Journal of the Marine Biological Association of the United Kingdom, 2011, 91(1), 107–116. © Marine Biological Association of the United Kingdom, 2010
doi:10.1017/S0025315410001219

Spatial patterns and seasonal fluctuations of intertidal macroalgal assemblages from Tarifa Island, southern Spain: relationship with associated Crustacea

JOSÉ M. GUERRA-GARCÍA, M. PILAR CABEZAS, ELENA BAEZA-ROJANO AND J. CARLOS GARCÍA-GÓMEZ
Laboratorio de Biología Marina, Departamento de Fisiología y Zoología, Facultad de Biología, Universidad de Sevilla, Sevilla, Spain

The dominant intertidal algal species from Tarifa Island, Strait of Gibraltar, together with the associated peracarid crustacean community, were studied over a two-year period (December 2005–December 2007). Gelidium corneum *and* Gymnogongrus patens *were dominant at the lower levels, close to the subtidal.* Valonia utricularis, Osmundea pinnatifida, *a turf of* Caulacanthus ustulatus *and* Gelidium *spp.,* Corallina elongata *and* Jania rubens *were distributed in intermediate levels, while* Ulva rigida, Chaetomorpha aerea *and* Fucus spiralis *were collected from upper levels. The main intertidal seaweeds of Tarifa Island showed a perennial behaviour, but maximum values of biomass were registered during late spring and beginning of summer for most of species while the highest seawater temperatures were measured in late summer and beginning of autumn.* Corallina elongata *and* Jania rubens, *the dominant species which shared a niche at platforms of intermediate levels, showed an opposite behaviour, probably to avoid competence:* C. elongata *showed higher biomass in April–June and lower values in August–October–December, while biomass of* J. rubens *was higher in December–February and lower in April–August. Associated crustaceans, including mainly amphipods (gammarids and caprellids) were also present throughout the whole year with similar seasonality to seaweeds. However, crustacean density in the intertidal was not only influenced by distribution of algae as substrate, but also by external factors, such as hydrodynamism, oxygen, weather conditions, competition or predation. The present study constitutes the first baseline study dealing with seasonal fluctuations of algae and associated crustaceans in a protected area of the Strait of Gibraltar, an important biogeographical zone between Europe and Africa and the Mediterranean and Atlantic.*

Keywords: Crustacea, ecology, intertidal, seasonality, seaweeds, southern Spain

Submitted 5 April 2010; accepted 25 May 2010; first published online 1 September 2010

INTRODUCTION

In intertidal ecosystems organisms are distributed in a particular way, occurring at specific levels along a height axis, from the lower to the upper shore (Underwood, 1981; Araújo *et al.*, 2005; Martins *et al.*, 2008). Zonation patterns of macroalgal assemblages in general are recognized to be the result of the effects of biological factors such as competition and grazing as well as physical factors such as wave action, aerial exposure, irradiance, temperature ranges and time available for nutrient exchange (see Lobban & Harrison, 1994; Choi & Kim, 2004). The causes underlying the distribution patterns of organisms in intertidal rocky systems have been approached by many authors (see Araújo *et al.*, 2005) and the zonation patterns of the littoral region have been studied all over the world, with comparisons made between sheltered and exposed sites and between different types of substratum (Neto, 2000a). In addition, because it is the interface between land and sea, the intertidal experiences environmental pressures from both realms (Simkanin *et al.*, 2005). Several studies have been conducted dealing with seasonal fluctuations of macroalgal assemblages or with temporal changes in abundances of intertidal species (Morgan & Mathieson, 1983; Neto, 2000a; Pedersén & Snoeijs, 2001). These studies, although laborious and time-consuming, are necessary to compile data of seaweed abundance within a whole year and along several years. These data are very relevant to understand ecological process, detect anthropogenic influence and even demonstrate possible effects of climate change. In fact, in recent years, studies showing the effects of climate change on organisms have become more prevalent within the scientific literature of terrestrial, freshwater and marine ecosystems from the tropics to the poles (Parmesan & Yohe, 2003; Root *et al.*, 2003; Simkanin *et al.*, 2005).

