Materials and methods

After photographing and video recording the fouling settlement on the immersed structures, one support was chosen as representative of the macrofouling present on the whole platform. In March and September 1993 samples were obtained by scraping an area of 600 cm^2 using three or four different aspects (North, South, East or West) at the same depth. The levels chosen were 0.5 m, 5.5 m and 11 m at PCWA and 0.5 m, 7 m and 12 m at ANTARES. In September, at PCWA, the shallowest samples were taken at 1 m depth because at the 0.5 m level the community was severely damaged. Samples were preserved in formalin before taxonomic examination. Species density is given as no/dm^2 and/or g/dm^2. All the specimens of *M. galloprovincialis* were measured (maximum valve diameter also called length): length-frequency distributions are given as percentages using 21 size classes (from 0.01–0.49 cm to 10.00–10.49 cm). The Kulczynski (Kulczynski, 1927) index for the qualitative

Table 1
Environmental parameters measured at the platforms at Ravenna and Crotone. The three values given refer to the minimum, mean and maximum registered for the twelve, monthly samples carried out over a period of one year (1975–76).

	RAVENNA				CROTONE			
	AGO A		PCWA					
	2 m	12 m	2 m	12 m	2 m	15 m	30 m	60 m
T °c	5.3	8.3	4.4	7.8	13.7	13.6	13.6	13.7
	13.9	12.8	13.3	13.1	16.4	16.4	16.0	15.6
	25.0	21.2	23.7	22.4	21.9	21.8	20.0	18.9
S‰	31.2	35.7	30.3	34.1	38.0	38.0	38.0	38.1
	33.7	36.9	32.8	35.4	38.2	38.2	38.2	38.3
	35.8	37.6	36.4	36.6	38.4	38.4	38.4	38.4
O_2 mg/l	6.8	2.5	7.4	3.9	6.9	7.0	7.3	7.0
	9.1	7.3	9.4	7.1	7.4	7.3	7.4	7.3
	13.1	9.2	13.0	9.4	7.6	7.4	7.5	7.6
PH	8.1	7.9	8.1	8.1	8.0	8.0	8.1	8.1
	8.2	8.1	8.3	8.2	8.1	8.1	8.1	8.1
	8.4	8.3	8.5	8.4	8.2	8.2	8.2	8.2
N-NO_2 μg/l	0.5	0.4	0.7	1.5	1.8	2.5	2.1	2.1
	4.7	2.7	6.5	6.1	4.2	4.5	3.4	4.1
	10.7	5.3	14.2	13.4	8.2	6.7	4.9	5.1
N-NO_3 μg/l	11.4	9.9	13.7	15.4	7.7	10.3	10.6	8.9
	76.2	25.2	103.4	61.1	24.6	26.7	22.8	27.2
	215.4	56.2	299.1	141.8	41.4	40.1	44.3	55.8
P-PO_4 μg/l	1.5	0.6	1.8	2.4	2.1	1.6	1.5	1.5
	4.4	6.2	4.3	6.4	4.5	2.8	2.6	4.5
	9.9	21.7	7.4	16.1	7.8	5.3	4.8	8.0

measure of similarity was used. 'UPGMA' (Sneath and Sokal, 1973) was used for cluster analysis. The biomass was expressed in non-decalcified wet weight and, for the fractions formed by *M. galloprovincialis*, also in dry weight (after 24 h at 105°C) and ash weight (3 h at 500°C). The taxonomic nomenclature used conforms to the checklist of Italian fauna species (Minelli et al., 1995).

3. Results

3.1. Taxonomic groups and fouling community

The species found and the relative densities of the most important taxa are given in Tables 2–6. Summing up the data 1993 from the two platforms, the total number of taxa found (identified mostly to species level) was 40, of which 38 were present on the PCWA and 30 on the ANTARES (Table 2). More than 70% of the taxa were common to both platforms. Bivalves and sedentary polychaetes were the most highly represented groups, with 8 species each, followed by barnacles (5 species).

On both platforms the fouling community was strongly dominated by *M. galloprovincialis*, which was present from the surface to about 2 m from the bottom. Amongst the mussels were other epibionts, including barnacles, other bivalves, serpulids, hydroids and sea-anemones. Mobile fauna was represented by brittle stars, turbellarians, ribbon worms, amphipods and decapods.

The samples taken near the bottom were characterized by a different association, even though one can at times find some individuals of *M. galloprovincialis*. At 11 m on PCWA platform some large empty shells of *Crassostrea gigas* were found covered largely with the zoantharians *Epizoanthus arenaceus*; also present were barnacles (especially *Balanus trigonus*), serpulids, and hydroids. The scaphopod *Fustiaria rubescens* was present only with empty shells, probably carried with the detritus by the sea currents.

At ANTARES the samples collected at 12 m were dominated by large, erect colonies of the encrusting bryozoan (*Schizoporella errata*), with less abundant *C. gigas*. At this level there were also barnacles, hydroids, serpulids, other bivalves, but *E. arenaceus* and sea-anemones were absent.

3.2. Comparison between platforms

Using the Kulczynski similarity index one can make some remarks about the PCWA and ANTARES macrofouling sampled in March and September (see dendrograms in Fig. 2). In Fig. 2a a comparison is made between the samples taken at the PCWA station in March

Table 2
Fouling organisms from 600 cm^2 scraped surfaces PCWA '93, ANTARES '93 and on 600 cm^2 artificial panels PCWA '76, AGO-A '76.

