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Seasonal variation and structure of a decapod (Crustacea) assemblage living in a *Caulerpa prolifera* meadow in Cádiz Bay (SW Spain)

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Abstract

The decapod taxocoenosis living in shallow muddy bottoms with the green algae *Caulerpa prolifera* was studied monthly between February 1994 and January 1996 in the Inner Bay of Cádiz (SW Spain). More than 32,000 specimens belonging to 35 species were collected. Six species were dominant (representing the 85.8% of the total number of specimens), but the structure of the taxocoenosis was regulated by the *Hippolyte* species, *Sicyonia carinata*, *Palaemon adspersus* and *Liocarcinus arcuatus*. There was no significant qualitative difference between years. There was no clear change in the dominance of groups of species during the year, as happened in the outer Bay. This is probably due to the sheltered character of the area and the more stable and dense vegetal cover, but some seasonal differences were found.

The benthic characteristics of the Inner Bay of Cádiz, such as shallow soft bottoms of fine and muddy sediments and the presence of macrophytes (seagrasses and seaweeds) might be key factors influencing the composition and structure of the general and seasonal decapod assemblage. In spite of human impacts on the bay (e.g. aquaculture activities, sewage), the values of the diversity, equitability and richness indexes appeared stable over time (higher than those found in outer adjacent areas) and no significant differences between years were found.

Keywords: Crustacea Decapoda; biodiversity; taxocoenosis; temporal variation; seaweed; *Caulerpa*; coastal lagoon; Spain

1. Introduction

The geographical situation of Cádiz Bay, in the southwest of the Iberian Peninsula and in the northern margin of the Gulf of Cádiz, is a confluence area where the Atlantic and Mediterranean, and the European and African, waters come together. This implies higher richness values as a result of the presence of species from these biogeographical regions (Gofas, 1998).

These influences, together with the coastal currents and the freshwater influence of the rivers Guadalete and, in part, Guadalquivir, determine the environmental conditions (salinity, temperature), food resources and larval dispersion (Seoane-Camba, 1965; Rodríguez, 1986) and, consequently, the richness, the abundances, the seasonality and, in general, the structure of the communities.

In addition, the effects of the human activities, such as the aquaculture in adjacent areas (Arias and Drake, 1994; Drake and Arias, 1997) and pollution of agricultural origin, urban effluents, and mining/industrial sewage determine the animal community (Naranjo et al., 1996; Estacio et al., 1997). Progressive increases of the concentration of fine sediments and organic matter have been recorded over time (Blasco et al., 1987; Muñoz Pérez and Sánchez-Lamadrid, 1994), as a result of aquaculture activities and polluted

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effluents. At the same time, a gradual enhancement in chlorophyll *a* concentration in the bay has been detected in the water column (Establier et al., 1990). The high sedimentation rate in the Inner Bay (which shows less influence of oceanic currents than the outer part) has favoured the presence of muddy bottoms and the onset of dense *Caulerpa prolifera* meadows.

The species of the macrofauna in the Gulf of Cádiz are relatively well known; the decapods have been studied by García Raso (1996), López De La Rosa (1997), López de la Rosa et al. (1998) and González Gordillo et al. (2001), among others. The studies of the structure of macrobenthic communities and seasonal changes in the different habitats are, however, limited (Arias, 1976; Arias and Drake, 1994; Drake et al., 1997; Del Vals et al., 1998). This also applies to the decapod assemblage (López de la Rosa et al., 2002) and to the animal communities living in *Caulerpa prolifera* meadows (López de la Rosa et al., 2002; Rueda and Salas, 2003).

The aim of this study is to characterise the composition and structure of a decapod assemblage living in shallow muddy bottoms, covered with the alga *Caulerpa prolifera* (Forskal) Lamouroux, within the Inner Bay of Cádiz and to compare the results with others from the outer Bay (López de la Rosa et al., 2002).

2. Material and methods

2.1. Area of study

The Bay of Cádiz is located between the coordinates: 36°23′–36°37′N and 6°09′–6°21′W (Fig. 1). It is a shallow ecosystem, which can be divided in three sectors (Parrado Romá and Achab, 1999): (A) an outer Bay (north of ‘‘Puente José León de Carranza’’), with a definite external marine influence, a maximum depth of 17 m, a narrow intertidal zone and where the sand and muddy sand are the dominant fractions in the bottoms' sediment; (B) an Inner Bay of shallow water (maximum depth of 11 m), under a limited external marine influence, with a wider intertidal area and where the mud is dominant; and (C) an intertidal system of salt marshes in the southeast end of the bay.