The Strait of Gibraltar is a biogeographical zone in which organisms of the Mediterranean Sea and the Atlantic Ocean, along one axis, and of Europe and Africa along the other, overlap (Guerra-García *et al.*, 2009). It is a very important geographical–geological region formed in the final phases of the Pliocene period, being the boundary for the Mediterranean region (to the east), the Lusitanian region (to the north-west) and the Mauretanian region (to the south-west). Seaweeds are, in many aspects, ideal organisms for the

Corresponding author:
J.M. Guerra-García
Email: jmguerra@us.es

study of biogeographical patterns on shallow, marine rocky shores: they are ubiquitous primary producers, attached and non-motile, and easy to collect and preserve (Bolton *et al.*, 2004). The 'Parque Natural del Estrecho' (Straits Natural Park) (Figure 1) was declared a protected area in 2003. It is a maritime–terrestrial park along 54 km of coastline in southern Spain and includes highly diverse and structured marine communities (García-Gómez *et al.*, 2003). Inside the Park, Tarifa Island is considered as a marine reserve, and constitutes the most interesting enclave of the park regarding the marine habitat (Guerra-García & García-Gómez, 2000). Tarifa Island is the most southern point of Europe, just between the Mediterranean Sea and Atlantic Ocean, with 21 hectares and 2 km of coastline. The unique biogeographical position, together with the substrate heterogeneity and the military access restrictions for a long time, has contributed to maintain very diverse rocky shore intertidal ecosystems. In spite of the importance of knowing the seasonal fluctuations of intertidal algae for adequate programmes of management and conservation in protected areas, there is a lack of these kinds of studies in the Strait of Gibraltar, and other areas of the Iberian Peninsula. Most of the approaches in southern Spain are based on community description on a spatial scale (Guerra-García *et al.*, 2000) and no studies are available dealing with temporal variation of macroalgal biomass along the year.

On the other hand, arthropods, and more specially the crustaceans, have been often used in macrophytobenthic studies to show relationships of predation and competition or to establish the environmental patterns that control the communities (García-Raso, 1988; Costello & Myers, 1987; Poore, 1994; Sánchez-Moyano & García-Gómez, 1998). Zonation patterns of marine algae and invertebrates, especially mussels, barnacles, snails and limpets, have been intensively studied, while only a few researches have studied the zonation patterns of epibenthic crustaceans in spite of being usually the dominant group of associated macrofauna. Furthermore, there is also a lack of studies dealing with seasonal fluctuations of intertidal crustaceans associated with seaweeds.

For all these reasons, the objective of the present work was to characterize the seasonal fluctuations of intertidal seaweeds and associated crustaceans along two years of study and to explore possible changes in algal biomass and how these changes could affect to the associated community.

MATERIALS AND METHODS

The study was conducted at the most southern point of Tarifa Island (Punta Marroquí, 36°00′00.7″N 5°36′37.5″W) (Figure 1). The height of the intertidal range in this location is 250 cm approximately (Figure 2) and we considered 5 levels to establish the zonation of the intertidal algae (level 1: from zero tidal level to 0.5 m; level 2: 0.5–1 m; level 3: 1–1.5 m; level 4: 1.5–2 m and level 5: 2–2.5 m). A ruler, set square and rope were used to establish the different heights. The first height was the zero tidal level and the process was continued until the vertical height of 2.5 m had been achieved, coinciding with upper limit of the intertidal community (see also Fa *et al.*, 2002; Guerra-García *et al.*, 2006). In each height, three replicates (quadrats 20 × 20 cm) were sampled. The surface was scraped and all macroalgae and associated fauna were collected. Samples were taken every two months from the different intertidal levels (December 2005 to December 2007). The samples were fixed in ethanol 80%, brought to laboratory and sieved using a mesh size of 0.5 mm. Peracarid crustaceans were sorted and separated

