BIODIVERSITY AND ZONATION PATTERNS OF CRUSTACEAN PERACARIDS AND DECAPODS OF COASTAL SOFT-BOTTOM ASSEMBLAGES (CENTRAL TYRRHENIAN SEA, ITALY)

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BIODIVERSITY AND ZONATION PATTERNS OF CRUSTACEAN PERACARIDS AND DECAPODS OF COASTAL SOFT-BOTTOM ASSEMBLAGES (CENTRAL TYRRHENIAN SEA, ITALY)

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MACROBENTHOS
CRUSTACEA PERACARIDA
CRUSTACEA DECAPODA
SOFT BOTTOMS
BIODIVERSITY
ZONATION
MEDITERRANEAN SEA

ABSTRACT. – The structure, horizontal and vertical zonations of crustacean peracarid and decapod assemblages were studied from soft bottoms along the Italian coasts of the Tyrrhenian Sea from 42°25'00''N to 41°12'49''N. At 69 of the 75 sampled stations, located within three bathymetric ranges (I: 8-15 m; II: 16-27 m; III: 36-53 m), 119 species and 2220 individuals were found. The identified coenotic units were characterized by a constant vertical discontinuity between the second and the third depth-ranges and by a horizontal zonation at the first and the second depth-ranges. The quality of water movements, mainly responsible of the above-mentioned vertical discontinuity (Riedl's second critical depth), and the sedimentation rates (granulometric composition of the sediments towards the depth) act together in structuring assemblages. The nature of surrounding bottoms (rocky shore, rocky banks, seagrasses) and the presence of river outflows, little harbours and/or urban settlements, modifying both the quality of sediment depth-zonation and the trophic conditions, interact with the above-mentioned driving factors in controlling zonation patterns. The resulted heterogeneous distribution of assemblages contributes to increased biodiversity in the studied soft bottoms.

MACROBENTHOS
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RÉSUMÉ. – La structure et les zonations verticales et horizontales des assemblages de Crustacés Péracarides et Décapodes ont été étudiées sur les fonds meubles le long des côtes italiennes de la Mer Tyrrénienne, de 42°25'00''N à 41°12'49''N. Cent dix-neuf espèces et 2220 individus ont été identifiées dans 69 des 75 stations échantillonnées, localisées dans trois bandes bathymétriques (I : 8-15 m ; II : 16-27 m ; III : 36-53 m). Les unités coenotiques identifiées sont caractérisées par une discontinuité verticale constante entre le 2^{e} et le 3^{e} niveaux de profondeur et par une zonation horizontale aux niveaux I et II de profondeur. La qualité de l'hydrodynamisme, principale responsable de la discontinuité verticale mentionnée ci-dessus (2^{e} profondeur critique de Riedl) et les taux de sédimentation (composition granulométrique des sédiments par rapport à la profondeur), interagissent pour structurer les assemblages. La nature des fonds environnants (côtes rocheuses, bancs de roche, prairies) et la présence d'embouchures de fleuves, de ports et/ou d'agglomérations urbaines, qui modifient la qualité de la zonation de profondeur du sédiment et les conditions trophiques, interagissent avec les facteurs guides ci-dessus dans le contrôle des modèles de zonation. La distribution hétérogène des assemblages qui en résulte contribue à l'augmentation de la biodiversité dans les fonds meubles étudiés.

INTRODUCTION

The knowledge and evaluation of both species diversity and zonation patterns of assemblages are of primary importance in studies concerning biodiversity of marine benthic systems (Sanders 1968, Riedl 1971, Pérès 1982, Bianchi & Morri 2000, Ellingsen 2001). In the Mediterranean Sea, continental shelf soft bottoms have been widely studied, from the general fundamental works of Picard (1965) and Ledoyer (1966) to more recent investigations (e.g. Ambrogi *et al*. 1990, Karakassis & Eleftheriou 1997, Somaschini *et al*. 1998, Massé 2000) aiming at identifying the roles of abiotic and/or biotic factors in structuring the assemblages and in determining species diversity, also in relation to river outflows (Ambrogi 1989) and environmental perturbations due to human impact (e.g. Ferretti *et al*. 1989, Papazacharias *et al*. 1998, Simboura *et al*. 1998). In particular, the depth-gradient and correlated factors, such as hydrodynamics, sediment texture, morphology of the coast and coastal inputs being considered the main determinants in zonation processes were subject to several studies (e.g. Fresi *et al*. 1983, Gambi *et al*. 1983-1984, Russo & Fresi 1983-1984, Zurlini & Bedulli 1983).

An increase of knowledge, which would be desirable in this framework, may be acquired by focusing studies on taxonomic groups and geographic areas which lack exhaustive information. Macrofaunal crustaceans of soft bottoms were the object of some studies under the above-mentioned points of view along European Atlantic (Marques & Bellan-Santini 1993, Sanchez-Mata *et al*. 1993) and Mediterranean coasts (Diviacco *et al*. 1983, Maggiore *et al*. 1983-1984, Minervini *et al*. 1983-1984, Diviacco & Somaschini 1994, Corbera & Cardell 1995), and in the central Tyrrhenian Sea in particular (Falciai 1981, Falciai & Spadini 1985, Somaschini & Ardizzone 1992, Scipione & Lattanzi 1995, Tomassetti & Chimenz Gusso 1998), although not all taxonomic groups were studied at the same level.

With the above considerations in mind, in the present paper the infra- and upper circalittoral soft-bottom crustacean peracarids and decapods were studied in a wide coastal area of the central Tyrrhenian Sea, along the Italian coast from Monte Argentario to Gaeta, whereas previous investigations were concentrated in the area in front of the River Tevere (Della Seta *et al*. 1977, Focardi *et al*. 1982, Minervini *et al*. 1982, Falciai *et al*. 1983, Falciai & Spadini 1985). The aim was to identify the biological diversity of the taxonomic groups found and to characterize the structure of assemblages, in relation to both the horizontal and vertical gradients.

MATERIALS AND METHODS

The present study takes into account data collected in the frame-work of two research projects along the Italian coast of the central Tyrrhenian Sea, from Monte Argentario (42°25’00’’ N) to Gaeta (41°12’49’’ N), covering about 235 km of coast. In particular, data were collected from Monte Argentario to Montalto di Castro in the frame-work of the “ENEL Montalto” Research Project (Chimenz Gusso & Taramelli Rivosecchi 1989) (Area I) and from Montalto di Castro to Gaeta in the frame-work of the “Tirreno Project” (Taramelli Rivosecchi *et al*. 1990, Chimenz Gusso *et al*. 1996) (Area II) (Fig. 1a). Both areas are characterized by a coast-line with varied morphologies, such as sandy beaches, rocky substrata, river mouths and coastal lagoons, and on the bottom by the presence of seagrass meadows and rocky banks.

With the aim at performing the present analysis at the same level in the two areas, only a selected number of samples was taken into account, those collected in summer-autumn, in September 1984 in Area I, and in July, September and November 1989 in Area II.

In Area I samples were collected at 15 stations (Fig. 1b) along six depth-transects, at 10, 20 and 40 m depth, by a modified Petersen hydraulic grab (650 cm^2; three samples per station). At three transects the 20 m samples were not collected due to the presence all along the coast, from about 10-12 m to 22-25 m depth, of extensive meadows of the seagrass *Posidonia oceanica* (Diviacco *et al*. 2001). In Area II samples were collected at 60 stations (Fig. 1c, d, e, f), by a van Veen grab (0.1 m^2; two samples per station), along the depth-gradient. Data were analysed considering the above-mentioned stations grouped into three bathymetric ranges, from 8 to 15 m (mean depth of 12 m ± 0.58), from 16 to 27 m (mean depth of 20.7 m ± 0.60) and from 36 to 53m (mean depth of 44.8 m ± 1.08), corresponding to the three depths of Area I. In Area II, due to the long distance covered along the coast, to better investigate the horizontal zonation of the studied taxa, the following sub-areas, according to the morphology of the coast, were also identified: sub-area A, from Montalto di Castro to Santa Severa (10 stations) (Fig. 1c), sub-area B, from Ladispoli to Fiumicino (15) (Fig. 1d), sub-area C, from Anzio to Torre Astura (7), sub-area D, from Fogliano Lake to Capo Circeo (11) (Fig. 1e), and sub-area E, from San Felice Circeo to Sperlonga (11) (Fig. 1f).

In addition to the faunal samples, sediment samples were taken at each station for grain size analysis, performed to sort the main granulometric fractions (sand, silt and clay) (Wentworth 1922). At stations 50A, 55A, 56A, 59A, and 30B, which are very close to seagrass meadows and rocky banks, samples were not collected. The structural complexity of the sediment was measured as diversity (Shannon-Wiener’s index H’), according to Fresi *et al*. (1983).

The faunal samples were processed through a sieve (mesh-size 1mm) and the retained fraction was preserved in 4% buffered formaldehyde. All benthic organisms were sorted into taxonomic groups. The fauna of the samples collected at each station (three in Area I and two in Area II) was mixed, in order to have a more representative sample. In the present analysis Crustacea Peracarida (Mysidacea, Cumacea, Tanaidacea, Isopoda, and Amphipoda) and Decapoda were taken into account and identified at species level. The samples have been deposited in the Museum of the Istituto di Zoologia dell’Università di Roma “La Sapienza”.

Community parameters such as species richness, abundances, Shannon-Wiener’s diversity index (H’) and Pielou’s evenness (J) were calculated. Analysis of variance (one-way ANOVA) was performed to assess differences found in the above-mentioned parameters along the depth-gradient, and between sub-areas in Area II; Tukey’s test was used for *post-hoc* comparisons after