Samples were collected from subtidal bottoms (depth between 1 and 3.3 m ± tidal variation) of the Inner Bay of Cádiz (36°29′N; 6°15′W) covered by a dense bed of the green algae *Caulerpa prolifera*.

2.2. Sampling method

Monthly samples were collected during the morning from February 1994 to January 1996, except in December 1995

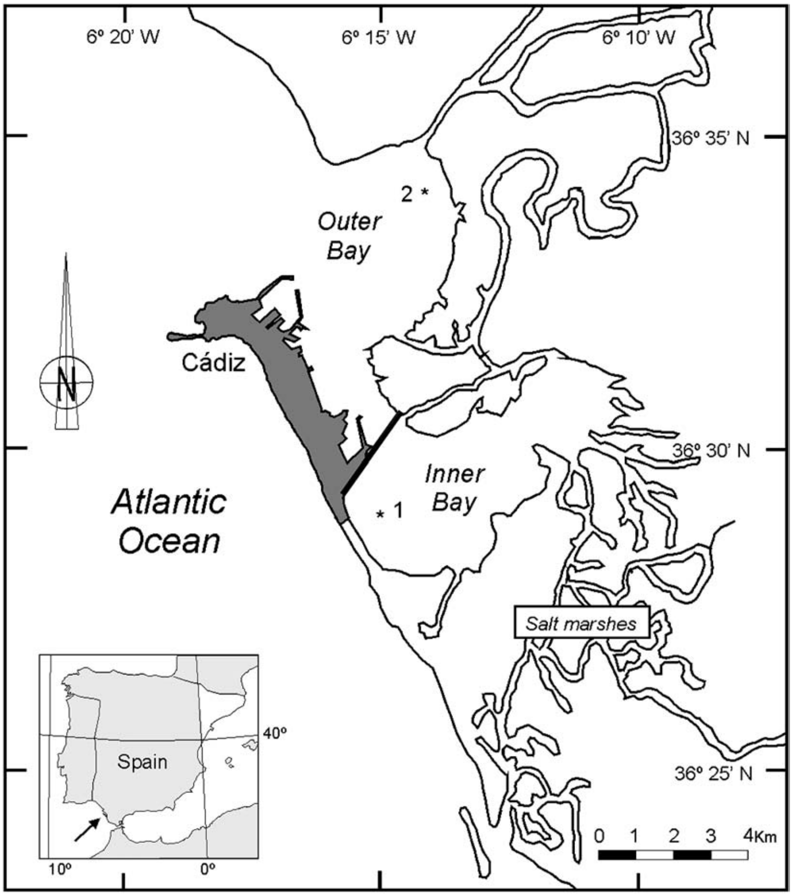

Fig. 1. Map of the studied area and location of sampling zone (*1) in the Inner Bay of Cádiz. The sampling zone of a previous study carried out in the outer Bay (López de la Rosa et al., 2002) is also indicated (2*).

due to unfavourable weather. Samples were obtained from a fishing boat by towing a semicircular dredge (width 1 m), with a 1-cm mesh Inner bag, for 10 min at a constant speed of 1 knot. The dredged area for each monthly sample was thus approximately 300 m^2. Sánchez-Moyano et al. (2001) studied the macrofauna of a meadow of *Caulerpa prolifera* in Algeciras Bay (Cádiz) and found that with 5 samples of 15×15 cm (total = 1125 cm^2) the minimum sampling area was sufficiently covered (sessile and vagile invertebrate macrofauna), so 300 m^2 is considered a large enough sampling area. For this reason and considering the large amount of material, samples were not replicated. The monthly successive samplings were conducted close enough to each other to avoid spatial differences distorting temporal variations in the taxocoenosis.

Samples were sieved on different mesh sizes: 10, 5, and 3 mm (the last size justified because of sediment retention within the bag). All the fractions were sorted quantitatively for monthly samples over the two years and the specimens were all identified.