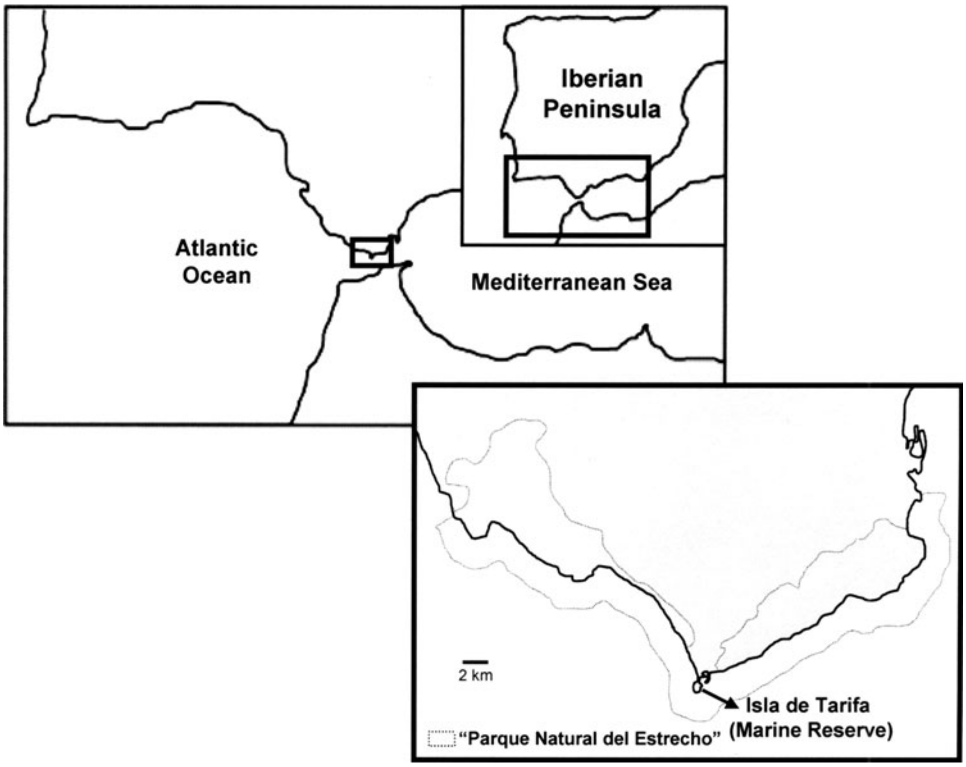

Fig. 1. Study area showing the location of 'Parque Natural del Estrecho' in the Strait of Gibraltar.

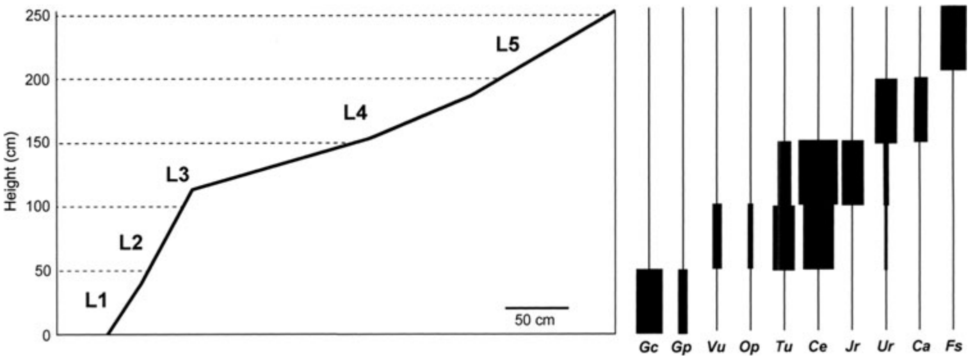

Fig. 2. Schematic diagram of the intertidal selected for the study in Tarifa Island. Representation of the vertical distribution of algal species. Gc, *Gelidium corneum*; Gp, *Gymnogongrus patens*; Vu, *Valonia utricularis*; Op, *Osmundea pinnatifida*; Tu, turf of *Caulacanthus/Gelidium*; Ce, *Corallina elongata*; Jr, *Jania rubens*; Ur, *Ulva rigida*; Ca, *Chaetomorpha aerea*; Fs, *Fucus spiralis*.