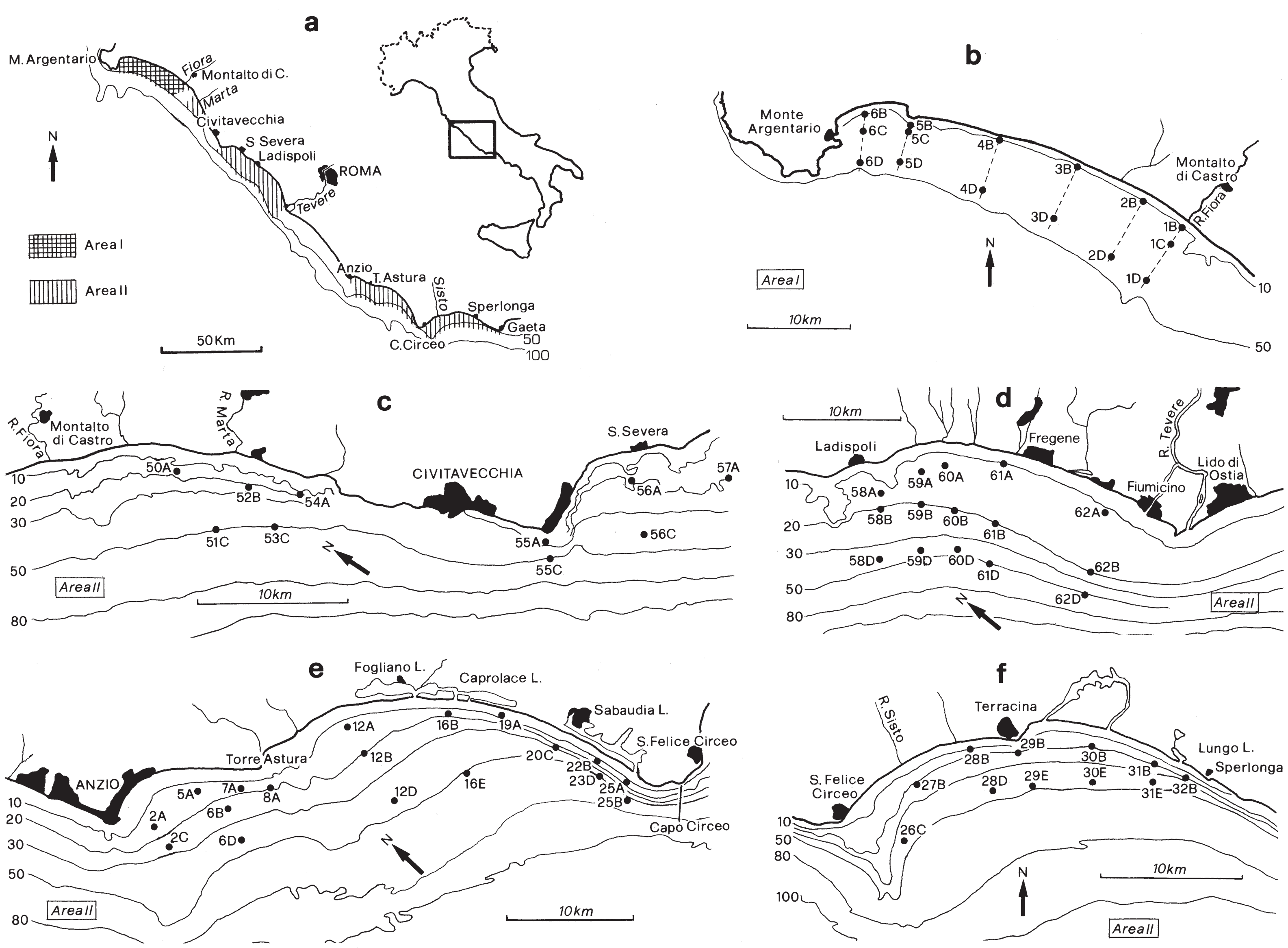

Fig. 1. – General map of the studied areas (a) and detailed maps of Area I (b) and Area II (c, d, e, f) with sampling stations indicated.

ANOVA. Correspondence Analysis was performed on both the granulometric fractions of sediments and the quantitative data of all the studied taxa. Statistical significance of axes generated by CA was inferred according to the model of McArthur (Frontier 1974). Correlation between biotic (number of species, abundances, diversity index, evenness, Axis I and Axis II derived from the CA) and abiotic (depth, sand, silt and clay, sediment diversity, Axis I derived from the CA) parameters was determined using Spearman's non-parametric rank correlation coefficient.

RESULTS

Descriptive analysis

Overall 119 species in 80 genera and 49 families, and a total of 2220 individuals were identified, distributed in the examined taxonomic groups as follows: mysids (1 species; 4 individuals), cumaceans (8; 40), tanaids (4; 1013), isopods (3; 13), amphipods (73; 1024), decapods (30; 126) (Table I). Only 9 species were present in more than 1% of the total abundance, representing 7.6% of the species and 74.3% of the individuals found in both studied areas: *Apseudes acutifrons** (922 ind.), *Ampelisca diadema** (305), *A. typica** (89), *A.* cfr. *ruffoi** (77), *Urothoe pulchella* (74), *Apseudes echinatus* (58), *Urothoe grimaldii* (48), *Autonoe spiniventris** (42), *Ampelisca brevicornis** (35). The species showed different trends along the depth-gradient (Table I) with only 15 species present at all depths, in particular the most abundant marked (*) above, besides *Megaluropus massiliensis*, *Harpinia dellavallei*, *Metaphoxus fultoni*, *Anapagurus laevis*, *Callianassa subterranea*, *Photis longicaudata*, *Processa edulis*, *Anapagurus serripes*, *Phtisica marina*. On the whole, the highest mean values (± SE) per station were present in Area I both for number of species (10.33 ± 1.26) and individuals (40.47 ± 11.47) in comparison to Area II (4.98 ± 0.49; 29.87 ± 8.50). This trend characterized each depth, with the exception of the higher values of abundance at the shallower depth-range in Area II. Regarding the sediment analysis, in both areas, the diversity index showed increasing trends with depth (Table II). In Area II the highest values were present in the sub-areas A and B and the lowest value in sub-area D.

The qualitative and quantitative results of Area I and Area II are presented and analysed separately, due to the different sampling methods used.

Area I: At the 15 studied stations 59 species were found, with a total of 607 individuals, belonging to mysids (1 species; 4 individuals), cumaceans (4; 31), tanaids (3; 175), isopods (3; 13), amphipods (40; 339) and decapods (8; 45) (Table I).

The number of species and individuals showed decreasing values from 10 to 40 m depth (Fig. 2Aa, b), with the exception of transect 1 and 6 for species, and transect 6 for individuals. All of the examined taxa showed similar decreasing trends with the exception of isopods and decapods for infull of species, and of tanaids and isopods for infull of individuals (Fig. 2Ac, d). Values of diversity (H') ranged from 0.96 to 2.64, showing the highest mean value at 10 m (Fig. 2Ae). The evenness (J) ranged from 0.40 to 0.97, showing the highest mean value at 40 m (Fig. 2Af). Amphipods presented the highest mean values of diversity and evenness at all depths, in comparison to the other taxa.

Area II: In this area the studied taxa were present in 54 of the 60 sampled stations. Overall 89 species with a total of 1613 individuals were identified, belonging to cumaceans (4 species; 9 individuals), tanaids (3; 838), amphipods (55; 685), and decapods (27; 81) (Table I).

The number of species showed the highest values at 16-27 m (Fig. 2Ba), while the number of individuals showed a strong decreasing trend with depth (Fig. 2Bb). Single taxonomic groups showed the same bathymetric trend, with the exception of tanaids for infull of species and cumaceans for infull of individuals, both characterized by scant presences (Fig. 2Bc, d). Values of H' diversity ranged from 0 to 2.57, showing along the depth the same trend observed for infull of species, while evenness (J), which ranged from 0 to 0.97, showed the lowest mean value at 8-15 m (Fig. 2Be, f). Amphipods presented the highest mean values of diversity and evenness at all depths, followed by decapods.

An analysis of the sub-areas considered showed that the higher number of species was reached in sub-areas B and E (Fig. 3a). In each sub-area, along the depth, the general trend of the whole area (Fig. 2Ba) was present in sub-areas B, C, and D. For number of individuals the highest values were present in sub-area B (Fig. 3b), with the same decreasing trend along the depth observed for the whole area (Fig. 2Bb). In the other sub-areas higher values were present at 16-27 m with the exception of sub-area E. Diversity showed the highest values in sub-area E and similar values in the other sub-areas (Fig. 3c). Along the depth higher values were present at 8-15 m in sub-area A, and at 16-27 m in the other sub-areas. Evenness values were higher in sub-areas C and E (Fig. 3d), and increased to depth, with the exception of sub-areas A and E. In the various sub-areas the dominant taxa had different distribution along the coast and with

Table I. – Mean (± SE) abundances per station (n = no. of stations) of the identified taxa at each depth (Area I) and at each depth-range (Area II). A-B-C: see ordination models of CA in Figs. 5, 7 and 8, respectively.