For granulometric analysis, the methodologies of Boyoucos (1934) and Guitian and Carballas (1976) (modified by Estacio, 1996) were applied. The analysis and determination of the organic carbon was made through chemical oxidation and gaseous chromatography.

2.3. Data analysis

To assess the importance of the different species, the total (over the two years) (Ni) and monthly abundances, the total dominances (Di) (relative abundance of a particular species within the whole study expressed as percentage), the frequencies (Ci) (calculated as the percentage of monthly samples in which a particular species is present over the two years, but the values range are given between 0 and 1) were calculated and the product of Di × Ci was also calculated.

For analysis of the structure of the taxocoenosis, the PRIMER software (Clarke and Warwick, 1994) was employed. Shannon's diversity index (H'), evenness index (J') and Margalef's richness index (d) (program DIVERSE) and dominance curves were calculated. The similarity, using the Bray–Curtis index, and an aggregation (program CLUSTER) and ordination analysis (program MDS) were made, using quantitative and qualitative data with transformation (fourth root) and after removing the rare species. The latter were the species with Di × Ci values lower than 0.01, with presence values $C < 0.10$ and with a total number of specimens lower than 10. Finally, possible significant differences were assessed between the decapod assemblages from the different monthly samples using an analysis of similarities (ANOSIM, one-way test) and the contribution of each species (program SIMPER). ANOSIM compares ranked similarities between and within groups, selected a priori (different years or season), using a randomisation test for significance (Clarke, 1993).

3. Results

3.1. Abiotic factors

In the sampling area the sediment composition was sand 66.5% (average value, $\sigma_{n-1} = 24.4$), silt 7.1% (average value, $\sigma_{n-1} = 5.4$) and clay 26.2% (average value, $\sigma_{n-1} = 18.7$). The percentages of sand are: medium sand 20.8%, fine sand 18.7% and very fine sand 20.1%. Thus, the dominant fraction was fine + very fine sand and mud. The organic carbon content of the sediment was generally higher than in the outer Bay, with values oscillating between 2.0% and 5.2% (medium value: 3.5%, $\sigma_{n-1} = 1.0$).

The water temperature in the bay shows a seasonal trend with high values in August (24–26 °C) and lower ones in December (12 °C). The average salinity values in the Inner Bay ranged from 32 in some autumn and winter months (wet season) to 42 in summer (dry season).

3.2. Decapod taxocoenosis

In total 32,746 specimens, belonging to 35 species, were collected during the two years. The monthly abundances (total and by species), densities (specimens m^{-2}) and richness, and the general values of dominances and frequencies are given in Table 1.

Hippolyte inermis, *Palaemon adspersus*, *Sicyonia carinata*, *Hippolyte leptocerus*–*H. garciarasoi*, *Liocarcinus arcuatus*, *Processa edulis*, *Macropodia parva*, *Palaemon serratus*, *Pisidia longicornis* (*longimana* form) and *Thoralus cranchii* were constant species (Ci > 75%); *Athanas nitescens*, *Macropodia czernjawskii* and *Philocheras fasciatus* were common species (75% > Ci > 50%). According to the Ci × Di% values (>5) the most important species in the taxocoenosis were *H. inermis*, *P. adspersus*, *S. carinata*, *H. leptocerus*–*H. garciarasoi* and *L. arcuatus*, which represented the 85.8% of the total number of specimens (whereas the constant species represent the 97.3%).

The monthly species richness fluctuates between 9 and 17, and when the rare or accidental species (those with Di × Ci values lower than 0.01) were eliminated values between 8 and 17 were obtained. The average value was 13.2, $\sigma_{n-1} = 1.8$ (without rare species).

The monthly variation of the abundances showed the existence of a maximum in each year (Fig. 2), but in the first year this happened at the end of summer–beginning of autumn and in the second year, in the beginning of summer. This structure was basically regulated by the abundance values of *Hippolyte* species. In the second year there was also a clear increase in the abundance of *Palaemon adspersus*. Another abundant species was *Liocarcinus arcuatus* with maximum abundances from August to November in both years. The average density of decapod specimens in the studied area was 4.7 m^{-2}, with $\sigma_{n-1} = 3.7$.