in the different groups: Amphipoda (Gammaridea and Caprellidea), Tanaidacea and Isopoda. No cumaceans or mysids were found during the study. The main seaweeds were identified to species level and the volume of each species was estimated as the difference between the initial and final volume when placed into a graduated cylinder with a fixed amount of water (see Pereira *et al.*, 2006; Guerra-García *et al.*, 2009). The dry weight of each seaweed was also measured (after 24 hours at 70°C), and correlations between volume and dry weight were established. Abundance of crustaceans was expressed in number of individuals per m^2. In each sampling, water temperature and salinity were measured using a conductivimeter WTW LF-323.

The affinities among stations based on the macroalgal biomass were established through cluster analysis using UPGMA (unweighted pair group method using arithmetic averages) and the Bray–Curtis similarity index. The relationships between crustacean assemblages, represented by total abundances (ind/m^2) and macroalgal composition were studied by canonical correspondence analysis (CCA). Multivariate analyses were carried out using the PRIMER package (Clarke & Gorley, 2001) and the PC-ORD programme (McCune & Mefford, 1997).

RESULTS

Salinity values were more or less constant (around 37 psu) along the two years of study, while water temperature ranged from 14.4°C (February) and 19.4°C (August and October) (Figure 3). Maximum air temperatures were registered in August, while the maximum of water temperatures were slightly delayed towards October. Both studied years showed a similar trend.

In connection with the spatial patterns of seaweeds along the intertidal, level 1 (0–0.5 m) was dominated by *Gelidium corneum* (Hudson) J.V. Lamouroux (=*G. sesquipedale*) and *Gymnogongrus patens* (Goodenough and Woodward) J. Agardh (Figure 2). The level 2 (0.5–1 m) was mainly constituted by *Valonia utricularis* (Roth) C. Agardh, *Osmundea pinnatifida* (Hudson) Stackhouse *(=Laurencia pinnatifida)* and a turf of *Caulacanthus ustulatus* (Mertens ex Turner) Kützing and several species of *Gelidium*. Corallinacea algae (*Corallina elongata* J. Ellis and Solander and *Jania rubens* (Linnaeus) J.V. Lamouroux) were dominant in level 3 (1–1.5 m), although *C. elongata* was also important in level 2. *Ulva rigida* C. Agardh was present from levels 2 to 4 while *Chaetomorpha aerea* (Dillwyn) Kützing was restricted to