	PCWA '93	ANT. '93	PCWA '76	AGO-A '76
ALGAE				
Enteromorpha intestinalis (Linneus) Link			*	*
Cladophora sp.			*	
Ulva rigida Agardk			*	
CILIOPHORA				
Metafolliculina sp			*	*
PORIFERA	*	*		
HYDROIDA				
Obelia dichotoma (Linnaeus)	*	*	*	*
Garveia franciscana (Torrey)			*	
Tubularia crocea Agassiz	*		*	*
Clytia hemisphaerica (Linnaeus)			*	*
Lafoeina tenuis M.Sars			*	
ACTINIARIA			*	*
Aiptasia mutabilis (Gravenhorst)	*	*		
Sagartiogeton undatus (O.F. Müller)	*	*		
ZOANTHIDEA				
Epizoanthus arenaceus (Delle Chiaje)	*			
TURBELLARIA				
Stylochus mediterraneus Galleni			*	*
Notoplana alcinoi (O. Schmidt)			*	*
NEMERTEA	*	*	*	*
POLYCHAETA				
Nereidae	*	*		
Neanthes caudata (Delle Chiaje)			*	*
Nereis succinea (Frey & Leuchart)			*	*
Ceratonereis costae Grube			*	*
Syllis amica Quatrefages			*	*
Serpula vermicularis Linnaeus	*	*	*	*
Serpula concharum Langerhans	*	*	*	*
Serpula sp.	*	*		
Pomatoceros triqueter (Linnaeus)	*	*	*	*
Pomatoceros sp.	*	*		
Hydroides elegans (Haswell)	*	*		
Hydroides dianthus Verril	*			
Hydroides norvegica Gunnerus				*
Hydroides sp.	*	*		
Polydora ciliata (Johnston)			*	*
Ficopomatus enigmaticus (Fauvel)				*
Sabella pavonina Savigny			*	
CIRRIPEDIA				
Balanus improvisus Darwin	*	*	*	*
Balanus eburneus Gould	*	*		
Balanus amphitrite Darwin	*	*		
Balanus trigonus Darwin	*	*		*
Balanus perforatus Bruguière	*	*		
DECAPODA				
Brachynotus sexdentatus (Risso)	*	*		
Pilumnus hirtellus (Linnaeus)	*			
Pachygrapsus marmoratus (Fabricius)			*	*
AMPHIPODA				
Caprella equilibra Say	*	*	*	*
Jassa marmorata Holmes	*	*	*	*
Stenothoe sp.			*	*
GASTROPODA				
Hinia reticulata Linnaeus	*	*	*	*
Opistobranchia (Nudibranchs)	*	*	*	*
BIVALVIA				
Scapharca inaequivalvis Bruguière	*	*		
Mytilus galloprovincialis Lamarck	*	*	*	*

—continued

Table 2 *Continued*

	PCWA '93	ANT. '93	PCWA '76	AGO-A '76
Mytilaster minimus (Poli)	*	*		
Crassostrea gigas (Thunberg)	*	*		
Chlamys varia (Linnaeus)	*			
Anomia ephippium Linnaeus	*		*	*
Hiatella arctica (Linnaeus)	*		*	*
Gastrochaena dubia (Pennant)	*			
Ostrea edulis Linnaeus	*	*		
Modiolus barbatus (Linnaeus)	*	*		
Aequipecten opercularis (Linnaeus)			*	*
Musculus marmoratus (Forbes)			*	*
SCAPHOPODA				
Fustiaria rubescens (Deshayes)	*			
BRYOZOA (Cheilostomata)				
Bugula stolonifera Ryland			*	*
Membranipora sp.			*	
Schizoporella errata (Waters)		*		
Schizoporella unicornis (Johnston in Wood)			*	
ASCIDIACEA				
Diplosoma listerianum (Milne-Edwards)			*	*
Styela plicata Lesueur	*		*	
OPHIUROIDEA	*	*		

'93: there is a greater similarity between the different exposures at the same depth than between samples taken at different depths (11 m, 5.5 m, 0.5 m). This relationship with depth can also be seen at the PCWA platform (Fig. 2c) for September, with the exception of the sample taken at a depth of 1 m with a northerly aspect. This latter is more comparable to the samples taken at 5 m. This situation probably reflects the lower number of mussels and sea-anemones observed on the northerly aspect in contrast with other aspects at the same depth. A comparison between the samples taken at the various depths in the two seasons shows that the depth factor discriminates more than the seasonal factor (Fig. 2e). The depth factor is less evident in the samples taken from the ANTARES platform. In March (Fig. 2b), there is a degree of similarity between the samples from depths of 0.5 m and 7 m, while the group of the deepest samples (12 m) is more isolated. The characterizing factor of the deep samples (12 m) was the presence of large colonies of *S. errata* and various serpulids which are almost completely absent from samples at lesser depths. In the samples taken in September (Fig. 2d), the most isolated group is that made up of near-surface samples (0.5 m), while the other samples are connected by virtue of relatively high similarity indices. This different fouling pattern may be determined by seasonal factors; in the near-surface samples taken in September the number of mussels was very high: For example, at ANTARES 0.5 m W there were 574 *M. galloprovincialis* per dm^2, most of which were very small in size, supporting the belief that summer conditions favour recruitment and growth.

3.3. Fouling biomass

An examination of the wet weights of the fouling samples taken from both the PCWA and ANTARES platforms shows that the higher values correspond to the near-surface and medium depths (between 0.5 m and 7 m), while at greater depths in general the values were lower (Tables 3–7). This is essentially due to the very small numbers of mussels at greater depths, both in the samples taken in March and those taken in September; in particular, the lowest values are to be found at the PCWA platform (Sept. '93) at a depth of 11 m.

The highest weight values at the PCWA platform were observed close to the surface, usually with a S and E exposure, reaching an absolute maximum of 1561.3 g/dm^2 in September.

In general, the wet weight values at the ANTARES platform in September were lower than the March values; at the PCWA platform the two values were closer to each other, although the lower value was recorded in March.

When one considers the dry and ash weights of mussels one can observe in general that ash weight corresponds a little less than half the corresponding wet weight value while a moderate organic matter content is demonstrated by the small difference between dry and ash weights.

Table 3
PCWA March '93: Density (n_0/dm^2) and wet weight (g/dm^2) of the most important taxa found at different aspect and depth.