					Area I			Area II			T.Ab.
					10m	20m	40m	8-15m	16-27m	36-53m	
	A	B	C		(n = 6)	(n = 3)	(n = 6)	(n = 13)	(n = 22)	(n = 19)	
Mysidae				*Gastrosaccus sanctus* (van Beneden, 1861)	0.17 (0.17)						1
				Mysidacea ind.	0.17 (0.17)		0.33 (0.33)				3
Bodotriidae	1			*Bodotria pulchella* (G.O. Sars, 1878)	3.00 (1.79)						18
	2			*Iphinoe armata* Ledoyer, 1965	1.00 (0.52)						6
		1	1	*Iphinoe tenella* G.O. Sars, 1878				0.08 (0.08)	0.04 (0.04)		2
				Iphinoe ind.	0.33 (0.21)			0.08 (0.08)		0.05 (0.05)	4
				Vaunthompsonia cristata Bate, 1858			0.17 (0.17)				1
Leuconidae				*Eudorella truncatula* (Bate, 1856)					0.04 (0.04)		1
Nannastacidae				*Cumella pygmaea* G.O. Sars, 1865					0.04 (0.04)		1
Diastylidae		2	2	*Diastylis rugosa* G.O. Sars, 1865					0.04 (0.04)	0.10 (0.10)	3
Pseudocumatidae	3			*Pseudocuma simile* G.O. Sars, 1900	0.33 (0.33)						2
				Cumacea ind.	0.33 (0.33)						2
Apseudidae	4	3	3	*Apseudes acutifrons* G.O. Sars, 1882	1.00 (0.63)	42.33 (41.80)	0.67 (0.67)	35.92 (20.70)	14.09 (6.17)	0.42 (0.27)	922
	5	4	4	*Apseudes echinatus* G.O. Sars, 1882		0.67 (0.67)	1.67 (0.67)		0.45 (0.36)	1.89 (0.48)	58
		5	5	*Apseudes latreillii* (Milne-Edwards, 1828)				0.15 (0.15)	0.23 (0.23)		7
				Apseudes ind.	3.00 (1.90)						18
Paratanaidae	6			*Leptochelia savignyi* (Kroyer, 1842)	1.33 (1.14)						8
Idoteidae				*Cleantis prismatica* (Risso, 1826)	0.17 (0.17)						1
Cirolanidae	7			*Cirolana neglecta* Hansen, 1890		0.67 (0.67)	1.00 (0.52)				8
	8			*Eurydice spinigera* Hansen, 1890	0.50 (0.50)		0.17 (0.17)				4
Ampeliscidae	9	6	6	*Ampelisca brevicornis* (A. Costa, 1853)	2.50 (1.45)	1.33 (1.33)	0.17 (0.17)	1.00 (0.59)	0.09 (0.06)		35
	10	7	7	*Ampelisca diadema* (A. Costa, 1853)	3.67 (3.47)	5.00 (2.89)		14.54 (10.50)	3.54 (1.82)	0.05 (0.05)	305
	11	8	8	*Ampelisca pseudospinimana* Bellan-Santini & Kaim-Malka, 1977			0.50 (0.34)			0.16 (0.11)	6
				Ampelisca rubella A. Costa, 1864				0.08 (0.08)			1
		9	9	*Ampelisca* cfr. *ruffoi* Bellan-Santini & Kaim-Malka, 1977				1.31 (1.31)	2.64 (1.51)	0.10 (0.07)	77
	12	10	10	*Ampelisca sarsi* Chevreux, 1888		0.67 (0.67)			0.50 (0.21)		13
		11	11	*Ampelisca spinifer* Reid, 1951				0.92 (0.84)	0.18 (0.14)		16
	13	12	12	*Ampelisca tenuicornis* Liljeborg, 1855	0.33 (0.33)				0.14 (0.14)		5
				Ampelisca truncata Bellan-Santini & Kaim-Malka, 1977					0.04 (0.04)		1
	14	13	13	*Ampelisca typica* (Bate, 1856)	1.50 (0.96)	4.67 (2.73)	0.83 (0.54)	2.15 (1.41)	1.41 (0.62)	0.10 (0.10)	89
				Ampelisca ind.	0.33 (0.21)	0.33 (0.33)	0.83 (0.54)	0.23 (0.17)	0.27 (0.23)	0.26 (0.15)	22
Aoridae		14		*Autonoe rubromaculatus* (Ledoyer, 1973)					0.14 (0.10)		3
	15	15	14	*Autonoe spiniventris* (Della Valle, 1893)	2.33 (1.38)	5.33 (3.93)	0.17 (0.17)	0.31 (0.31)	0.32 (0.17)		42
				Autonoe ind.					0.14 (0.10)		3
		16		*Leptocheirus guttatus* (Grube, 1864)				0.08 (0.08)	0.41 (0.26)		10
		17	15	*Leptocheirus mariae* G. Karaman, 1973					0.14 (0.07)		3
				Leptocheirus pectinatus (Norman, 1869)					0.04 (0.04)		1
		18	16	*Microdeutopus armatus* Chevreux, 1887						0.10 (0.10)	2
Colomastigidae				*Colomastix pusilla* Grube, 1861		0.33 (0.33)					1
Corophiidae				*Corophium acherusicum* A. Costa, 1851		0.33 (0.33)					1
		19	17	*Corophium rotundirostre* Stephensen, 1915			0.17 (0.17)			0.42 (0.42)	9
				Corophium runcicorne Della Valle, 1893	0.17 (0.17)				0.04 (0.04)		2
		20	18	*Siphonoecetes dellavallei* Stebbing, 1899	0.17 (0.17)				0.09 (0.09)		3
Dexaminidae				*Atylus massiliensis* Bellan-Santini, 1975	0.17 (0.17)						1
				Atylus vedlomensis (Bate & West., 1862)	0.17 (0.17)						1
		21		*Dexamine spiniventris* (A. Costa, 1853)				0.23 (0.23)	0.14 (0.14)		6
		22		*Dexamine spinosa* (Montagu, 1813)				0.08 (0.08)	0.18 (0.11)		5
	16			*Guernea coalita* (Norman, 1868)	2.33 (2.14)					0.05 (0.05)	15
Eusiridae				*Apherusa chiereghinii* Giordani-Soika, 1950					0.04 (0.04)		1
				Apherusa vexatrix Krapp-Schickel, 1979					0.04 (0.04)		1
Hyalidae				*Hyale camptonyx* (Heller, 1866)				0.08 (0.08)			1
				Hyale ind.					0.04 (0.04)		1
Isaeidae	17	23	19	*Photis longicaudata* (Bate & West., 1862)		1.33 (1.33)	0.17 (0.17)	0.08 (0.08)	0.04 (0.04)		7
Ischyroceridae				*Ericthonius punctatus* (Bate, 1857)					0.04 (0.04)		1
		24	20	*Jassa marmorata* Holmes, 1903					0.23 (0.11)	0.63 (0.28)	17
Leucothoidae				*Leucothoe lilljeborgii* Boeck, 1861			0.17 (0.17)				1
		25	21	*Leucothoe oboa* G.S. Karaman, 1971				0.15 (0.15)	0.18 (0.14)		6
	18			*Leucothoe serraticarpa* Della Valle, 1893	0.33 (0.21)						2
		26		*Leucothoe spinicarpa* (Abildgaard, 1789)				0.31 (0.24)	0.04 (0.04)		5
				Leucothoe ind.	0.17 (0.17)					0.05 (0.05)	2

Table I. – *(suite)*

Liljeborgiidae		27		*Liljeborgia dellavallei* Stebbing, 1906				0.15 (0.15)			2
Lysianassidae				*Acidostoma nodiferum* Stephensen, 1923			0.17 (0.17)				1
	19	28	22	*Hippomedon massiliensis* Bellan-Santini, 1965	0.50 (0.34)			0.61 (0.54)	0.18 (0.11)		15
	20			*Lepidepecreum longicorne* (Bate & Westwood, 1861)	0.17 (0.17)	0.33 (0.33)					2
		29		*Lysianassa costae* Milne Edwards, 1830				0.38 (0.38)			5
		30		*Lysianassa longicornis* Lucas, 1849				0.23 (0.23)			3
				Lysianassa ind.					0.04 (0.04)		1
		31		*Orchomene humilis* (A. Costa, 1853)				0.23 (0.23)			3
	21			*Orchomenella nana* (Kroyer, 1846)			0.33 (0.21)				2
				Tmetonyx nardonis (Heller, 1866)					0.04 (0.04)		1
Megaluropidae	22			*Megaluropus massiliensis* Ledoyer, 1976	2.83 (2.64)	0.33 (0.33)	0.17 (0.17)				19
Melitidae				*Ceradocus orchestiipes* A. Costa, 1853					0.04 (0.04)		1
				Cheirocratus sundevallii (Rathke, 1843)					0.18 (0.14)		4
				Elasmopus rapax A. Costa, 1853						0.05 (0.05)	1
				Gammarella fucicola (Leach, 1814)					0.04 (0.04)		1
				Maera grossimana (Montagu, 1808)			0.17 (0.17)		0.04 (0.04)		2
				Maera schmidtii Stephensen, 1915						0.05 (0.05)	1
Oedicerotidae	23			*Monoculodes griseus* (Della Valle, 1893)			0.33 (0.33)				2
		32		*Monoculodes subnudus* Norman, 1889					0.14 (0.14)		3
	24			*Perioculodes longimanus longimanus* (Bate & Westwood, 1868)	1.50 (0.92)	1.67 (1.67)			0.04 (0.04)		15
				Pontocrates arenarius (Bate, 1858)	0.17 (0.17)						1
	25			*Synchelidium haplocheles* (Grube, 1864)	0.83 (0.54)						5
		33	23	*Westwoodilla rectirostris* (Della Valle, 1893)					0.04 (0.04)	0.05 (0.05)	2
Phoxocephalidae				*Harpinia antennaria* Meinert, 1890			0.17 (0.17)			0.05 (0.05)	2
		34	24	*Harpinia crenulata* (Boeck, 1871)						0.10 (0.10)	2
	26	35	25	*Harpinia dellavallei* Chevreux, 1910		0.33 (0.33)	1.00 (0.68)	0.31 (0.24)	0.36 (0.18)		19
	27			*Harpinia truncata* G.O. Sars, 1891			0.50 (0.34)				3
				Harpinia ind.		0.33 (0.33)					1
	28			*Metaphoxus fultoni* (Scott, 1890)	2.33 (2.14)	0.33 (0.33)	0.17 (0.17)				16
	29			*Metaphoxus simplex* (Bate, 1857)		0.33 (0.33)	0.33 (0.33)			0.05 (0.05)	4
				Paraphoxus oculatus (G.O. Sars, 1879)			0.17 (0.17)				1
Pontoporeiidae	30	36	26	*Bathyporeia guilliamsoniana* (Bate, 1857)	2.00 (0.93)	0.33 (0.33)		0.08 (0.08)	0.23 (0.15)		19
	31			*Bathyporeia* cfr. *megalops* Chevreux, 191	0.50 (0.22)						3
				Bathyporeia ind.		0.33 (0.33)	0.17 (0.17)		0.04 (0.04)		3
Urothoidae		37		*Urothoe elegans* Bate, 1857					0.04 (0.04)	0.05 (0.05)	2
	32	38	27	*Urothoe grimaldii* Chevreux, 1895	5.00 (2.56)				0.82 (0.45)		48
	33	39	28	*Urothoe pulchella* (A. Costa, 1853)	6.67 (2.43)			0.46 (0.31)	1.27 (1.00)		74
				Urothoe ind.	0.67 (0.33)		0.17 (0.17)		0.04 (0.04)		6
Caprellidae				*Caprella acanthifera* Leach, 1814					0.04 (0.04)		1
				Pseudolirius kroyerii (Haller, 1879)	0.17 (0.17)						1
Phtisicidae		40		*Phtisica marina* Slabber, 1769			0.17 (0.17)	0.08 (0.08)	0.04 (0.04)		3
				Amphipoda ind.	0.17 (0.17)						1
Palaemonidae				*Palaemonetes antennarius* (H. Milne Edwards, 1837)					0.04 (0.04)		1
Alpheidae		41		*Alpheus dentipes* Guérin-Méneville, 1832				0.15 (0.15)	0.04 (0.04)		3
	34	42	29	*Alpheus glaber* (Olivi, 1792)			0.83 (0.40)		0.04 (0.04)	0.26 (0.10)	11
		43		*Athanas nitescens* (Leach, 1814)				0.23 (0.23)	0.04 (0.04)		4
Hippolytidae				*Hippolyte longirostris* (Czerniavsky, 1868)					0.04 (0.04)		1
		44		*Thoralus cranchii* (Leach, 1817)				0.38 (0.38)	0.09 (0.06)		7
Processidae		45	30	*Processa canaliculata* Leach, 1815				0.08 (0.08)	0.27 (0.13)		7
		46	31	*Processa edulis* (Risso, 1816)				0.23 (0.12)	0.04 (0.04)	0.05 (0.05)	5
Crangonidae				*Aegaeon cataphractus* (Olivi, 1792)		0.33 (0.33)					1
				Philocheras monacanthus (Holthuis, 1961)					0.04 (0.04)		1
				Philocheras ind.					0.09 (0.06)		2
Callianassidae		47	32	*Callianassa subterranea* (Montagu, 1808)		0.33 (0.33)		0.23 (0.23)	0.09 (0.06)	0.21 (0.16)	10
				Callianassidae ind.					0.04 (0.04)	0.05 (0.05)	2
Upogebiidae				*Upogebia deltaura* (Leach, 1815)						0.05 (0.05)	1
		48		*Upogebia pusilla* (Petagna, 1792)					0.09 (0.06)		2
Scyllaridae				Scyllaridae ind.						0.05 (0.05)	1
Diogenidae	35			*Diogenes pugilator* (Roux, 1829)	2.50 (1.18)	0.33 (0.33)					16
Paguridae	36			*Anapagurus laevis* (Bell, 1846)			1.50 (1.50)	0.08 (0.08)	0.04 (0.04)		11
	37	49	33	*Anapagurus serripes* (Hope, 1851)			0.33 (0.33)	0.08 (0.08)	0.09 (0.06)		5
				Anapagurus ind.					0.23 (0.09)		5