The monthly values of the equitability and diversity indexes showed a similar evolution (Fig. 3). Their average values were,

Table 1
Faunistic result. Monthly abundances by species and total abundances (2 years) (Ni), densities (specimens m^{-2}), richness (No. of species), general dominances (Di) and frequencies (Ci) (other explanations in text)

Species	F94	M94	A94	My94	Jn94	Jl94	Ag94	S94	O94	N94	D94	J95	F95	M95	A95	My95	Jn95	Jl95	Ag95	S95	O95	N95	J96	Ni	Di	Ci	Ci × Di
Hippolyte inermis	130	33	372	136	127	154	994	628	2742	526	702	616	616	486	598	526	1478	1192	152	230	332	838	476	14,084	43.01	1.00	43.01
Palaemon adspersus	3	2	28	6	23	16	180	24	48	22	14	28	52	116	194	648	1030	784	144	142	98	90	648	4340	13.25	1.00	13.25
Sicyonia carinata	1	3	292	196	30	2	104	4	516	212	432	68	140	242	144	380	210	62	144	254	100	526	96	4158	12.70	1.00	12.70
Hippolyte leptocerus–*H. garciarasoi*	50	15	50	40		100	936	318	182	24	24	36	48	12	38	140	278	442	40	30	18	28	20	2869	8.76	0.96	8.38
Liocarcinus arcuatus	1	2	44	36	50	12	472	10	152	290	116	80	118	58	34	56	94	78	312	306	4	246	78	2649	8.09	1.00	8.09
Processa edulis	1	1	66	34	22	42	132	4	96	28	26	12	18	52	34	98	190	260	34	20			8	1178	3.60	0.91	3.28
Macropodia parva	7	8	18	28	2	52	128	46	38	72	42	24	102	14	14	22	92	28	14	14	2	102	12	881	2.69	1.00	2.69
Palaemon serratus	1		30		2	2	28	78	92	80	36	46	38	2	2		12	2	12	10	24	148		645	1.97	0.83	1.63
Pisidia sp.		9	8	14	62	66	218	20	10	2	12		2		2		8	22	46	36		4	12	553	1.69	0.78	1.32
Thoralus cranchii	4	2	10	24	2	10	234	12	60	8	12	2	10	12	6	16	36	22		4		2	2	490	1.50	0.91	1.37
Athanas nitescens	4	8			2	2	156	8	4					2		18	46	48	2	6			6	312	0.95	0.65	0.62
Macropodia czernjawskii	13	10	32	4		20	18	10		2		2	12	6	12	16	12		4			6	14	193	0.59	0.74	0.44
Philocheras fasciatus	1		2	2			2		28	2	6			6	8	16	12	6	4	4		4		103	0.31	0.70	0.22
Panopeus africanus		2					10		2									10	28	20			6	78	0.24	0.30	0.07
Hippolyte varians		1		2	2		6		8	2	2	10	24		2							2		61	0.19	0.48	0.09
Diogenes pugilator			2	2	2	6				2					2	6	2				2			26	0.08	0.39	0.03
Palaemon longirostris																							24	24	0.07	0.04	0.00
Inachus phalangium							4		2	2									4			6		18	0.05	0.22	0.01
Palaemon elegans													2				6					2	6	16	0.05	0.17	0.01
Pilumnus hirtellus		1				2	8										2						2	15	0.05	0.22	0.01
Pilumnus villosissimus											2		2							8				12	0.04	0.13	0
Palaemon xiphias																							8	8	0.02	0.04	0
Melicertus kerathurus																		2		4				6	0.02	0.09	0
Liocarcinus vernalis					2							2								2				6	0.02	0.13	0
Philocheras monacanthus									2															2	0.01	0.04	0

(*continued on next page*)

Table 1 (*continued*)