PCWA March '93	11 m N		11 m W		11 m S			
	no/dm²	g/dm²	no/dm²	g/dm²	no/dm²	g/dm²		
Balanus trigonus	13.33	8.25	11.83	4.33	9.67	7.90		
Balanus perforatus	0.17		0.00		0.00			
Balanus ebumeus	0.00		0.00		0.00			
Balanus improvisus	0.00		0.00		0.00			
Balanus amphitrite	0.00		0.50	0.07	0.00			
Obelia dichotoma	0.17	0.38	0.17	0.41	0.17	0.70		
Pomatoceros triqueter	2.50		1.67		1.0			
Crassostrea gigas	1.50	55.11	1.33	22.84	2.00	34.14		
Mytilaster minimus	0.00		0.00		0.17			
Mytilus galloprovincialis	0.00		0.50	21.46	0.30	77.85		
Hiatella arctica	0.50		1.17		0.17			
Nemertea	0.00		0.00		0.00			
Epizoanthus arenaceus	176.67	4.69	90.83	2.08	164.67	8.75		
Others	-	10.90	-	*	-	*		
PCWA March '93	5.5 m N		5.5 m W		5.5 m S		5.5 m E	
	no/dm²	g/dm²	no/dm²	g/dm²	no/dm²	g/dm²	no/dm²	g/dm²
Balanus trigonus	0.17		0.83	0.19	1.00		1.17	
Balanus perforatus	0.00		0.00		0.00		0.00	
Balanus ebumeus	0.17		0.00		0.00		0.00	
Balanus improvisus	0.00		0.00		0.00		0.00	
Balanus amphitrite	0.00		0.00		0.00		0.17	
Obelia dichotoma	0.00		0.00		0.00		0.00	
Pomatoceros triqueter	0.00		0.17		0.17		0.00	
Crassostrea gigas	0.33	0.09	0.00		0.00		0.17	2.19
Mytilaster minimus	0.00		0.00		0.00		0.17	
Mytilus galloprovincialis	40.00	416.12	71.00	298.20	79.00	363.01	60.00	346.28
Hiatella arctica	2.33	0.16	6.83	0.50	26.50	1.75	4.17	0.26
Nemertea	0.00		0.00		0.00		0.00	
Epizoanthus arenaceus	0.00		0.00		0.00		0.00	
Others	-	0.29	-	1.11	-	1.90	-	1.27
PCWA March '93	0.5 m N		0.5 m W		0.5 m S		0.5 m E	
	no/dm²	g/dm²	no/dm²	g/dm²	no/dm²	g/dm²	no/dm²	g/dm²
Balanus trigonus	1.33		2.50		0.00		1.08	
Balanus perforatus	8.67	13.13	0.36		0.90		5.38	6.41
Balanus eburneus	8.00	7.88	5.71	2.10	4.19	1.58	3.23	
Balanus improvisus	1.00		0.00	0.68	0.59		0.00	
Balanus amphitrite	0.33		0.00		1.49	0.68	0.00	
Obelia dichotoma	0.00		0.00		0.00		0.00	
Pomatoceros triqueter	0.17		0.00		0.00		0.00	
Crassostrea gigas	1.17	3.32	1.07		0.90	1.17	1.44	3.83
Mytilaster minimus	36.67	0.65	3.92	0.02	4.50		14.53	0.86
Mytilus galloprovincialis	369.17	380.16	168.00	780.00	177.00	1061.87	43.00	945.41
Hiatella arctica	0.00		0.00		0.00		0.00	
Nemertea	19.67	3.53	0.71		0.59		13.98	3.69
Epizoanthus arenaceus	0.00		0.00		0.00		0.00	
Others	-	7.99	-	0.53	-	1.36	-	6.49

3.4. Mussels

Mussels represent the dominant component in fouling, exceeding 99% of the biomass weight in many samples from both near-surface and medium-depths (Table 7). Figures 3 and 4 show the length-frequency distribution as percentages of the individuals sampled at these depths.

In the March sample from PCWA, 2 cohorts are very

Table 4
PCWA September '93: Density (n_0/dm^2) and wet weight (g/dm^2) of the most important taxa found at different aspect and depth.

PCWA September '93	11 m N		11 m W		11 m S		11 m E	
	no/dm²	g/dm²	no/dm²	g/dm²	no/dm²	g/dm²	no/dm²	g/dm²
Balanus trigonus	4.17	6.66	8.58	14.12	28.33	29.47	18.75	18.27
Balanus improvisus	0.00		0.83		0.00		0.00	
Tubularia crocea	0.00		0.08		0.08	0.74	0.00	
Crassostrea gigas	1.00	11.85	0.50	5.34	1.67	39.86	0.33	6.58
Mytilaster minimus	0.00		0.17		0.17		0.00	
Mytilus galloprovincialis	0.00		0.10	0.40	0.25	0.02	0.00	
Actiniaria	0.00		0.00		0.00		0.00	
Styela plicata	0.00		0.00		0.00		0.00	
Others	-	3.59	-	7.14	-	20.01	-	16.15
PCWA September '93	5.5 m N		5.5 m W		5.5 m S		5.5 m E	
	no/dm²	g/dm²	no/dm²	g/dm²	no/dm²	g/dm²	no/dm²	g/dm²
Balanus trigonus	4.67	0.58	1.67	0.23	0.84		1.04	
Balanus improvisus	11.83	1.21	3.67	0.61	6.96	0.58	6.16	0.47
Tubularia crocea	0.00		0.33		0.00		0.00	
Crassostrea gigas	0.83	0.68	1.42	7.21	0.00		0.31	
Mytilaster minimus	0.00		0.17		0.00		0.00	
Mytilus galloprovincialis	23.00	218.30	40.42	116.20	59.00	500.00	23.00	264.90
Actiniaria	11.67	0.32	7.25	0.15	0.00		8.41	0.97
Styela plicata	0.17		0.58	0.80	0.00		0.59	1.31
Others	-	1.51	-	1.30	-	0.92	-	*
PCWA September '93	1 m N		1 m W		1 m S		1 m E	
	no/dm²	g/dm²	no/dm²	g/dm²	no/dm²	g/dm²	no/dm²	g/dm²
Balanus trigonus	0.19		0.76		0.36		1.10	
Balanus improvisus	1.17	0.36	10.74	2.79	0.36		4.03	
Tubularia crocea	0.00		0.00		0.00		0.00	
Crassostrea gigas	1.17	11.34	0.00		0.00		0.73	1.84
Mytilaster minimus	4.66	0.83	0.00		0.36		0.00	
Mytilus galloprovincialis	185.00	526.40	584.00	1372.00	834.00	1117.20	438.00	1553.00
Actiniaria	18.45	0.85	289.04	5.28	209.31	4.09	242.37	6.58
Styela plicata	1.86	0.66	0.39		0.36		0.00	
Others	-	*	-	*	-	*	-	*

*insignificant weight

evident at a depth of 0.5 m. The first comprised mainly extremely small specimens (1st class 0.01–0.49 cm), the other specimens belonging to classes 8–10. At medium depths (5.5 m) the two cohorts probably overlap and there is no evidence of recent recruitment (1st class). The largest size of mussels (7 cm) is similar to that observed at 0.5 m.