Table I. – *(suite)*

				Cestopagurus timidus (Roux, 1830)					0.04 (0.04)		1
				Pagurus prideauxi Leach, 1815						0.05 (0.05)	1
				Pagurus ind.						0.10 (0.07)	2
Galatheidae				*Galathea bolivari* Zariquiey Alvarez, 1950					0.04 (0.04)		1
Porcellanidae				*Pisidia longimana* (Risso, 1816)				0.08 (0.08)			1
Leucosiidae				*Ebalia edwardsii* O.G.Costa, 1838					0.04 (0.04)		1
Majidae				*Macropodia linaresi* Forest & Zariquiey Alvarez, 1964				0.08 (0.08)			1
				Macropodia rostrata (Linnaeus, 1761)		0.33 (0.33)					1
Parthenopidae				*Parthenope angulifrons* Latreille, 1825				0.08 (0.08)			1
Pirimelidae		50		*Sirpus zariquieyi* Gordon, 1953				0.08 (0.08)	0.04 (0.04)		2
Portunidae		51	34	*Liocarcinus maculatus* (Risso, 1827)				0.15 (0.15)		0.05 (0.05)	3
	38			*Liocarcinus vernalis* (Risso, 1816)	0.33 (0.33)	0.33 (0.33)		0.08 (0.08)			4
				Liocarcinus ind.	0.33 (0.21)	1.00 (0.00)					5
Goneplacidae		52	35	*Goneplax rhomboides* (Linnaeus, 1758)					0.09 (0.09)	0.05 (0.05)	3
Xanthidae				*Pilumnus spinifer* H. Milne Edwards, 1834				0.08 (0.08)			1
				Decapoda ind.		0.33 (0.33)	0.17 (0.17)				2
				Tot. Ab.	313	211	83	811	692	110	2220

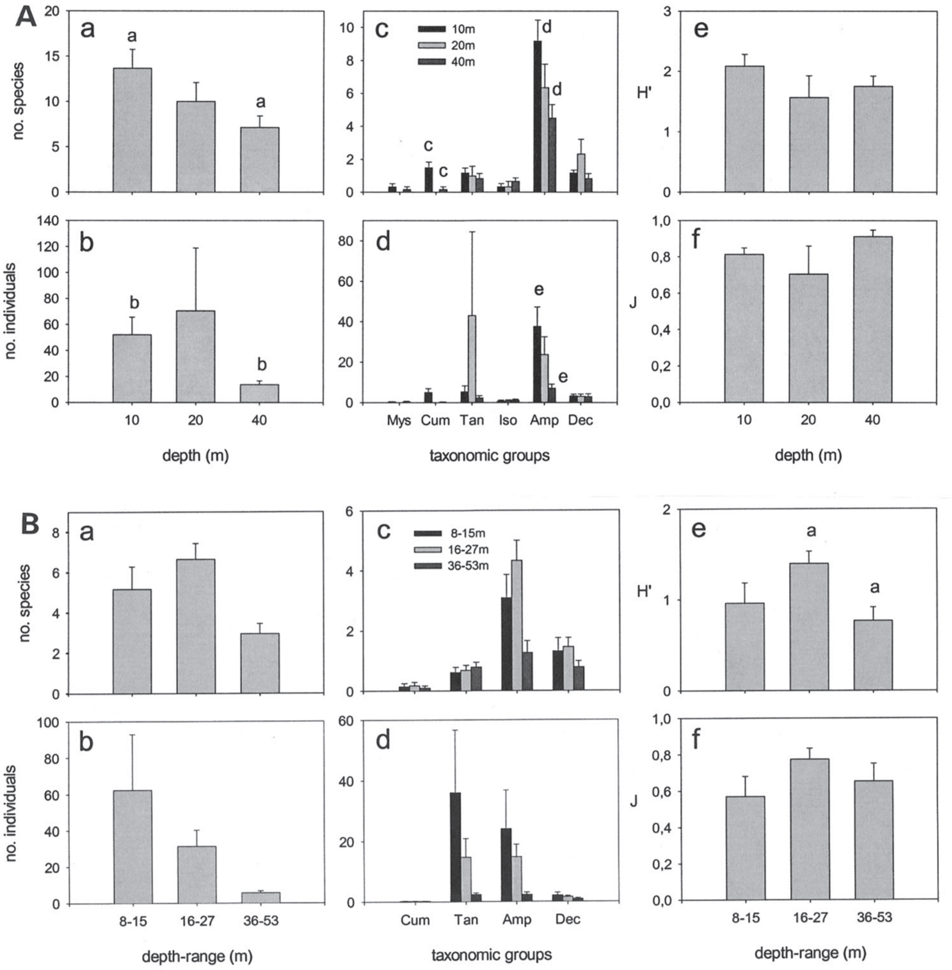

Fig. 2. – A, Area I. Mean values (± SE) of species richness and abundances of the whole studied fauna (a, b) and the single taxonomic groups (c, d), and of diversity (e) and evenness (f) of the whole fauna, at the three depths. Mys: Mysidacea; Cum: Cumacea; Tan: Tanaidacea; Iso: Isopoda; Amp: Amphipoda; Dec: Decapoda. Pairs of letters from a to e show the statistically significant differences found: a ($p = 0.024$), b ($p = 0.019$), c ($p = 0.006$), d ($p = 0.011$), e ($p = 0.010$). B, Area II. Mean values (± SE) of species richness and abundances of the whole studied fauna (a, b) and the single taxonomic groups (c, d), and of diversity (e) and evenness (f) of the whole fauna, at the three depth-ranges. Cum, Tan, Amp, Dec: see above. Pair of letters show the statistically significant differences found: a ($p = 0.003$).

Table II. – Top, Mean values (± SE) of diversity (H') of sediments (granulometric fractions) in Area I at each depth, in Area II at each depth-range, and in each sub-area (A-E) on the whole and at the three depth-ranges. Pairs of letters from a to h show the statistically significant differences found: a (p = 0.014), b (p ⩽ 0.001), c (p = 0.035), d (p = 0.016), e (p ⩽ 0.001), f (p = 0.004), g (p = 0.042), h (p = 0.042). Bottom, Area II. Total abundances of the dominant species, listed according to the numerical dominance of families, in each sub-area at the three depth-ranges (n = no. of stations). Species are numbered as in Table I, column B.

	Area I	Area II	A	B	C	D	E
Total			0,87 (0,04)	0,84 (0,08)	0,56 (0,08)	0,44 (0,09)	0,61 (0,11)
I	0,16 (0,02) **a**	0,49 (0,08) **b**		0,57 (0,17)	0,44 (0,10)	0,57 (0,21)	0,15 (0,00)
II	0,57 (0,26)	0,58 (0,08)	0,91 (0,03) **d e**	0,89 (0,12)	0,55 (0,08) **d f**	0,24 (0,03) **e f**	0,41 (0,19) **c**
III	0,96 (0,03) **a**	0,85 (0,05) **b**	0,83 (0,06)	1,01 (0,02) **g h**	0,95 (0,00)	0,62 (0,18) **g**	0,87 (0,06) **c h**

	depth-range	8-15m					16-27m					36-53m				
	sub-areas	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Families	Species n	2	5	3	2	1	4	5	3	5	5	4	5	1	4	5
Apseudidae	3, 4, 5	1	464	4			92	220	9	2	2	6	22		6	10
Ampeliscidae	7, 9, 13, 11, 6, 10, 8, 12		250	9			8	163	15		1		1			7
Urothoidae	39, 38		1		4	1				39	7					
Lysianassidae	28, 29, 30, 31	11	8					4								
Aoridae	15, 16	1	4				3			10	3					
Ischyroceridae	24						1	2			2	1	2		1	8
Phoxocephalidae	35		4					6	2							
Leucothoidae	25, 26	3	3					1	3	1						
Callianassidae	47	3								1	1	1				3
Corophiidae	19												8			
Hippolytidae	44	5					1				1					
Dexaminidae	21	3								3						
Pontoporeiidae	36				1					2	3					

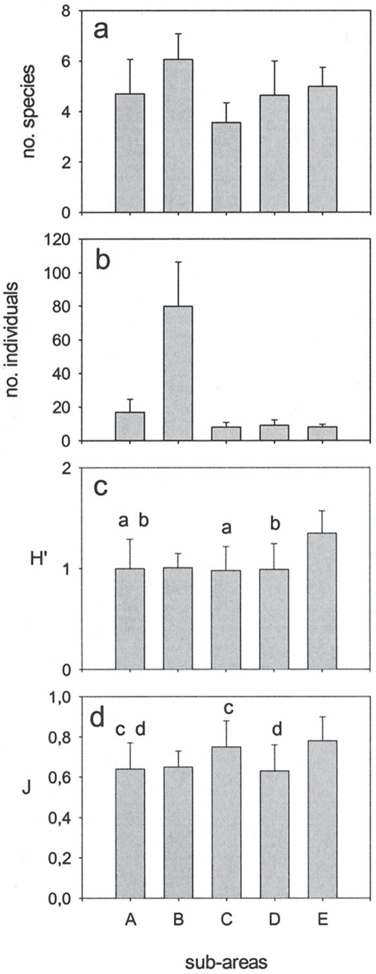

Fig. 3. – Area II. Mean values (± SE) of species richness (a), abundances (b), diversity (c) and evenness (d) in the considered sub-areas (A-E). Pairs of letters from a to d show the statistically significant differences found: a (p = 0.006), b (p = 0.002), c (p = 0.006), d (p = 0.002).

the depth (Table II), sometimes, being dominant only in single sub-areas.

Statistical analysis

Area I

Sediments: Correspondence Analysis (CA) was performed on 15 stations (observations) and on the percentage of sand, silt and clay (variables). In the ordination model related to the first two axes, the stations of 10 and 20 m, which are very close to each other, are localized near the sand-point, and those of 40 m, which are more scattered, are localized near the silt- and clay- points. Only the station 1C (20 m) is in the space where the 40 m stations are localized (Fig. 4).

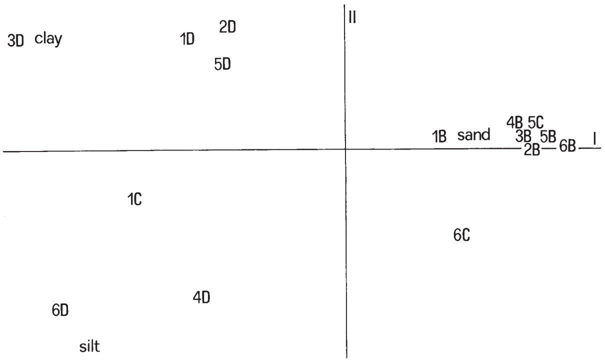

Fig. 4. – Area I: Sediments. Ordination model of the Correspondence Analysis based on 15 stations and the three granulometric fractions. The axes account for the 83.3% (I) and the 16.7% (II) of the total variance; axis I is significant for values higher than 61.1%. Station-points: 1B – 6D (see Fig. 1b).

Fauna: CA was performed on 15 stations (observations) and a reduced number of species (38) (variables), eliminating those present with only one individual. This kind of analysis allows to plot simultaneously in the factorial space both station– and species-points, but to have a more readable graphic representation they are figured separately (Fig. 5a, b). In the plane of the first two axes, the station-points are located according to the depth-gradient. In particular, most of the 10 m stations (B) are located in a close position (cluster B), while the 40 m stations (D) are located in a scattered position (clusters C1 and C2). The 20m stations (C) are located in proximity of the shallower stations, with the exception of transect 1. The stations of this transect, which is situated in front of the River Fiora, are very close in the factorial space, and all toward the 40 m stations.