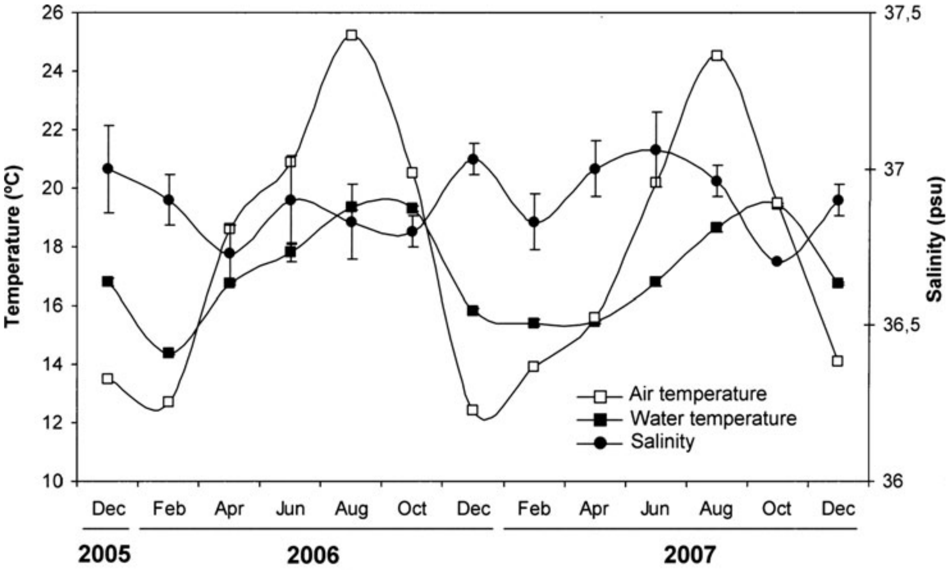

Fig. 3. Data (mean ± SD) of salinity, air temperature and water temperature in the study area.

level 4. *Fucus spiralis* Linnaeus was the only species found in level 5 (Figure 2).

There were conspicuous seasonal fluctuations of biomass in the macroalgal assemblage (Figure 4). Most of species showed higher values of biomass in late spring and beginning of summer. *Gelidium corneum* and *Gymnogongrus patens* from level 1 (with the highest influence of sublittoral zone) did not show clear and repeatable seasonal patterns: *G. corneum* showed highest values of biomass in August and lowest values in December–February, while *G. patens* showed an irregular behaviour depending on the year. All the dominant seaweeds of level 2 (*V. utricularis*, *O. pinnatifida* and *Gelidium/Caulacanthus* turf) showed peaks of abundance in April–June and minimum values in October–December. *Corallina elongata* and *Jania rubens* from the platforms of level 3, showed an opposite behaviour: *C. elongata* showed biomass higher than 1000 g/m^2 in April–June and values lower than 100 g/m^2 in August–October–December, while biomass of *J. rubens* was higher in December–February and lower in April–August (Figure 4). The green algae *Ulva rigida* increased its biomass during late spring and summer, with maximum values measured in June during the two years. *Chaetomorpha aerea* showed a similar pattern for the first year, but in the second year the peak was reached in February instead of August. *Fucus spiralis*, the only species recorded in level 5, also showed a different seasonality depending on the year: during 2006 this algae reached maximum values in June, while maximum biomass was measured in October during the second year (Figure 4). Values of biomass and volume were significantly correlated ($P < 0.01$) for all the macroalgal species (Figure 5). In spite of the seasonal fluctuations measured for most of the species, the composition of each intertidal level was rather constant along the whole year, as shown by the cluster analysis based on algal biomass at each sampling event every two months from December 2005 to December 2007 (Figure 6). Levels 1 and 5 were the most different from the remaining levels, according to the Bray–Curtis similarity index, while levels 2 and 3 showed a similarity close to 30%.

A total of 25,749 crustaceans were collected during the present study from the intertidal of Tarifa Island (15,688 gammarids, the most represented group, 7227 caprellids,