In the September samples from the PCWA platform a mode is present at 0.5 m with a maximum in the 2nd class, indicating recent recruitment. At the medium depth the community was similar to that found in March.

In the sample taken in March from the ANTARES platform at 0.5 m with a maximum in the 2nd class, indicating recent recruitment. At the medium depth the community was similar to that found in March.

In the sample taken in March from the ANTARES platform at 0.5 m, 2 cohorts can be distinguished, with maxima corresponding to classes 2 and 10. At 7 metres the community is made up of a single population consisting of medium-sized mussels, around 5 cm (class 11). In the September near-surface sample (Fig. 4c), there is a single cohort of extremely young specimens that is dominant. At 7 metres in September (Fig. 4d), the settlement presents two modes with maxima corresponding to classes 3 and 11, which define two different cohorts.

In the near-surface samples from both platforms two cohorts are always present in March and one in September. The presence of class 1 specimens demonstrates an extremely recent recruitment. At medium depths, at the times when the sampling was carried out, class one was

Table 5
ANTARES March '93: Density (no/dm^2) and wet weight (g/dm^2) of the most important taxa found at different exposure and depth.

Antares March '93	12 m N		12 m W		12 m S		12 m E	
	no/dm^2	g/dm^2	no/dm^2	g/dm^2	no/dm^2	g/dm^2	no/dm^2	g/dm^2
Balanus trigonus	2.50	2.89	29.75	24.64	4.50	5.46	22.50	11.20
Balanus perforatus	0.00		0.50	2.48	0.00		0.00	
Balanus ebumeus	0.00		0.25		0.00		0.00	
Balanus improvisus	0.25		0.00		0.00		0.00	
Garveia franciscana	0.25	3.30	0.25	0.14	0.25	0.30	0.00	
Obelia dichotoma	0.00		0.25	1.49	0.00		0.25	0.87
Pomatoceros triqueter	5.00	1.05	3.00	1.25	1.00		6.50	
Schizoporella errata	0.25	49.24	0.25	28.13	0.25	19.22	0.25	
Crassostrea gigas	0.25	0.84	1.50	104.07	0.25		2.25	148.83
Mytilus galloprovincialis	2.75	34.54	0.25	0.83	0.02	1.15	0.50	0.06
Nemertea	0.00		0.00		0.00		0.00	
Ophiuroidea	0.00		0.00		0.00		0.00	
Others	-	7.64	-	20.97	-	14.12	-	4.29

Antares March '93	7 m N		7 m W		7 m S		7 m E	
	no/dm^2	g/dm^2	no/dm^2	g/dm^2	no/dm^2	g/dm^2	no/dm^2	g/dm^2
Balanus trigonus	3.34		6.00	2.74	3.82	1.38	6.00	3.40
Balanus perforatus	0.50		0.34		1.16	0.82	0.34	
Balanus ebumeus	0.00		0.34		0.00		0.16	
Balanus improvisus	0.34		1.00	0.16	0.00		0.00	
Garveia franciscana	0.00		0.16	0.02	0.00		0.00	
Obelia dichotoma	0.00		0.00		0.00		0.00	
Pomatoceros triqueter	0.16		0.00		0.00		0.00	
Schizoporella errata	0.16		0.16	16.00	0.00		0.16	0.56
Crassostrea gigas	0.00		0.00		0.50		0.16	
Mytilus galloprovincialis	12.00	689.15	55.00	738.21	77.00	879.86	80.00	703.04
Nemertea	0.00		0.00		0.00		0.00	
Ophiuroidea	1.50		1.00	0.80	3.66	2.80	0.00	
Others	-	2.51	-	*	-	*	-	1.33

Antares March '93	0.5 m S-E		0.5 m N		0.5 m W	
	no/dm^2	g/dm^2	no/dm^2	g/dm^2	no/dm^2	g/dm^2
Balanus trigonus	0.00		1.59		4.22	
Balanus perforatus	2.38	2.03	6.88	12.10	7.39	10.21
Balanus eburneus	0.00		0.00		0.54	
Balanus improvisus	0.00		1.59		0.00	
Garveia franciscana	0.00		0.00		0.00	
Obelia dichotoma	0.00		0.00		0.00	
Pomatoceros triqueter	0.00		0.00		0.00	
Schizoporella errata	0.00		0.00		0.00	
Crassostrea gigas	2.38	4.34	1.59	3.04	3.17	9.76
Mytilus galloprovincialis	138.00	897.24	64.00	442.71	41.00	408.01
Nemertea	0.00		9.51	0.79	10.05	1.65
Ophiuroidea	0.00		0.00		0.00	
Others	-	*	-	*	-	*

*insignificant weight

Table 6
ANTARES September '93: Density (no/dm^2) and wet weight (g/dm^2) of the most important taxa found at different aspect and depth