The correlations found between the studied parameters are given in Table III.

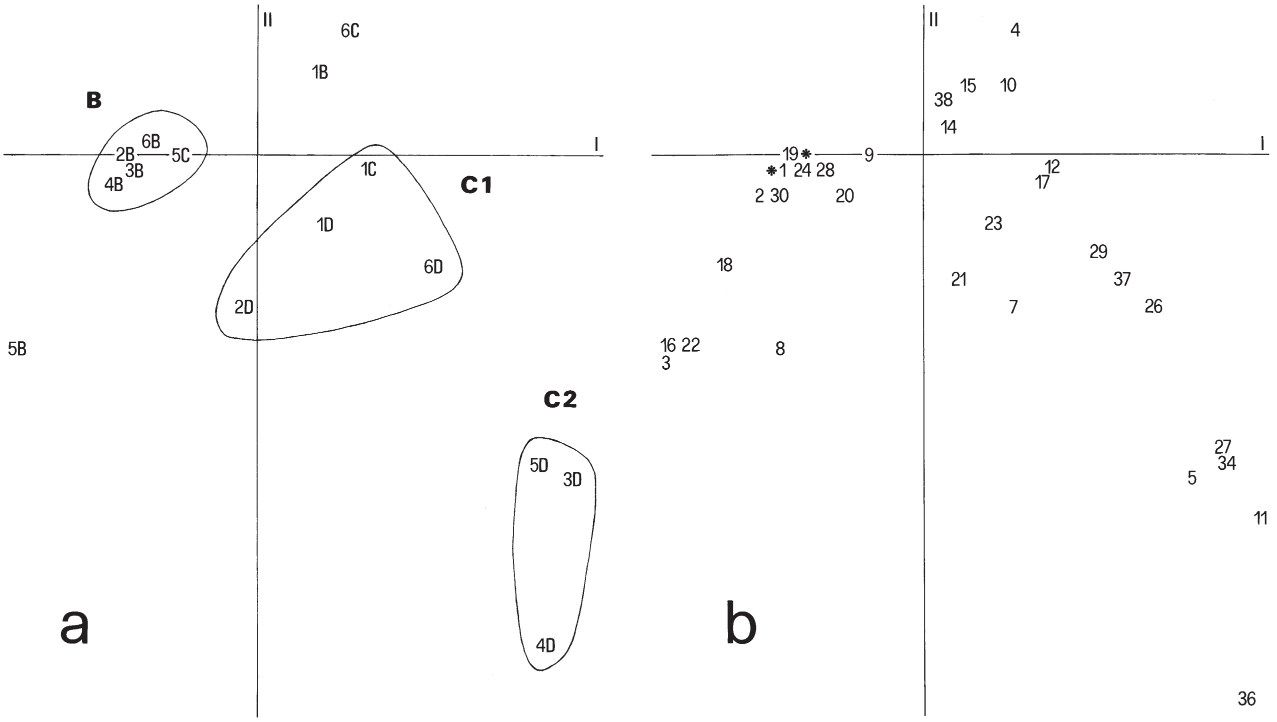

Fig. 5. – Area I: Fauna. Ordination model of Correspondence Analysis based on 15 stations and 38 species. The axes account for the 15.8% (I) and the 14.8% (II) of the total variance; both are significant for values higher than 11.1% and 11.3%, respectively. a: station-points (see Fig. 1b). b: species-points (see Table I, column A). Points marked by an asterisk are multiple-points: the species-point 1 covers points 6 – 13 – 31 – 35, and 19 covers 25 – 32 – 33.

Table III. – Correlation coefficients (r) (and probability, p) between population and sediment parameters. Significant coefficients are indicated in bold character. ***: p<0.001 (very highly significant); **: p<0.01 (highly significant); *: p<0.05 (significant); n.s.: not significant. a: Area I; b: Area II.

		Ab	H'	J	AxI	AxII	depth	sand	silt	clay	AxI sed.	H' sed.
NS	r	**0,783**	**0,789**	-0,128	-0,501	0,331	**-0,638**	0,375	-0,254	-0,509	0,366	-0,328
	p	0,00 ***	0,00 ***	0,639 n.s.	0,0556 n.s.	0,219 n.s.	0,00988**	0,162 n.s.	0,353 n.s.	0,0517 n.s.	0,176 n.s.	0,224 n.s.
Ab	r		0,273	**-0,648**	-0,404	**0,552**	**-0,691**	0,436	-0,172	**-0,681**	0,449	-0,370
	p		0,312 n.s.	0,00832 **	0,131 n.s.	0,0312 *	0,00409**	0,101 n.s.	0,532 n.s.	0,00471 **	0,0889 n.s.	0,167 n.s.
H'	r			0,414	-0,321	-0,0821	-0,293	0,1000	-0,161	-0,114	0,0857	-0,0859
	p			0,120 n.s.	0,235 n.s.	0,763 n.s.	0,281n.s.	0,714 n.s.	0,558 n.s.	0,676 n.s.	0,753 n.s.	0,753 n.s.
J	r				0,306	**-0,529**	**0,554**	**-0,513**	0,227	**0,713**	**-0,548**	0,411
	p				0,257 n.s.	0,0413 *	0,0312*	0,0480 *	0,403 n.s.	0,00235 **	0,0325 *	0,124 n.s.
AxI	r					-0,414	**0,811**	**-0,879**	**0,883**	**0,682**	**-0,861**	**0,856**
	p					0,120 n.s.	0,00***	0,00 ***	0,00 ***	0,00471 **	0,00 ***	0,00 ***
AxII	r						**-0,621**	0,496	-0,347	**-0,600**	0,475	-0,476
	p						0,0129*	0,0576 n.s.	0,199 n.s.	0,0175 *	0,0708 n.s.	0,0708 n.s.
depth	r							**-0,794**	**0,717**	**0,794**	**-0,794**	**0,770**
	p							0,00***	0,00215**	0,00***	0,00***	0,00***

a

		Ab	H'	J	AxI	AxII	depth	sand	silt	clay	AxI sed.	H' sed.
NS	r	**0,836**	**0,828**	0,180	0,182	**-0,383**	**-0,324**	0,294	-0,206	**-0,400**	**0,316**	-0,0509
	p	0,00***	0,00***	0,247 n.s.	0,242 n.s.	0,0114*	0,0343*	0,0556 n.s.	0,184 n.s.	0,00805**	0,0392*	0,744 n.s.
Ab	r		**0,517**	-0,0754	0,205	**-0,337**	**-0,341**	0,249	-0,206	**-0,321**	0,260	0,0622
	p		0,00***	0,629 n.s.	0,186 n.s.	0,0272*	0,0254*	0,106 n.s.	0,184 n.s.	0,0357*	0,0916 n.s.	0,690 n.s.
H'	r			**0,553**	-0,0103	-0,193	-0,138	0,248	-0,153	**-0,312**	0,272	-0,124
	p			0,00***	0,947 n.s.	0,213 n.s.	0,377 n.s.	0,108 n.s.	0,326 n.s.	0,0417*	0,0774 n.s.	0,427 n.s.
J	r				0,0547	0,156	0,177	-0,0435	0,0944	0,0443	-0,0279	-0,0278
	p				0,726 n.s.	0,315 n.s.	0,254 n.s.	0,781 n.s.	0,545 n.s.	0,777 n.s.	0,858 n.s.	0,859 n.s.
AxI	r					-0,0702	-0,0354	**-0,332**	**0,400**	0,207	**-0,329**	**0,409**
	p					0,653 n.s.	0,821 n.s.	0,0300*	0,00810**	0,182 n.s.	0,0312*	0,00663**
AxII	r						**0,693**	**-0,602**	**0,482**	**0,693**	**-0,618**	**0,505**
	p						0,00***	0,00***	0,00115**	0,00***	0,00***	0,00***
depth	r							**-0,520**	**0,416**	**0,628**	**-0,528**	**0,432**
	p							0,00***	0,00570**	0,00***	0,00***	0,00399**

b

Area II

Sediments: The ordination model of CA is related to 43 stations; these are the same utilized in the model for the analysis of fauna obtained eliminating the stations closely related to seagrasses and rocky bottoms, and where the samples for sediment analysis were not collected (see below). In the model (Fig. 6), the sand-point is localized, as in Area I, in the positive space of axis I, while the silt- and clay-points are in the negative space. Station-points are obviously ordered according to the percentage of their granulometric fractions but not always according to depth.

Fauna: The ordination model of CA is related to 51 stations and 52 species. A selected number of observations and variables were utilized. Station 55C, which is characterized only by an indeterminate individual, stations 8A and 12A, which showed in a preliminary analysis a very eccentric position in the factorial space, and species present with only one individual were eliminated. In the plane of the first two axes, station- and species-points are ordered according to depth and/or substratum (Fig. 7a, b). Different clusters can be identified:

– cluster A, represented by 6 stations from 12 to 27 m (mean depth: 18.33 m ± 2.12 SE) (Table IV), belonging to the I and II depth-ranges, all very close to seagrass meadows and rocky banks;

– cluster B, with 7 stations from 8 to 23 m (16.00 m ± 2.01) (I and II depth-ranges) all localized in sub-areas D and E, south of Torre Astura; the station 31B (22 m), south of Torre Astura, is in an isolated position between clusters A and B;

– cluster C, with stations very close to each other, and which can be divided into two sub-clusters (see dotted line): – on the right are 16 stations (cluster Cr) situated from 12 to 23 m (17.60 m ± 1.05) (I and II depth-ranges) only from Torre Astura toward North (sub-areas A, B, C), with the

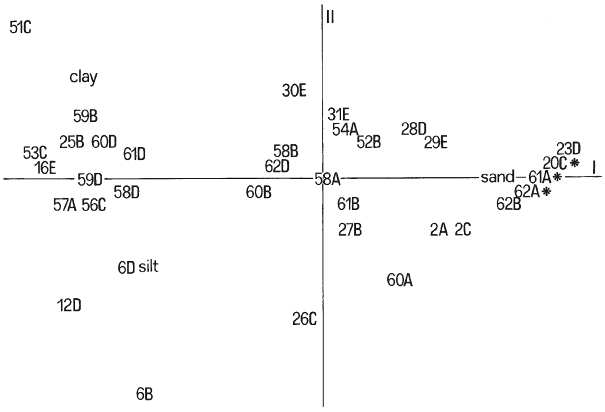

Fig. 6. – Area II: Sediments. Ordination model of Correspondence Analysis based on a reduced number of stations (43) and the three granulometric fractions. The axes account for the 89.7% (I) and the 10.3% (II) of the total variance; the axis I is significant for values higher than 61.1%. Station-points: 52B – 32B (see Fig. 1c, d, e, f). Points marked by an asterisk are multiple-points: the station-point 20C covers points 28B – 32B, 61A covers 5A – 16B – 22B – 25A, and 62A covers 7A – 19A.

exception of station 27B (24 m), which is in front of the River Sisto; – on the left are 14 stations (cluster Cl) situated all along the coast considered, from 40 to 52 m (44.61 m ± 1.16) (III depth-range), with the exception of the shallower station 52B (26 m) which is in front of the River Marta; the isolated stations of 5A and 61A, both localized at the I depth-range (11 and 9 m, respectively), but in front of Anzio and Fregene harbour and/or town, could also belong to cluster C;

– cluster D with 5 stations from 36 to 53 m (45.80 m ± 2.99) (III depth-range), localized south of Anzio (sub-areas C, D and E), with the exception of 56C.