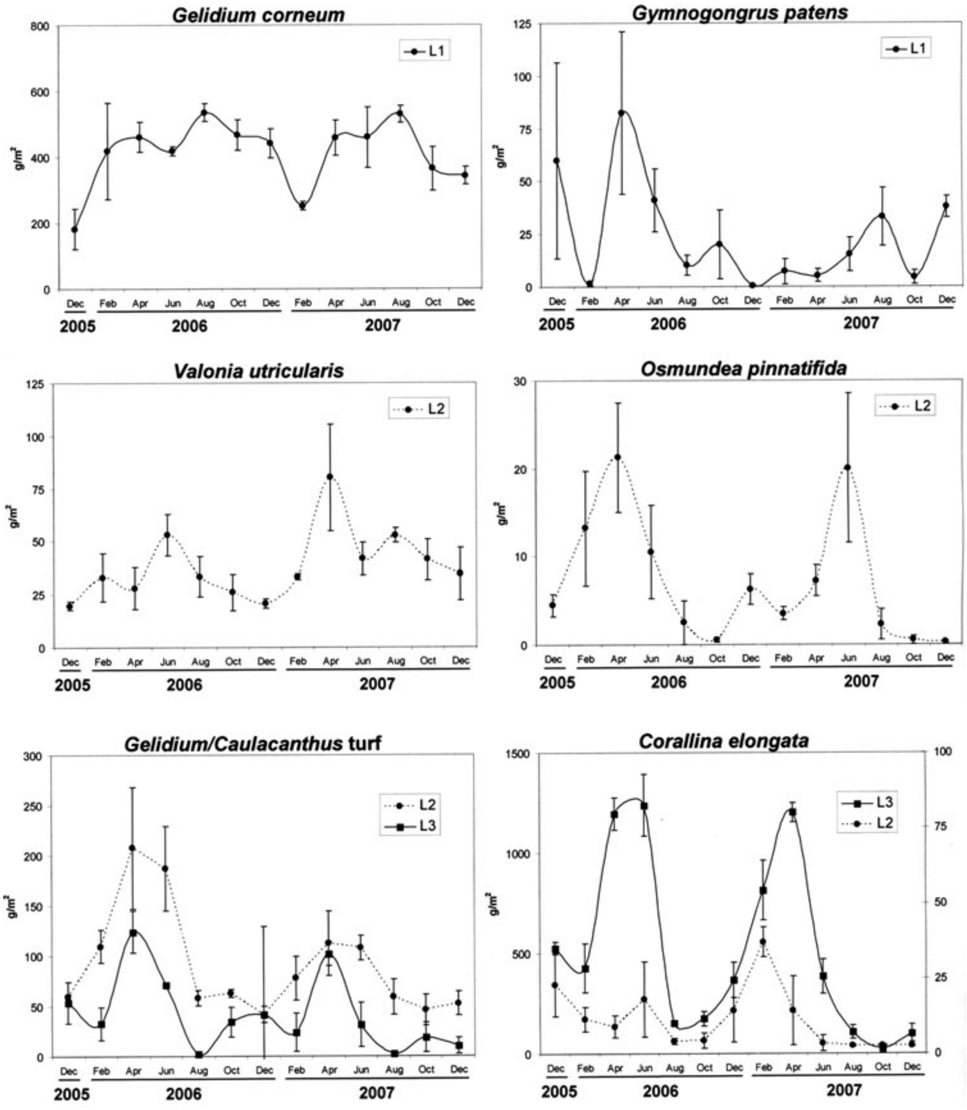

Fig. 4. Seasonal fluctuations of algae biomass (g/m^2) in each intertidal seaweed. L, level. Values are mean ± SD.