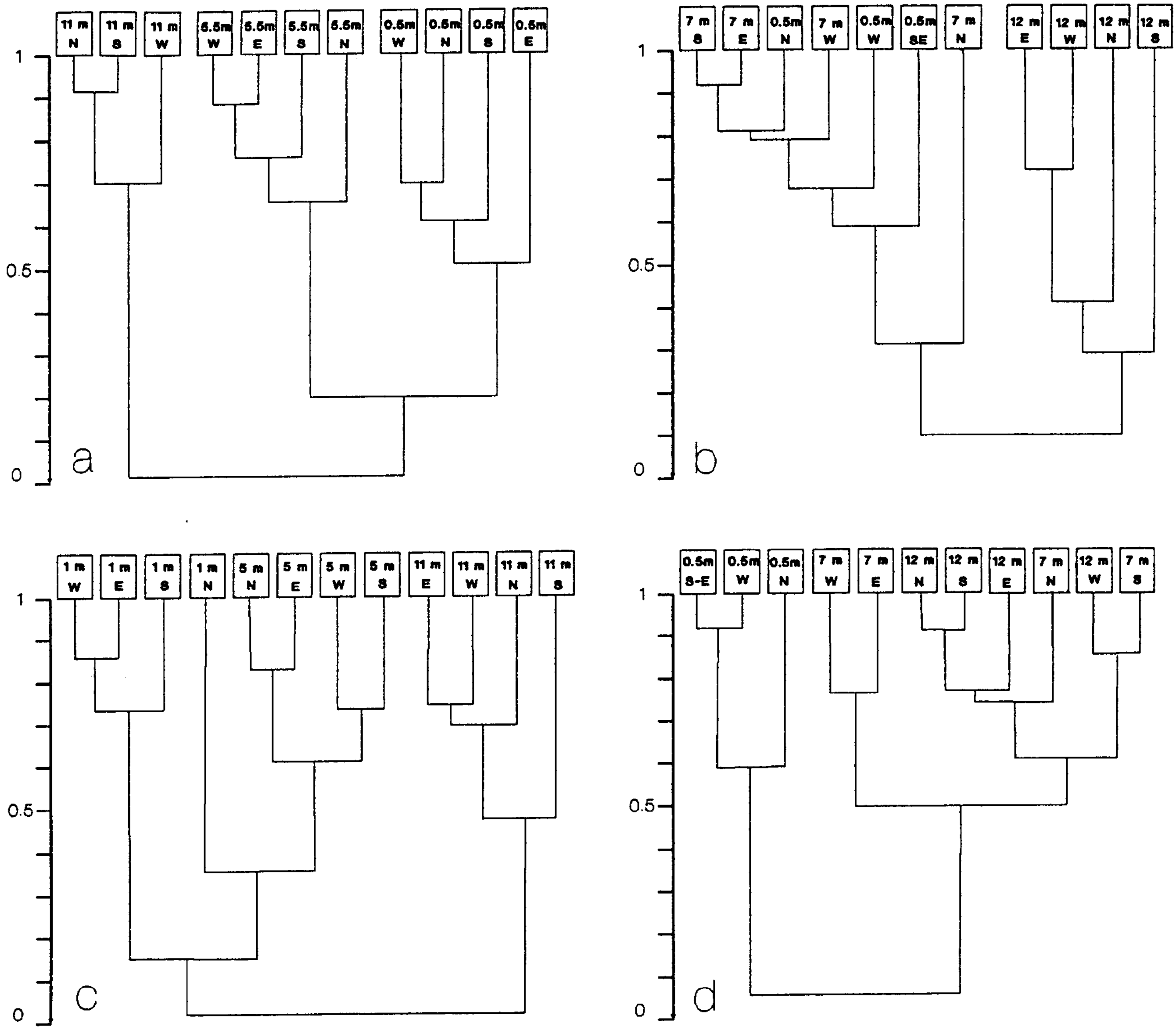
Antares September '93	12 m N		12 m W		12 m S		12 m E	
	no/dm^2	g/dm^2	no/dm^2	g/dm^2	no/dm^2	g/dm^2	no/dm^2	g/dm^2
Balanus trigonus	25.00	13.06	10.00	6.78	24.83	16.09	18.92	5.93
Balanus perforatus	0.25		0.00		0.67		0.67	1.50
Balanus improvisus	0.25		0.16		0.00		0.08	
Pomatoceros triqueter	3.75		1.92		2.92		0.67	
Schizoporella errata	0.08	15.96	0.08	41.00	0.08	30.95	0.08	13.75
Crassostrea gigas	1.50	45.08	1.08	40.36	0.67	61.06	0.42	0.72
Mytilaster minimus	0.00		0.00		0.33		0.67	
Mytilus galloprovincialis	6.00	31.60	3.70	10.80	6.83	19.24	8.67	62.00
Hiatella arctica	0.42		0.33		0.25		1.00	
Nemertea	0.08		0.00		0.00		0.00	
Actiniaria	0.00		0.00		0.00		0.00	
Others	-	9.40	-	5.46	-	*	-	
Antares September '93	**7 m N**		**7 m W**		**7 m S**		**7 m E**	
	no/dm^2	g/dm^2	no/dm^2	g/dm^2	no/dm^2	g/dm^2	no/dm^2	g/dm^2
Balanus trigonus	7.67	7.12	10.67	5.50	10.00	17.72	5.58	7.08
Balanus perforatus	0.33		0.17		0.25		0.42	1.26
Balanus improvisus	0.25		0.67		0.00		0.42	
Pomatoceros triqueter	0.08		0.25		0.17		1.00	0.24
Schizoporella errata	0.08	1.84	0.08	9.79	0.08	15.71	0.08	12.87
Crassostrea gigas	0.08	13.77	0.33		1.00	0.36	0.25	0.87
Mytilaster minimus	0.00		0.00		0.33		0.67	
Mytilus galloprovincialis	19.60	190.30	34.83	124.40	8.58	74.60	23.00	54.90
Hiatella arctica	0.33		1.50	0.16	0.75		1.08	
Nemertea	0.00		0.58		0.00		1.00	
Actiniaria	0.00		0.08		0.00		0.17	
Others	-	5.07	-	1.65	-	2.51	-	7.88
Antares September '93	**0.5 m S-E**		**0.5 m N**		**0.5 m W**			
	no/dm^2	g/dm^2	no/dm^2	g/dm^2	no/dm^2	g/dm^2		
Balanus trigonus	0.08		0.44		0.34			
Balanus perforatus	0.08		1.17	1.20	3.34	2.32		
Balanus improvisus	0.08		0.00		1.50			
Pomatoceros triqueter	0.08		2.33		0.50			
Schizoporella errata	0.08		0.00		0.00			
Crassostrea gigas	0.92	1.07	0.00		1.16	2.55		
Mytilaster minimus	2.92		3.20		5.34			
Mytilus galloprovincialis	507.92	336.60	245.00	780.10	574.00	766.10		
Hiatella arctica	0.00		0.30		0.32			
Nemertea	1.67		5.55		12.16			
Actiniaria	20.75	0.48	72.33	1.02	26.16	0.45		
Others	-	0.85	-	*	-	25.18		

*insignificant weight

no longer present, which possibly indicates a movement of the mussels recruited at 0.5 m towards greater depths.