On the grounds of the results achieved by the above-described model, a new analysis was performed aiming at clarifying the spatial representation of some station-points which are often superimposed, mainly in correspondence to the center of the axes. Therefore the stations belonging to cluster A, the station 31B, the station 59A, where sediments data are not available, and moreover species present with one individual were eliminated. Thus, the new analysis was performed on 43 stations and 35 species. In the ordination model based on the first two axes (Fig. 8a, b), cluster B is again clearly disjuncted from the other stations, which are localized along axis II in a sort of continuum. However,

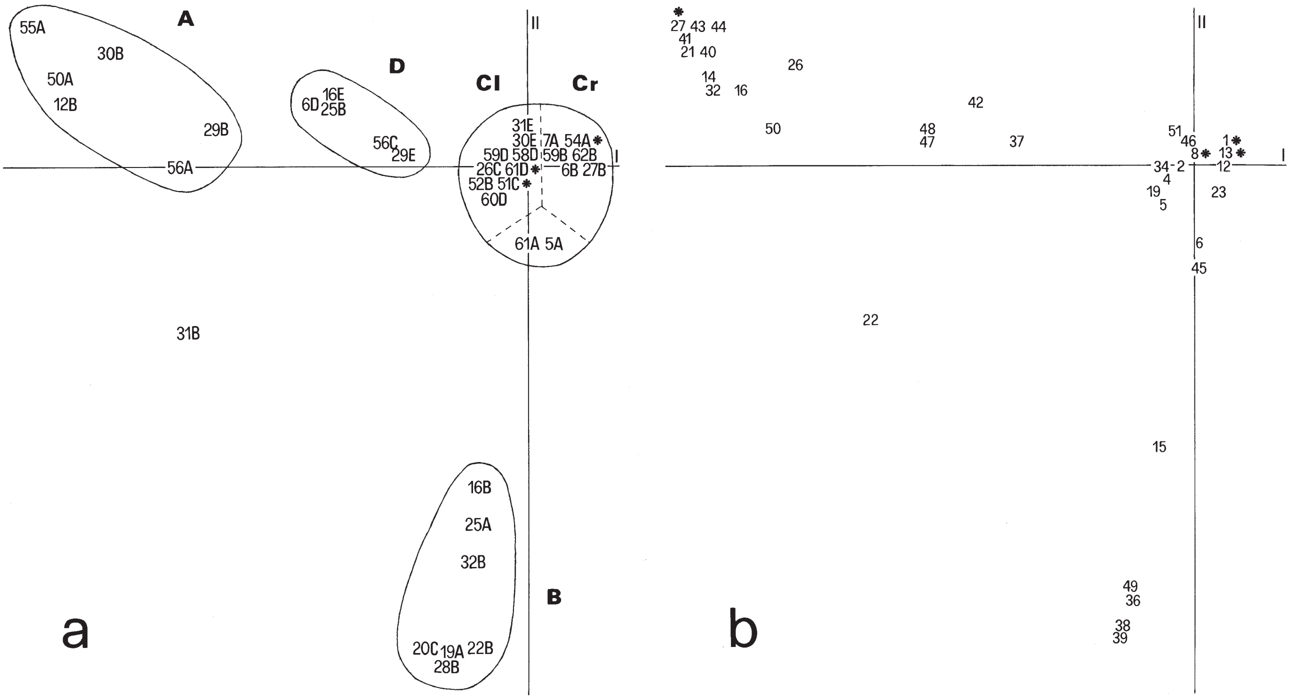

Fig. 7. – Area II: Fauna. Ordination model of Correspondence Analysis based on 51 stations and 52 species. The axes account for the 9.8% (I) and the 9.4% (II) of the total variance; both are significant for values higher than 8.7% and 8.9%, respectively. a: station-points (see Fig. 1c, d, e, f). Points marked by an asterisk are multiple-poins: the station-point 61D covers points 23D – 28D, 51C covers 53C – 62D – 12D, and 54A covers 57A – 58A – 58B – 59A – 60A – 60B – 61B – 62A – 2A – 2C. b: species-points (see Table I, column B). The species-point 1 covers points 3 – 7 – 9 – 10 – 11 – 20 – 28 – 35, 8 covers 18 – 24 – 33, 13 covers 17 – 25 – 52, and 27 covers 29 – 30 – 31.

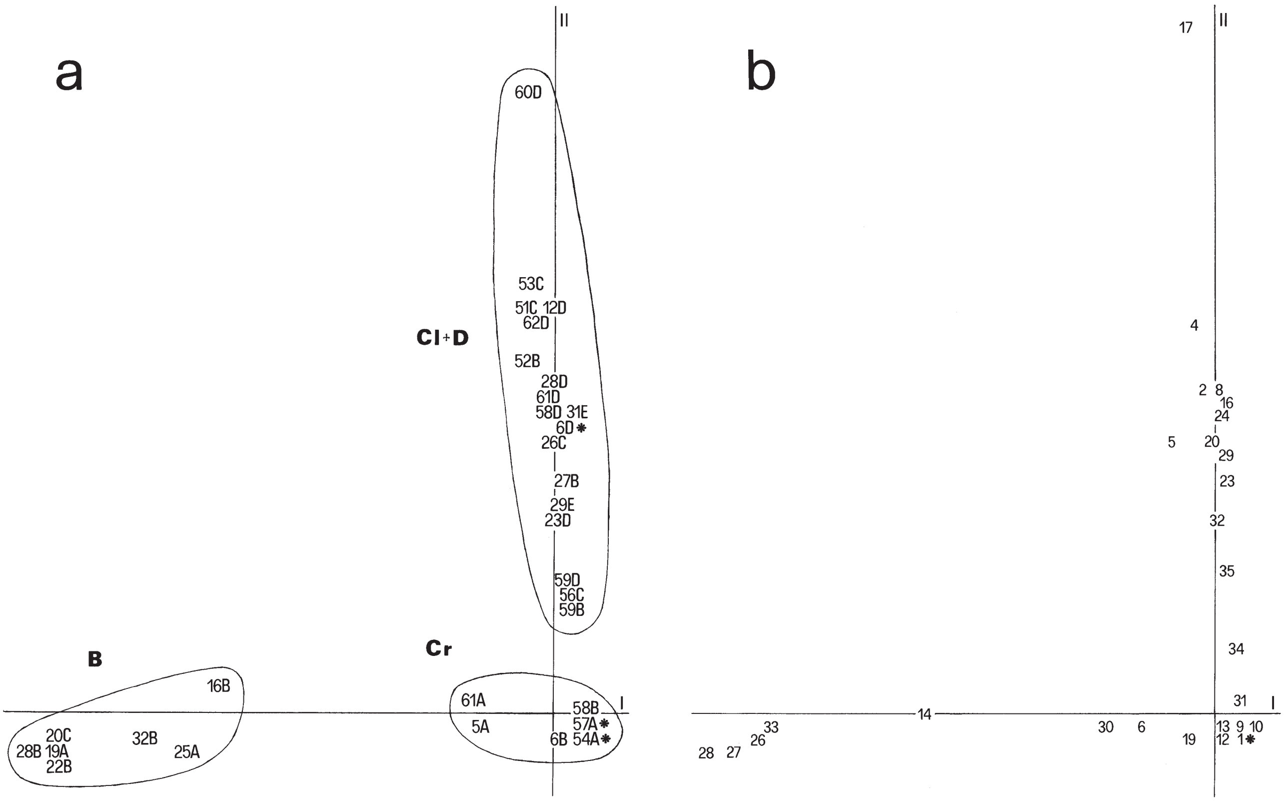

Fig. 8. – Area II: Fauna. Ordination model of Correspondence Analysis based on a reduced number of stations, 43, and 35 species. The axes account for the 13.0% (I) and the 11.9% (II) of the total variance; the axis I is significant for values higher than 11.8%. a: station-points (see Fig. 1c, d, e, f). Points marked by an asterisk are multiple-points: the station-point 54A covers points 58A – 60A – 60B – 61B – 62A – 2C, 57A covers 62B – 2A – 7A, and 6D covers 16E – 25B – 30E. b: species-points (see Table I, column C). The species-point 1 covers points 3 – 7 – 11 – 15 – 18 – 21 – 22 – 25.

a more homogeneous group of stations can be distinguished at the center of the axes. This is represented by the same stations which constituted cluster Cr in the previous model. Furthermore, another group can be identified along the positive branch of axis II, represented by almost all the deeper stations (cluster Cl and cluster D of the previous model); in fact, only three stations of the II depth-range are present; among these, 52B and 27B, which are in front of the Rivers Marta and Sisto, respectively.

The correlations found between the studied parameters are given in Table IIIb.

DISCUSSION

The studied macrofaunal crustaceans are on the whole well represented, although each taxonomic group is characterized by different values of species richness and abundance. Among peracarids, amphipods confirm their important leading role in defining the structure of assemblages; all along the considered gradients, they are dominant, mainly as concerns species richness, as also stressed in other environments such as hard bottoms (Conradi *et al.* 2000), seagrass systems (Mazzella *et al.* 1989), maerl beds (De Grave 1999) and estuaria (Sanchez-Mata *et al.* 1993). Due to their wide ecological and functional spectrum (e.g. Scipione 1989, Krapp-Schickel 1993, Bellan Santini 1998), they may play a key-role in coastal benthos.

Regarding to the differences found at the level of the examined taxonomic groups, it should be taken into account that the sampling method used may have in some cases a different efficiency in collecting the various taxonomic groups. In fact, in soft bottoms, some groups, due to the multiplicity of their adaptations (e.g. way of life characteristically suprabenthic, migratory activity, patchy distribution of populations, different mobility also related to size), may be better sampled, for example, by suprabenthic sledge (Cunha *et al.* 1999), modified Macer-GIROQ sledge (Dauvin *et al.* 2000), Charcot dredge (Maggiore *et al.* 1983-84, Minervini *et al.* 1983-84), bottom trawl (Minervini *et al.* 1982) or artificial-light epibenthic trap (Corbera & Garcia-Rubies 1998).

In this study, both sampling devices used (notwithstanding in some cases they might have underestimated assemblage consistency) showed their efficiency in describing the same zonation patterns, also in comparison to previous results, for example, by Charcot dredge (Fresi *et al.* 1983). The methods, besides the different volumes analysed and the different coastal extent sampled in the two areas, might be in part responsible for the differences found at the level of some community parameters. In fact, the hydraulic grab utilized in Area I might have resulted in a higher number of species and individuals collected per station, in spite of the lower number of samples analysed. On the other hand, the larger coastal area taken into account for the sampling strategy in Area II allowed to point out a higher total species richness due to the presence of more various bottom-types and habitats.