Species	F94	M94	A94	My94	Jn94	Jl94	Ag94	S94	O94	N94	D94	J95	F95	M95	A95	My95	Jn95	Jl95	Ag95	S95	O95	N95	J96	Ni	Di	Ci	Ci × Di
Pagurus anachoretus																						2		2	0.01	0.04	0
Galathea squamifera														2										2	0.01	0.04	0
Ethusa mascarone													2											2	0.01	0.04	0
Ilia nucleus													2											2	0.01	0.04	0
Brachynotus sexdentatus																				2				2	0.01	0.04	0
Acanthonyx lunulatus										2														2	0.01	0.04	0
Macropodia deflexa																					2			2	0.01	0.04	0
Macropodia linaresi																							2	2	0.01	0.04	0
Macropodia longirostris													2											2	0.01	0.04	0
Pisa tetraodon		1																						1	0	0.04	0
No. of specimens	216	98	954	524	328	486	3630	1162	3982	1276	1426	926	1190	1010	1090	1942	3508	2958	940	1092	582	2006	1420	32,746			
Density/m^2	0.72	0.33	3.18	1.75	1.09	1.62	12.10	3.87	13.27	4.25	4.75	3.09	3.97	3.37	3.63	6.47	11.69	9.86	3.13	3.64	1.94	6.69	4.73				
No. of species	12	15	13	13	13	14	17	12	16	16	13	12	17	13	14	12	16	14	14	17	9	15	17				

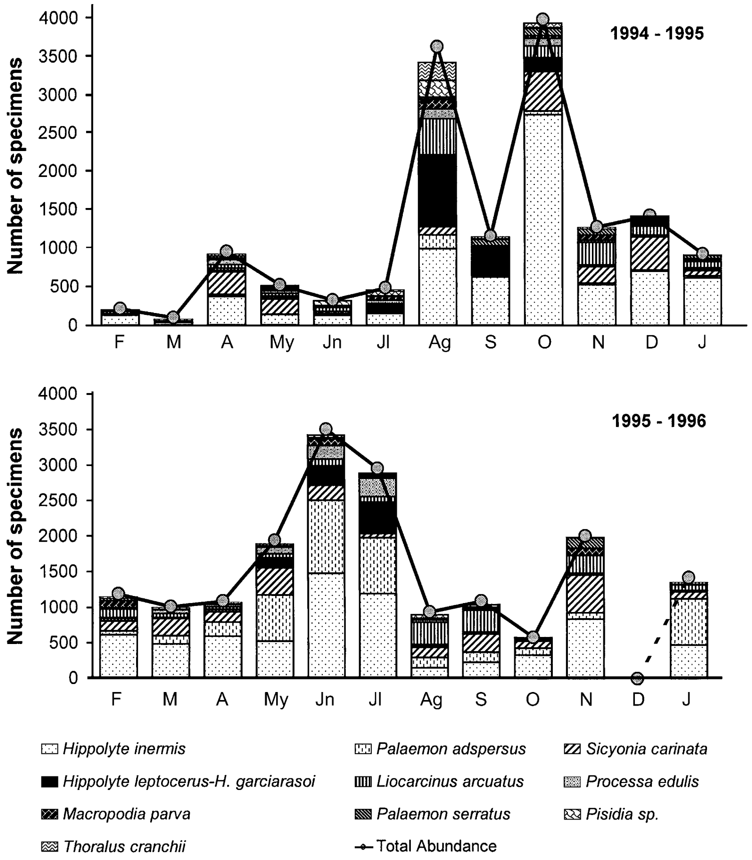

Fig. 2. Monthly variations of the abundances of the dominant species during the studied period.

respectively: $J = 0.62$, $\sigma_{n-1} = 0.09$, with a range between 0.44 and 0.79 (a little wider in the first year) and $H' = 1.63$, $\sigma_{n-1} = 0.27$, with a range between 2.13 and 1.21 (both values in the first year). In general, they showed minima in autumn–beginning of winter (October–January) and maxima in spring (March, first year) and summer (August, second year). The values of the richness index showed oscillations between 1.26 and 3.05; the average values were 1.9, with $\sigma_{n-1} = 0.36$ (first year: 1.97, $\sigma_{n-1} = 0.39$, maximum 3.05; second year: 1.84, $\sigma_{n-1} = 0.33$, maximum 2.26).

The *k*-dominance curves (Fig. 4) showed a J-shape, with high dominances of abundant species, which could indicate that the assemblage is living under "non-optimal" or "restricted" conditions.