4. Discussion

This present study classifies 32 different species and in addition errant polychaetes (Nereidae), nemerteans, Ophiuroidea and nudibranchs, which were not classified to species level (Table 2). During the research carried out from April '75 to April '76 (Relini et al., 1976) a total of 36 different species was observed, to which should be added some species of Actiniaria not classified to species level and some nemerteans present in Table 2. Fourteen species are common to the two studies, that is, the most important ones in terms of numbers and biomass, and



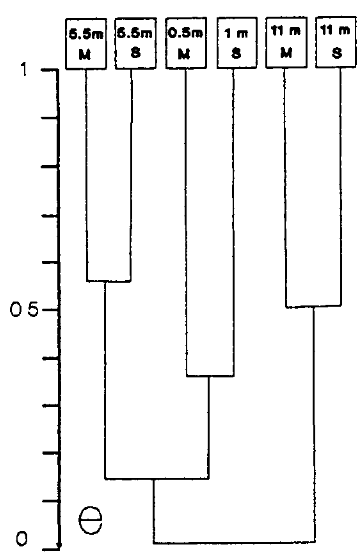


Fig. 2. Dendrograms of similarity (Kulczynski index) resulting from normal qualitative cluster analysis (UPGMA). a: samples taken at PCWA in March '93 from different aspects, North (N), East (E), South (S) and West (W); b: samples taken at ANTARES in March '93; c: samples taken at PCWA in September '93; d: samples taken at ANTARES in September '93; e: samples taken at PCWA in March and September '93 (sum of the various aspects for each depth).

Table 7
Values of density, wet, dry and ash weight of mussels sampled at different aspect and depth of two platforms. The two last columns refer to wet weight of fouling and corresponding w.w. fraction (%) of mussels.

PCWA Depth	MARCH	mussels number no/dm²	mussels wet weight g/dm²	mussel dry weight g/dm²	mussels ash weight g/dm²	fouling weight g/dm²	mussel fraction %
0.5 m	N	369.00	380.16	189.77	156.03	416.66	37.45
0.5 m	W	168.00	780.00	377.55	309.13	783.33	39.46
0.5 m	S	177.00	1061.87	514.82	417.52	1066.66	39.14
0.5 m	E	43.00	945.41	430.75	341.84	966.66	35.36
5.5 m	N	40.00	416.12	189.20	150.03	416.66	36.01
5.5 m	W	71.00	298.20	123.83	98.27	300.00	32.76
5.5 m	S	79.00	363.01	142.29	112.02	366.66	30.55
5.5 m	E	60.00	346.28	160.09	130.77	350.00	37.36
11 m	N	-	-	-	-	79.33	-
11 m	W	0.50	21.46	11.19	9.59	51.19	18.73
11 m	S	0.30	77.85	41.31	35.63	119.34	29.86
11 m	E						

ANTARES Depth	MARCH	mussels number no/dm²	mussels wet weight g/dm²	mussel dry weight g/dm²	mussel ash weight g/dm²	fouling weight g/dm²	mussel fraction %
0.5 m	S-E	138.00	897.24	714.03	405.53	900.00	45.06
0.5 m	N	64.00	442.71	363.20	183.22	450.00	40.72
0.5 m	W	41.00	408.01	275.68	159.94	416.66	38.39
7 m	N	12.00	689.45	365.23	317.52	691.66	45.91
7 m	W	55.00	738.21	427.42	370.65	757.93	48.90
7 m	S	77.00	879.86	508.58	433.05	884.86	48.94
7 m	E	80.00	703.04	374.02	304.48	708.33	42.99
12 m	N	3.00	34.54	15.84	12.98	99.50	13.05
12 m	W	0.20	0.83	0.46	0.40	184.00	0.22
12 m	S	0.20	4.59	2.20	1.90	40.25	4.72
12 m	E	0.50	0.22	-	-	165.25	0.00

PCWA Depth	SEPTEMBER	mussels number no/dm²	mussels wet weight g/dm²	mussel dry weight g/dm²	mussel ash weight g/dm²	fouling weight g/dm²	mussel fraction %
1 m	N	185.00	526.40	351.84	263.27	540.40	48.72
1 m	W	584.00	1372.00	891.00	620.05	1380.07	44.93
1 m	S	834.00	1117.20	630.68	517.07	1121.29	46.11
1 m	E	438.00	1553.00	969.10	710.24	1561.38	45.49
5.5 m	N	23.00	218.30	178.69	109.09	222.60	49.01
5.5 m	W	40.40	116.20	83.38	55.31	126.50	43.72
5.5 m	S	59.00	500.00	309.95	272.00	501.50	54.24
5.5 m	E	23.00	264.90	154.84	132.10	267.65	49.36
11 m	N	-	-	-	-	22.10	-
11 m	W	0.10	0.40	0.22	0.20	27.00	0.74
11 m	S	0.20	0.02	-	-	90.10	0.00
11 m	E	-	-	-	-	41.00	-

ANTARES Depth	SEPTEMBER	mussels number no/dm²	mussels wet weight g/dm²	mussel dry weight g/dm²	mussel ash weight g/dm²	fouling weight g/dm²	mussel fraction %
0.5 m	S-E	508.00	336.60	278.24	173.71	339.00	51.24
0.5 m	N	245.00	780.10	577.50	416.15	782.32	53.19
0.5 m	W	574.00	766.10	624.14	400.78	796.60	50.31
7 m	N	19.60	190.30	150.55	100.08	218.10	45.89
7 m	W	35.00	124.40	96.03	64.22	141.50	45.39
7 m	S	8.50	74.60	54.19	39.34	110.90	35.47
7 m	E	23.00	54.90	44.55	28.93	85.10	34.00
12 m	N	6.00	31.60	14.83	13.01	115.10	11.30
12 m	W	3.70	10.80	5.61	4.82	104.40	4.62
12 m	S	6.80	19.24	9.20	7.58	127.34	5.95
12 m	E	8.60	62.00	37.55	32.34	129.80	24.92