Peracarid and decapod fauna was clearly depth-zoned, and showed different coenotic units at the first and second depth-ranges considered (infralittoral zone), characterized by a horizontal zonation along the coast in relation to various environmental conditions. A discontinuity between the above-mentioned identified units and that localized at the third examined depth-range (upper circalittoral zone) was almost constantly present in the coastal areas considered. Below this discontinuity the studied fauna was distributed according to a sort of continuum with depth and evenly along the coast.

A general trend along the depth-gradient is the gradual impoverishment of assemblages towards the depth, at the third depth-level, both for number of species and, mainly, individuals, which is accompanied by a slight decrease of diversity (H') and increase of evenness (J). This seems to be a pattern occurring in soft bottoms according to an increase of the finest fractions in the sediment (Fresi *et al.* 1983, Karakassis & Eleftheriou 1997) and in relation to decreasing habitat heterogeneity (Sanders 1968, Biernbaum 1979), as observed in different areas for crustacean amphipods (Falciai & Spadini 1985, Diviacco & Somaschini 1994) and decapods (Minervini *et al.* 1983-84), and for molluscs (Russo & Fresi 1983-84). This trend is confirmed in the present study for peracarids and decapods by the negative correlations found between species richness, abundances, diversity (H'), and the clay-fraction.

The irregular trends of population parameters observed at the intermediate depth-range, and the absence in some cases of significant differences between this depth-level and the other two, also as concerns sediment diversity, seem to indicate the presence of a transition zone. This zone may represent an "ecotone", where an overlapping of forms from different assemblages is present, determining the highest species richness and diversity values according to the concept of "margin effect" (Odum 1971). This trend is clearly identifiable in Area II; on the contrary, in Area I, because of the few sampled stations at this depth (20 m), different trends were observed, as shown by lower H' values and a higher variability of abundances. In fact, the highest values of abundance are due only to the tanaid *Apseudes acutifrons*, probably for the presence, at one station, of plant detritus (Tomassetti & Chimenz Gusso 1998).

The Correspondence Analysis allowed to identify, along the studied gradients, different coenotic units which may be attributed in a more or less evident way to the typical soft-bottom assemblages earlier described for the Mediterranean Sea (Pérès & Picard 1964, Picard 1965, Pérès 1967, 1982, Bellan-Santini 1985).

In particular, the following was recognized:

– A coenotic unit well structured and characterized by an important presence of forms from hard bottoms and seagrasses (cluster A; Fig. 7). This is localized in Area II in various spots along the coast in proximity of *Posidonia oceanica* meadows and rocky banks at the I and II depth-levels, mainly in sub-areas A and E. This coenotic unit is characterized by the highest mean values of number of species, diversity and evenness (Table IV). Of all the 38 species found at the stations which belong to this cluster, 31 are exclusive, contributing to determine the clear biocoenotic identity of this coenotic unit in comparison to the other assemblages found. In Table V the species belonging to the clusters and the groups of stations identified by Correspondence Analysis (Fig. 5b, 7b) are listed in relation to their ecology according to the main literature (e.g. Bellan Santini 1998). Many species found have a wider ecological spectrum, living in almost all infralittoral and circalittoral bottom-types to muddy sediments. This feature may be reconducted to the co-existence of a great amount of micro-habitats due to the presence, on a sandy matrix, of elements deriving from neighbouring bottoms as coarse sediment and gravels from hard substrata, fine sediment entrapped by *Posidonia oceanica*, plant detritus or floating algae (Toulmond 1964). Therefore, notwithstanding the biocoenotic identity observed, this coenotic unit may hardly be attributable to a well-defined assemblage although being similar to that of coarse sand and gravel exposed to bottom currents (SGCF) (Somaschini *et al.* 1998) and to coastal detritic (DC) (Bellan Santini 1998). As pointed out by Ledoyer (1968), the SGCF assemblage is generally well-defined and important from a qualitative point of view, but can present a strong affinity with the deeper DC, usually enriched by a finer fraction in the sediment.

– A coenotic unit which may be attributable to the assemblage of fine well sorted sands (SFBC) represented by cluster B in Areas I and II, and by st. 5B in Area I (Fig. 5, 7, 8). This is clearly disjuncted from the other coenotic units and is located at the I and II depth-levels, at a deeper main depth in Area II (Table IV). In Area I, this coenotic unit extends all along the coast with the exception of the area in front of the River Fiora (transect 1), while in Area II it is present only in sub-areas D and E, in front of Caprolace and Sabaudia, and Lungo coastal lakes, respectively. Of all the 37 species found, 22 are exclusive. In Area I, this coenotic unit is characterized by higher values of population parameters (Table IV) with a total number of species more than three times higher than in Area II. This is also due to the presence of forms characterized by a wider granulometric spectrum or related to plant substrata (Table V). Extended *Posidonia oceanica* meadows with their upper limit at about 10 m depth (Diviacco *et al.* 2001) represent a constraint for bathymetric extension of this coenotic unit, determining also the presence of a finer fraction (% clay) in the sediment (Table IV); this allows the occurrence of the above-mentioned species which superimpose to the more typical forms of SFBC assemblage, producing a transition coenotic unit which has been defined as "sables fins organogènes" (Ledoyer 1968). In Area II, the absence of *P. oceanica* in correspondence to the sampled stations (Diviacco *et al.* 2001) determines the presence of a purer coenotic unit and its deeper extension (Picard 1965, 1983). In Area I the rocky coast in correspondence to transect 5 is responsible for the position in the ordination model of st. 5B and st. 5C. At 10 m depth notwithstanding the higher content of the sandy fraction, probably a gravel component, deriving from the rocky bottoms, determines also the co-existence of species typical of SGCF and plant substrata, mixed and muddy sediments (Table V).

– A coenotic unit typical of "mixed sediments" at the I and II depth-levels, present only in sub-areas A, B, C of Area II (cluster Cr; Fig. 7, 8). This is characterized by the highest mean number of individuals and a relatively high number of species (Table IV). Of all the 30 species found, 15 are exclusive. The above-mentioned sub-areas, and in particular sub-area B, are clearly influenced by the River Tevere run-off, as shown by the values of population parameters and as previously stressed for the whole fauna (Falciai *et al.* 1983). In fact, the prevailing water-current regime in the vicinity of the river mouth directs north-westward both inorganic and organic inputs (Millot 1987), which determined higher values of the finer fraction, and increased particulate organic matter with higher productivity (Pérès 1982). A peculiar feature that characterizes this coenotic unit and that does not occur in the other coastal zones studied (Tables I, II) is the co-existence of many *Ampelisca* species (8 of the 10 identified) and their high abundances, accounting for the 34.02% of the whole coenotic unit. This feature is recorded in coastal detritic bottoms (Kaim-Malka 1969, Bellan-Santini 1983) and in presence of a high content of suspended matter (Bellan-Santini & Dauvin 1988). Although only *Ampelisca diadema*, *A.* cfr. *ruffoi* and *A. typica* were represented by dense populations (92.06% of the whole *Ampelisca* species found), their presence in sintopy might be related to the stability of populations (Dauvin *et al.* 1993). The other species, as *Ampelisca sarsi*, *A. tenuicornis*, *A. spinifer* and *A. truncata*, which, in the order, prefer progressively muddy sediments, although represented by more rarefied populations, are exclusive of this coenotic unit in this area, and their abundances seem to be connected to their major or minor affinity to muddy content in the sediment (Bellan-Santini 1983). Together with the *Ampelisca* species the bulk is constituted by *Apseudes acutifrons* (60.89%), which usually presents its highest densities in mixed sediments (Maggiore *et al.* 1983-84, Tomassetti & Chimenz 1998) (Table V).

In Area II in front of the urban settlements of Fregene and Anzio (st. 61A and 5A), notwithstanding the very shallow depth (9 m–11 m) and the granulometric composition of the sediment similar to those of cluster B (Table IV), a pure assemblage of SFBC cannot be recognized. The urban impact and its effluents, probably with a high content of organic matter, determine higher mean values of

Table IV. – Mean values (± SE) per station of parameters related to the clusters and the groups of stations identified in the ordination models of Correspondence Analysis in Area I (Fig. 5) and in Area II (Fig. 7).

Clusters and stations	no. st.	depth (m)	sand (%)	silt(%)	clay (%)	H' sed.	Tot. sp.	no.species	abundances	H'	J
					Area I						
5B + Cluster B	6	11,67 ± 1,67	96,87 ± 0,62	1,55 ± 0,30	1,58 ± 0,47	0,16 ± 0,02	33	13,5 ± 2,20	47,83 ± 14,95	2,12 ± 0,17	0,84 ± 0,02
1B - 6C	2	15,00 ± 5,00	84,85 ± 1,25	9,45 ± 3,55	5,70 ± 4,80	0,49 ± 0,05	13	9,00 ± 2,00	103,00 ± 64,00	1,15 ± 0,19	0,54 ± 0,14
Cluster C1	4	35,00 ± 5,00	40,60 ± 5,89	20,00 ± 8,01	39,40 ± 2,33	0,98 ± 0,06	24	9,25 ± 2,17	18,75 ± 5,73	1,95 ± 0,21	0,92 ± 0,02
Cluster C2	3	40,00 ± 0,00	39,6 ± 9,62	19,57 ± 6,27	40,83 ± 11,40	0,98 ± 0,04	13	6,33 ± 0,88	13,00 ± 2,08	1,64 ± 0,23	0,89 ± 0,07
					Area II						
Cluster A	6(2)	18,33 ± 2,12	91,60 ± 2,80(2)	5,80 ± 0,20(2)	2,60 ± 2,60(2)	0,33 ± 0,08(2)	38	9,83 ± 1,78	15,83 ± 4,68	2,11 ± 0,15	0,96 ± 0,01
Cluster B	7	16,00 ± 2,01	95,01 ± 1,02	4,99 ± 1,02	0	0,23 ± 0,03	10	4,71 ± 1,13	11,29 ± 4,44	1,08 ± 0,32	0,60 ± 0,16
5A - 61A	2	10,00 ± 1,00	93,50 ± 0,50	6,50 ± 0,50	0	0,29 ± 0,01	9	5,00 ± 1,00	17,00 ± 7,00	1,29 ± 0,35	0,80 ± 0,12
Cluster Cr	16	18,00 ± 1,06	55,79 ± 7,23	30,67 ± 4,71	13,54 ± 3,78	0,76 ± 0,06	30	6,31 ± 0,89	79,44 ± 24,85	1,11 ± 0,15	0,65 ± 0,08
Cluster Cl	14	43,29 ± 1,71	35,39 ± 8,27	35,97 ± 5,34	28,64 ± 4,42	0,84 ± 0,07	23	3,43 ± 0,60	7,64 ± 1,26	0,91 ± 0,16	0,73 ± 0,09
Cluster D	5	45,80 ± 2,99	22,04 ± 13,54	45,44 ± 8,85	32,52 ± 5,86	0,85 ± 0,04	6	2,20 ± 0,73	3,40 ± 1,91	0,58 ± 0,28	0,59 ± 0,24

Table V. – Species belonging to the various clusters and groups of stations identified by Correspondence Analysis. In each cluster and group of stations, species are grouped in relation to their ecology according to the main literature.