The aggregation and MDS ordination analysis from quantitative data (Fig. 5A, B) showed the existence (with a similarity higher than 70%) of two groups (A and B, with a stress values of 0.17), and two isolated samples (June 1994 and October 1995). Group A was composed of the samples of February, March, July and September 1994, in which the number of

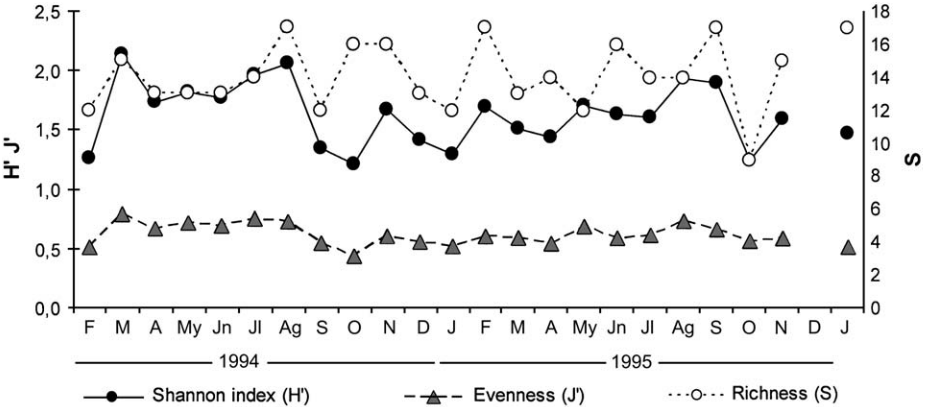

Fig. 3. Monthly values of the equitability and diversity indexes between February 1994 and January 1996.

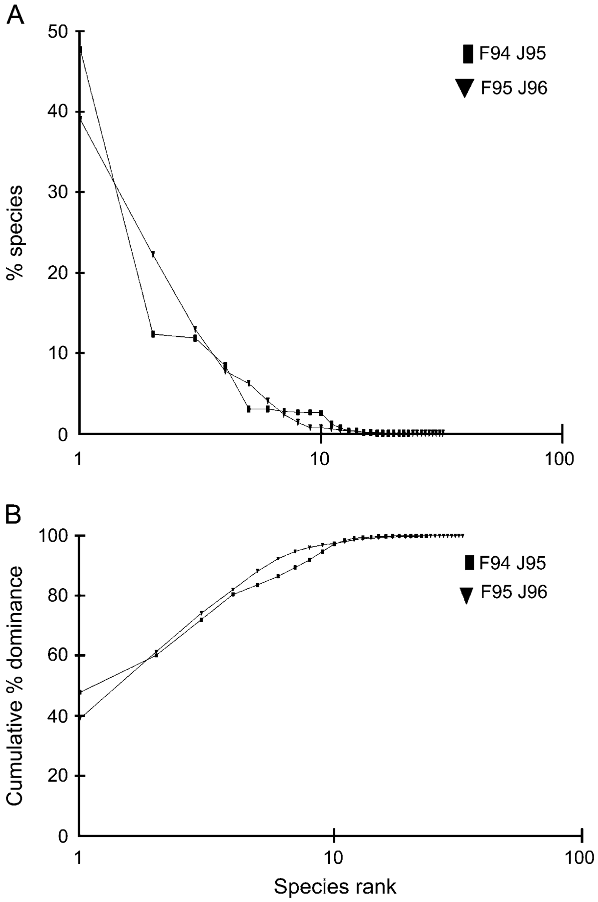

Fig. 4. Dominance curves of the two studied years: February 1994 to January 1995 and February 1995 to January 1996. (A) %Species curve, (B) cumulative %dominance curve.

specimens of *Sicyonia carinata* and *Liocarcinus arcuatus* were lower. Moreover, this ordination was, in part, related with total abundances, since the samples with higher values clustered near the left margin. This trend was also related with the abundance of *L. arcuatus*.

Quantitatively, low significant difference was found between years 1994 and 1995, but the group was barely separable (global test: $R = 0.11$, $p = 0.03$). Between seasons, a significant difference was found in the global result (global test: $R = 0.215$, $p = 0.002$); but the pairwise tests' results showed no significant differences between winter–spring ($R = 0.17$, $p = 0.054$), winter–summer ($R = 0.18$, $p = 0.08$) and spring–summer ($R = 0.23$, $p = 0.054$), whereas between winter–autumn ($R = 0.22$, $p = 0.045$), spring–autumn ($R = 0.26$, $p = 0.013$) and summer–autumn ($R = 0.28$, $p = 0.015$) significant differences were always associated with the autumn season. The similarity percentages – taking into account species contributions and using as factor/indicators the seasons (SIMPER program) ranged between 68.2 (winter–autumn) and 72.4 (spring–summer).