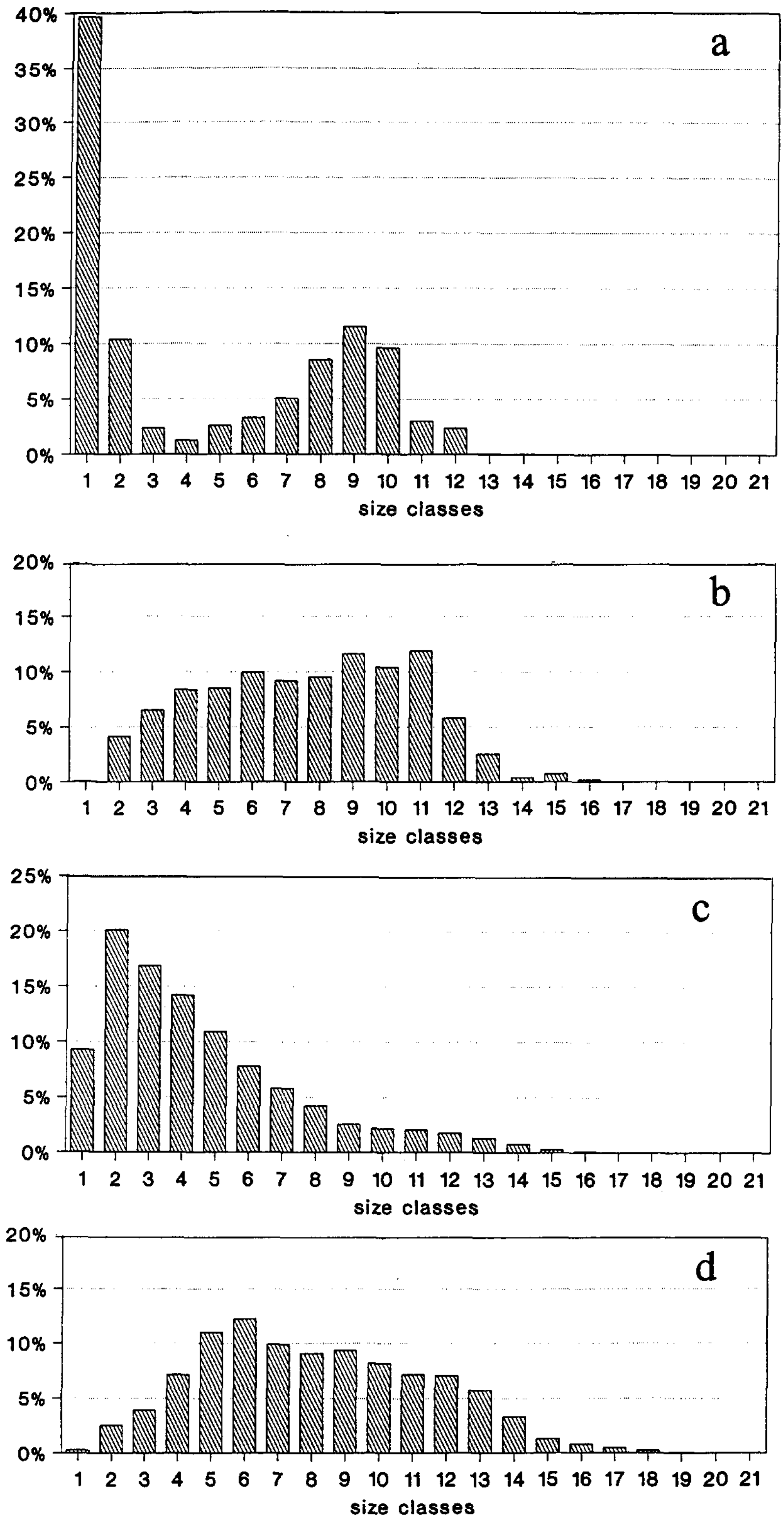


Fig. 3. Length/frequency distributions of mussels at PCWA (each is the sum of the various aspects): a) March '93, 0.5 m depth; b) March '93, 5.5 m depth; c) September '93, 1 m depth; d) September '93, 5.5 m depth. Each size class has a 0.49 cm range.