Cluster A	Clusters B	Cluster Cr	St. 5A - 61A (Area II)	Clusters C1 - C2 (AI), Cl - D (AII)
photophilic algae and seagrasses	**sandy sediments**	**mixed and muddy sediments**	**sandy sediments:** *Ampelisca brevicornis*; **muddy sediments:** *Processa canaliculata*	**muddy sediments**
Autonoe rubromaculatus, Leptocheirus guttatus, Dexamine spiniventris, Orchomene humilis, Sirpus zariquieyi	*Autonoe spiniventris*, *Bathyporeia guilliamsoniana*, *Urothoe grimaldii*, *U. pulchella*; Area I: *Bodotria pulchella*, *Iphinoe armata*, *Ampelisca brevicornis*, *Metaphoxus fultoni*, *Bathyporeia megalops*, *Diogenes pugilator*	*Ampelisca diadema*, *A*. cfr. *ruffoi*, *A. spinifer*, *Apseudes acutifrons* (mixed sed.)		*Apseudes echinatus*, *Corophium rotundirostre*, *Monoculodes griseus*, *Harpinia dellavallei*, *H. truncata*, *Alpheus glaber*, *Callianassa subterranea*, *Goneplax rhomboides*, *Cirolana neglecta*
photophilic algae + seagrasses + coralligenous bottoms	**wide granulometric spectrum** (Area I)	**wide granulometric spectrum**		**mixed and muddy sediments**
Alpheus dentipes, *Athanas nitescens*, *Thoralus cranchii*	*Ampelisca tenuicornis*, *Hippomedon massiliensis*, *Synchelidium haplocheles*, *Perioculodes longimanus long.*, *Corophium runcicorne*, *Lepidepecreum longicorne*	*Ampelisca sarsi*, *A. typica*, *A. tenuicornis*, *Hippomedon massiliensis*, *Harpinia dellavallei*, *Perioculodes longimanus longimanus*		*Diastylis rugosa*, *Apseudes latreillii*, *Harpinia crenulata*, *H. antennaria*, *Westwoodilla rectirostris*, *Anapagurus laevis* (mixed sed.)
SGCF and plant substrata	**plant substrata** (Area I)	**sandy sediments**	St. 1B - 6C (Area I)	**wide granulometric spectrum**
Dexamine spinosa (st. 31B), *Maera grossimana*	*Leptochelia savignyi*	*Iphinoe tenella*, *Liocarcinus vernalis*	**mixed sediments:** *Apseudes acutifrons*, *Ampelisca diadema* (also muddy sed.); **sandy sediments:** *Autonoe spiniventris*, *Liocarcinus vernalis*; **wide granulometric spectrum:** *Ampelisca typica*	*Ampelisca pseudospinimana*, *A. sarsi*, *Microdeutopus armatus*, *Metaphoxus simplex*, *Urothoe elegans.*
wide ecological spectrum	**muddy-sand/sandy-mud** (AreaII)	**muddy sediments**		**wide ecological spectrum**
Lysianassa costae, *Phtisica marina*, *Leucothoe spinicarpa, Liljeborgia dellavallei*, *Lysianassa longicornis*, *Cheirocratus sundevalli*	*Anapagurus serripes*	*Corophium runcicorne*, *Leucothoe oboa*		*Photis longicaudata*, *Orchomenella nana*, *Phtisica marina*
muddy sediments	St. 5B (Area I)	**wide ecological spectrum**		**muddy-sand/sandy-mud:** *Anapagurus serripes*; **SVMC:** *Upogebia pusilla;* **sandy sediments**: *Liocarcinus maculatus*
Monoculodes subnudus	**sandy sediments:** *Megaluropus massiliensis, Pseudocuma simile* (deeper sands); **SGCF and plant substrata:** *Guernea coalita*; **mixed sediments:** *Eurydice spinigera*; **muddy sediments:** *Leucothoe serraticarpa*	*Leptocheirus mariae*, *Siphonoecetes dellavallei*, *Photis longicaudata*		
		plant substrata		**SGCF and plant substrata**
		Jassa marmorata, *Processa edulis*		*Jassa marmorata*, *Guernea coalita*, *Maera grossimana*

number of individuals and diversity, and the presence of a transition zone (Somaschini *et al.* 1998) toward the "mixed sediments" assemblage (Fig. 7, 8). In Area I, a coenotic unit, which is in an intermediate position between SFBC and "mixed sediments" assemblage (Table V), was found on silty sand (st. 6C) and clayey sand (st. 1B, in front of River Fiora) sediments. Overall, a high number of species and individuals was present as in "mixed sediments" assemblage (Area II, Table IV).

The discontinuity present all along the coast between the above-mentioned coenotic units and the third depth-level may be reconducted to qualitative changes of hydrodynamics according to Riedl's second critical depth (Riedl 1971). It is more pronounced where SFBC assemblage occurs, while in presence of "mixed sediments" assemblage, mainly in relation to the presence of river outflows or urban settlements, it is less evident, as similarly observed in the South Tyrrhenian Sea for decapods (Minervini *et al.* 1983-1984) and other taxonomic groups (Gambi *et al.* 1983-1984, Russo & Fresi 1983-1984).

Under the above-mentioned discontinuity, at the III depth-level, in correspondence to the upper circalittoral zone, the following can be recognized:

– A coenotic unit which may be related in a broad sense to the muddy detritic (DE) assemblage, first identified by Picard (1965). This is present all along the considered coast in Area I (clusters C1 and C2; Fig. 5) and in all sub-areas of Area II (clusters Cl and D; Fig. 7, 8). The difficulty in clearly identifying well-defined assemblages in circalittoral soft bottoms, at level of muddy detritic and towards the deep shelf, was stressed (Pérès 1982, Fresi *et al.* 1983, Karakassis & Eleftheriou 1997, Papazacharias *et al.* 1998, Somaschini *et al.* 1998). In fact, an area of a complex mixture characterized by several transition zones extends from coastal environment (e.g. assemblages of DC or SFBC) to pure coastal terrigenous mud (VTC) (Febvre-Chevalier 1969, Salen-Picard 1983). Peracarids and decapods are distributed along a sort of continuum characterized by a progressive transition from DC and mixed sediments towards DE and in part to VTC assemblages, according to a gradual change in sediment composition (Sanders 1960). Within this coenotic unit, in correspondence to decreasing values of the mean depth and increasing values of the muddy component, decreasing values per station of population parameters as species richness, abundances, diversity and evenness were observed (Table IV). Of all the 49 species found, 21 are exclusive. The high number of species is mainly due to the heterogeneous character of this coenotic unit (Table V). The occurrence of the isopod *Cirolana neglecta*, considered typical of

DE (e.g. Picard 1965), corroborates the results about the presence of this assemblage. On the contrary, the presence of the tubicolous species *Jassa marmorata* seems unusual, as commonly recorded on photophilic algae and fouling (Bellan Santini 1998). Probably, the presence of gravel or coarse sand and/or floating algae allows the settlement of *J. marmorata* and other species (Table V) in "enclaves" (Ledoyer 1968).

On the whole, the presence of many transition zones and overlapping highlights, also for peracarids and decapods, the difficulty in drawing boundaries and in defining assemblages (Ledoyer 1968, Mills 1969, Fresi *et al.* 1983, Bellan-Santini 1985). The interaction of several factors may determine the described general patterns.

The analysis performed on the granulometric structure of the sediments highlighted the well-known important relationships between this "super-parameter" and faunal distribution (e.g. Sanders 1958, Fresi *et al.* 1983). A strong similarity is detected between the ordination models performed on sediment and faunal data in both areas, also stressed by the significant correlations found. The sediment structure is positively correlated to the observed zonation patterns (Axis I of CA), although along the depth-gradient an increase of sediment diversity and decreasing values of population parameters were observed; an increase of grain-size diversity does not always correspond to better structured assemblages (Fresi *et al.* 1983). The depth itself and correlated factors (e.g. a higher content of the finer fraction) which are positively correlated to the zonation of fauna, and a decreasing habitat heterogeneity may play a role. At shallower depths, along the horizontal gradient, in the area under the influence of the River Tevere, to high values of sediment diversity, due to inorganic terrigenous inputs, corresponds a rich but not particularly better structured "mixed sediment" coenotic unit, mainly characterized by high abundances. In this case, also organic inputs are of importance.

In Area I, where the similarity between ordination models is more evident, the different peculiarities of transects 1 and 6, due to the affinity of the II depth-level for mud and sand, respectively, are shown in both models, clearly highlighting that the structure of sediments and assemblages are under the control of the same determinant (Fresi *et al.* 1983). But, the stronger discontinuity present in the sediment model, between "sandy" and "muddy" stations, confirms that more factors contribute to determine more shaded and complex faunal zonation patterns.

In Area II, a comparison between the ordination models of sediment and fauna allowed to point out as follows:

– The vertical discontinuity is not constantly present in the sediment model. Some stations of the III depth-level, mainly in sub-area E, which belong to cluster Cl+D in the faunal ordination, are located towards the sand-point; probably, due to their major proximity to the coast, they are subject to different sedimentation rates in comparison to the other deep stations (Pérès 1982). The depth and the changing in quality of water movements (Riedl's second critical depth) result to be the stronger and driving factors in peracarids and decapods depth-zonation, acting, sometimes, not through the grain-size and therefore the sediment structure (Sanders 1960).

– The horizontal discontinuity, present in the faunal ordination due to the presence of the River Tevere, is absent in the sediment ordination. Therefore, the granulometric component of the sediment, also in this case, resulted to be insufficient in defining assemblages and zonation patterns. The organic inputs, which modify the settling substrata and the body-water, and the trophic conditions superimpose to environmental and sediment gradients, and may play a major role in structuring benthic assemblages (Pearson & Rosenberg 1978, Ambrogi 1989) as observed in this study in presence of the River Tevere, and also in relation to urban settlements (Anzio and Fregene) and minor rivers (Fiora, Marta and Sisto).

CONCLUSION

The heterogeneous distribution of sediment types and assemblages, due to different inputs of environmental factors, also mediated by rocky bottoms, highly extended seagrass meadows, inorganic and organic terrigenous outflows, contribute to increase biodiversity in the studied soft bottoms. In particular, this study stressed the role of the proximity of rocky substrata and seagrasses, and the presence of large rivers in increasing biodiversity, under different points of view in relation to the preferred ecological requirements of the species.

Crustacean peracarids and decapods may be considered sensible ecological descriptors, in particular amphipods being the driving taxonomic group in determining the structure of assemblages. In fact, their zonation patterns seem to be under the control of the same factors of the whole fauna, as pointed out similarly by the positive correlations previously found between faunal zonation patterns and the silty and clayey fractions (Fresi *et al.* 1983) and the response to the presence of river outflows (Falciai *et al.* 1983, Falciai & Spadini 1985).

This study allowed to characterize from a biocoenotic point of view a large coastal area, notwithstanding that the patchiness in the distribution of organisms may have important implications at such wide spatial scale (e.g. Somerfield & Gage 2000). The complexity and diversification of distributional patterns of crustacean peracarids and decapods in Mediterranean coastal soft bottoms was highlighted.

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