Qualitatively, between years there was no significant difference (global test: $R = 0.01$, $p = 0.37$). Seasonally, a significance difference occurred (global test: $R = 0.30$, $p = 0.001$); in pairwise tests' analysis differences were detected between all seasons, less between winter and summer ($R = 0.14$, $p = 0.16$). The similarity percentages – species contributions – using the seasons as a factor (SIMPER program) ranged between 82.8 (winter–summer) and 76.6 (winter–autumn).

4. Discussion

The composition of the decapod assemblage analysed is typical of soft bottoms with vegetal cover (seaweeds and/or seagrasses) (Guillen and Pérez-Ruzafa, 1993; López de la Rosa et al., 2002; García Raso et al., in press).

The values of diversity, equitability and richness indexes in the studied taxocoenosis are more stable over time than those found in adjacent areas of the outer Bay with a similar vegetal assemblage (López de la Rosa et al., 2002); here there is no clear change in the dominances of a particular group of species. This probably is the result of being a sheltered area with little influence of tidal currents and seasonal storms. These hydrodynamic factors have a strong incidence on granulometric composition and the amount of organic matter in the sediment (Pearson and Rosenberg, 1978; Warwick et al., 1991), so as to generate more granulometric variability in the outer areas of the Bay of Cádiz (Ligero et al., 1999). In the studied Inner Bay, the dominant fraction of the sediment (fine–very fine sands and mud, with higher organic carbon content) shows the existence of an intense sedimentation, which is normal in a sheltered area.

In the Bay of Cádiz the environmental conditions and the human activities produce an increase in the organic carbon of the sediment of about 2.70 mg C g^{-1} $year^{-1}$ (Gómez-Parra and Forja, 1992). The values of C/N obtained are similar to those given by Forja et al. (1994), which supports the hypothesis of these authors on the input of allochthonous organic material.

The fact that the Inner Bay is an area subject to high organic loads and with relatively limited water renewal might imply, at least, lower species richness compared to the outer Bay (López de la Rosa et al., 2002). This is partially true since the outer Bay yielded more species in total (42 against 35), but the average monthly values of richness were very similar (13.4 against 13.17). In contrast, the abundance and density were higher in the Inner Bay (av. 4.74 specimens m^{-2} against 0.89 in the outer Bay), probably as a consequence of the concentration of organic mater (which represents an increase of food) and the higher vegetal cover. The latter is a very important factor in the characterization of the structure of the benthic communities, as indicated in the analysis of the decapod assemblage of the outer Bay (López de la Rosa et al., 2002). This vegetal cover increases the structural heterogeneity and provides more ecological niches, resulting in higher taxocoenosis complexity and specific richness. In addition, algae and seagrass give shelter to juveniles and retain larvae, reducing the number of those transported away (Ólafsson et al., 1994).

The cycle of the seaweeds determines the abundance of associated species, together with their own behaviour or