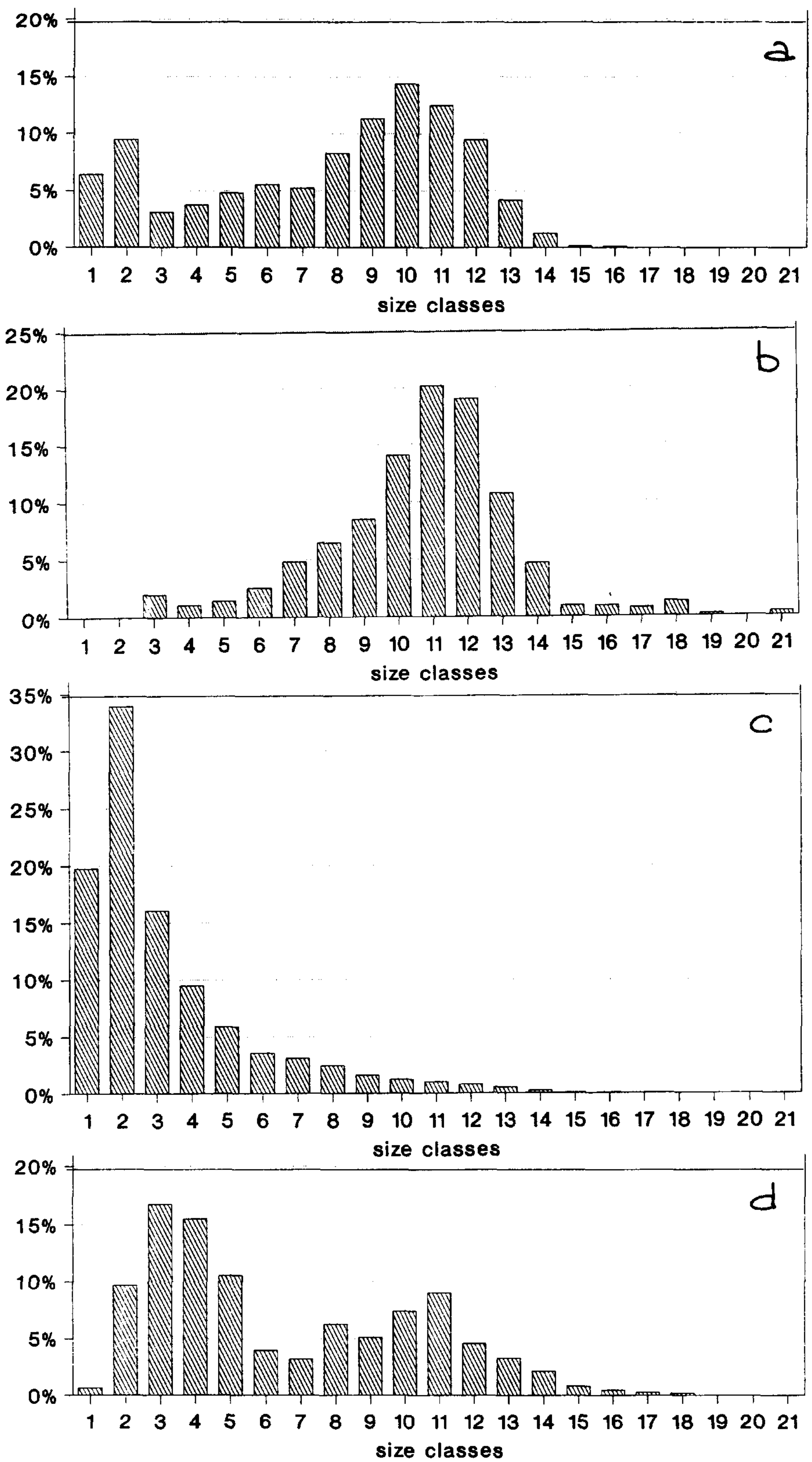


Fig. 4. Length/frequency distributions of mussels at ANTARES (each is the sum of the various aspects): a) March '93, 0.5 m depth; b) March '93, 7 m depth; c) September '93, 0.5 m depth; d) September '93, 7 m depth. Each size class has a 0.49 cm range.

also the ones that characterize the fouling. There is, however, one important exception: the disappearance of *Ostrea edulis*, present in '75–'76 and now replaced by *Crassostrea gigas*. This latter species was not observed on the panels in the earlier study, but one cannot exclude the possibility that it was already present on the deepest part of the supports in 1975–76. In comparing the 1993 results with those from '75–'76 one has to consider the fact that different methods were used: in '75–'76 asbestos panels (600 cm^2) were immersed and removed at regular intervals, while in '93 standard surface samples (all organisms were scraped away on 600 cm^2) were taken from piles at two different periods.

Using the Kulczynski similarity index one finds a greater similarity between the samples obtained at different exposures, but at the same depth, than between different depths. This latter factor (depth) is therefore more discriminative than the seasonal factor, as was also found in the Loano artificial reef in the Ligurian Sea (Zamboni et al., 1992). Wet weights show higher values in the samples taken both at the near-surface (0.5 m) and at medium depths due to the massive presence of mussels (Table 7).

There were no large differences in the weight of the fouling or mussel either between the two platforms or the two seasons, even though the highest values were recorded in September on the PCWA platform (1 m) with 1561.3 g/dm^2 of which 99.4% was due to mussels (Table 7). Samples taken near the bottom had a lower biomass. When one considers settlement periods and growth of mussels one can draw the conclusion that over a period of 5–6 months it is possible to reach fouling weights of 155 kg/m^2 which exceed the 100 kg recorded from the one-year panels during the experiment carried out in 1975–76. On the whole, there were no substantial differences, either qualitative or quantitative, between the fouling observed off Ravenna in 1975–76 and that observed in the present study. Thus it is possible to confirm the observations of 1976, that the macrofouling on the platforms off Ravenna is relatively homogeneous. It is mainly composed of a small number of species, some of which are represented by a large number of individuals, and to a depth of 9–10 m it is dominated by mussels which, in the space of only a few months, attain extremely high values of both density and biomass. The biomass values at Ravenna are the highest recorded from offshore structures in the Mediterranean Sea (Relini and Relini, 1994). Similar biomass values for mussels were found on the concrete blocks in the artificial reef near M. Conero (Ancona-Middle Adriatic Sea) (personal data), while on an oceanographic platform 8 miles offshore Venice, only 62.6 $Kg/m^2/yr$ wet weight of fouling of which 7.2 $Kg/m^2/yr$ of mussels were found (Montanari et al., 1992). In Crotone platforms (Ionian Sea) near surface 0.8 $Kg/m^2/yr$ of fouling and 0.49 Kg of mussels were recorded. On a platform situated 3.5 miles from the coast of Fiumicino (Roma), in the Tyrrhenian Sea, 37.7 Kg/m^2 at 5 m depth and 23.2 Kg/m^2 at 10 m of fouling wet weight were measured (Ardizzone et al., 1980), but time is not known. Mussels are considered to be the most serious fouling organism likely to foul central North Sea platforms, whereas on the northern North Sea platforms kelps are considered to be of far greater importance (Forteath et al., 1984). On North Sea platforms mussel beds can reach 5 cm thickness in five years, with individuals reaching a length of 4 cm during their second summer and 8 cm in their eighth summer. The removal of mussel beds appears to be necessary after about 6 or 8 years but the removal of areas covered by soft growth needs not to take place for at least 10 or 12 years (Forteath et al., 1984). At Ravenna mussels must be removed once a year, because they can attain a layer 20–30 cm thick in twelve months. The mussels are collected and used as human food. So this very large growth of mussels due to eutrophic water is dangerous from fouling point of view, but is a very good harvest for local fishermen.

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