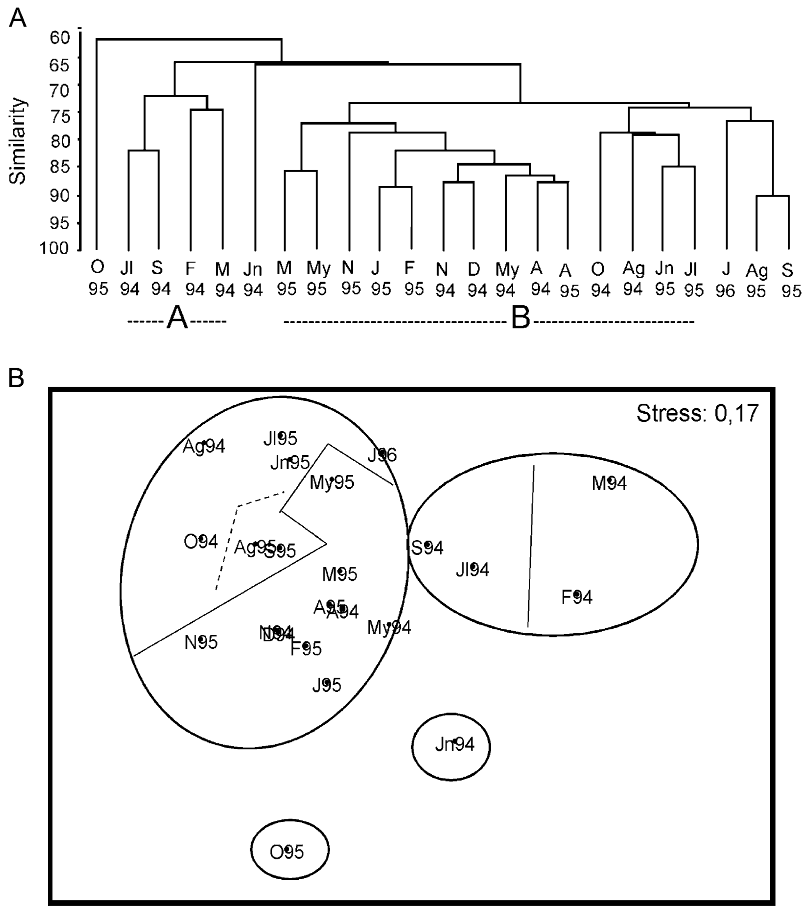

Fig. 5. Aggregation analysis (A) and MDS ordination plots (B) of monthly samples of both studied years (February 1994 to January 1995 and February 1995 to January 1996).

life cycle (Dayton, 1971; Heck and Orth, 1980; Sánchez-Moyano et al., 2001). Similarly, in the studied area there is an extensive meadow of *Caulerpa prolifera*, whose vegetative cycle is strongly dependent on the water temperature and shows a seasonal pattern of growth, with a peak in the summer months in the Algeciras Bay (Cádiz) (Sánchez-Moyano et al., 2001). In the decapod assemblage, the Hippolytidae (species characteristic of seagrass and seaweed meadows) are dominant species with highest abundances in the warm period, summer and autumn, thus showing a coupling with the algal cycle. Other abundant species such as *Sicyonia carinata* and *Liocarcinus arcuatus* are associated with fine and muddy sediments but also with seagrasses and seaweeds (Lagardère, 1971; Ingle, 1980; Freire et al., 1990, 1991; Števčić, 1991). The abundance cycle of *S. carinata* was seen to be irregular or fluctuating, probably because the species remains buried in the sediment during the day (the sampling time) and emerges during the night. The cycle of *L. arcuatus* shows two maxima, in August–September and in November (in both years), one of which, late summer coincides with the greatest development of the algae (Sánchez-Moyano et al., 2001) and the other with its own recruitment period (Freire et al., 1991). Thus, these coincidences might explain the two maxima. *Palaemon adspersus*, another dominant species, shows the highest abundances in the end of spring and the beginning of summer, which is the breeding period of the species. This period is coincident with the timing of its maximum abundance in other Iberian areas such as the river Ebro delta (Guerao and Ribera, 2000). According to Hagermam and Ostrup (1980), however, *P. adspersus* probably migrates to deeper waters during late summer or autumn and returns to shallow waters in spring for reproduction.

Seasonality was also found in the molluscan assemblages from this area (Rueda and Salas, 2003), but in this group the increase of food (organic matter due to sediment retention) available for juveniles could represent the most important factor for the population dynamics and for the entire assemblage, since the dense algal cover may reduce the interannual variability because of the survival of most juveniles (mainly of the dominant species) (Sánchez-Moyano et al., 2001).

The lack of strong seasonal changes (dominant species) in the decapod taxocoenosis along the year, contrary to the outer Bay (López de la Rosa et al., 2002), is probably due to the sheltered character of the area and the more stable and dense vegetal cover. Similar results have been found in the evolution of the decapod communities from sheltered biotopes such as calcareous concretions and rhizomes of *Posidonia oceanica* (García Raso and Fernández Muñoz, 1987; García Raso, 1990), but not in open habitats with high water energy such as coastal detritic bottoms (Manjón-Cabeza and García Raso, 1998).

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