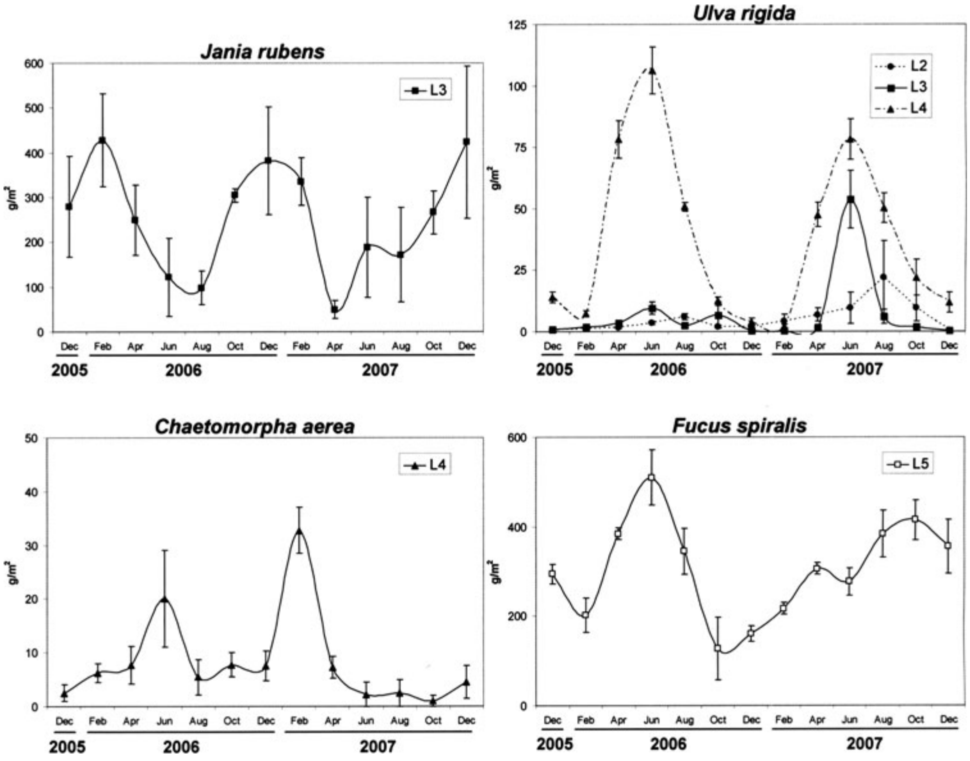

Fig. 4. Continued.

2770 isopods and 64 tanaids). The highest abundances of crustaceans were measured in levels 1, 2 and 3 (Figure 7). Caprellids were the dominant taxa in levels 1 and 3, associated to *G. corneum* and *C. elongata* respectively, while gammarids dominated levels 2, 4 and 5. Caprellids were absent in level 5. Isopods were more represented in levels 2 and 3, although they were present in all levels. Tanaids were the less abundant taxa, being more represented in levels 4 and 5. In connection with seasonal fluctuations, patterns were similar in all the intertidal levels: highest densities from April to October (late spring and summer), coinciding with peaks in biomass of most algal species, and lowest densities from December to February (winter). The axis 1 of the CCA analysis absorbed 64.8% of the total variance and correlated mainly with *G. corneum* (Figure 8; Table 1). This axis separated levels 1 and 3, dominated by caprellids from the remaining levels (2, 4 and 5) dominated by gammarids. The second axis explained only 6% of the total variance and separated level 2, dominated by gammarids and isopods, from levels 4 and 5, also with gammarids being the most important group, but with higher representation of tanaids.

DISCUSSION

The main intertidal seaweeds of Tarifa Island showed a perennial behaviour. The species were present along the whole year, although maximum values of biomass were registered during late spring and beginning of summer for most of algae. This fact probably determined that the associated crustaceans were also present throughout the whole year. This seasonality is likely to be related to cyclic variations in environmental factors such as seawater temperature, day-length and wave action (Neto, 2000a). Relationships between these environmental factors and the abundance and seasonality of seaweeds have been widely discussed and it has been reported that the maximum values of biomass and plant length are coincident with summer seawater temperature and longer day-lengths (Soeder & Stengel, 1974; Kautsky & van der Maarel, 1990; Neto, 2000a). The present study reflects that in Tarifa Island, Strait of Gibraltar, although higher water temperatures are measured by the end of summer, the peaks of algal biomass are measured earlier (from April to June) and many of the dominant seaweeds suffer an important decrease of biomass in August. This is probably due to extremely high air temperatures (occasionally over 40°C) measured during some days of July and August (personal observation), which are surely critical for most of macroalgae. In fact, intertidal seaweeds are periodically exposed to air where they experience a variety of potentially stressful environmental conditions, including nutrient limitation, high temperature, desiccation and osmotic stress (Davison & Pearson, 1996).

On the other hand, in the 1970s a paradigm emerged that upper limits were set by physical factors and lower limits by biological interactions (Connell, 1972). Neto (2000b) during an ecological study of intertidal algal communities in the Azores, found that at the upper levels of the intertidal, the higher values of biomass were recorded in winter, when the wave action was higher and the air temperature lower, and the contrary was observed at the lower levels, with higher biomass in summer. This could explain the higher values measured during winter 2007 for *Fucus spiralis*, located in the higher level of the study area in Tarifa Island. In the Mediterranean waters of the Iberian Peninsula, peaks of algal biomass have been measured also in late spring (Sala & Boudouresque, 1997), as in the present study for most of

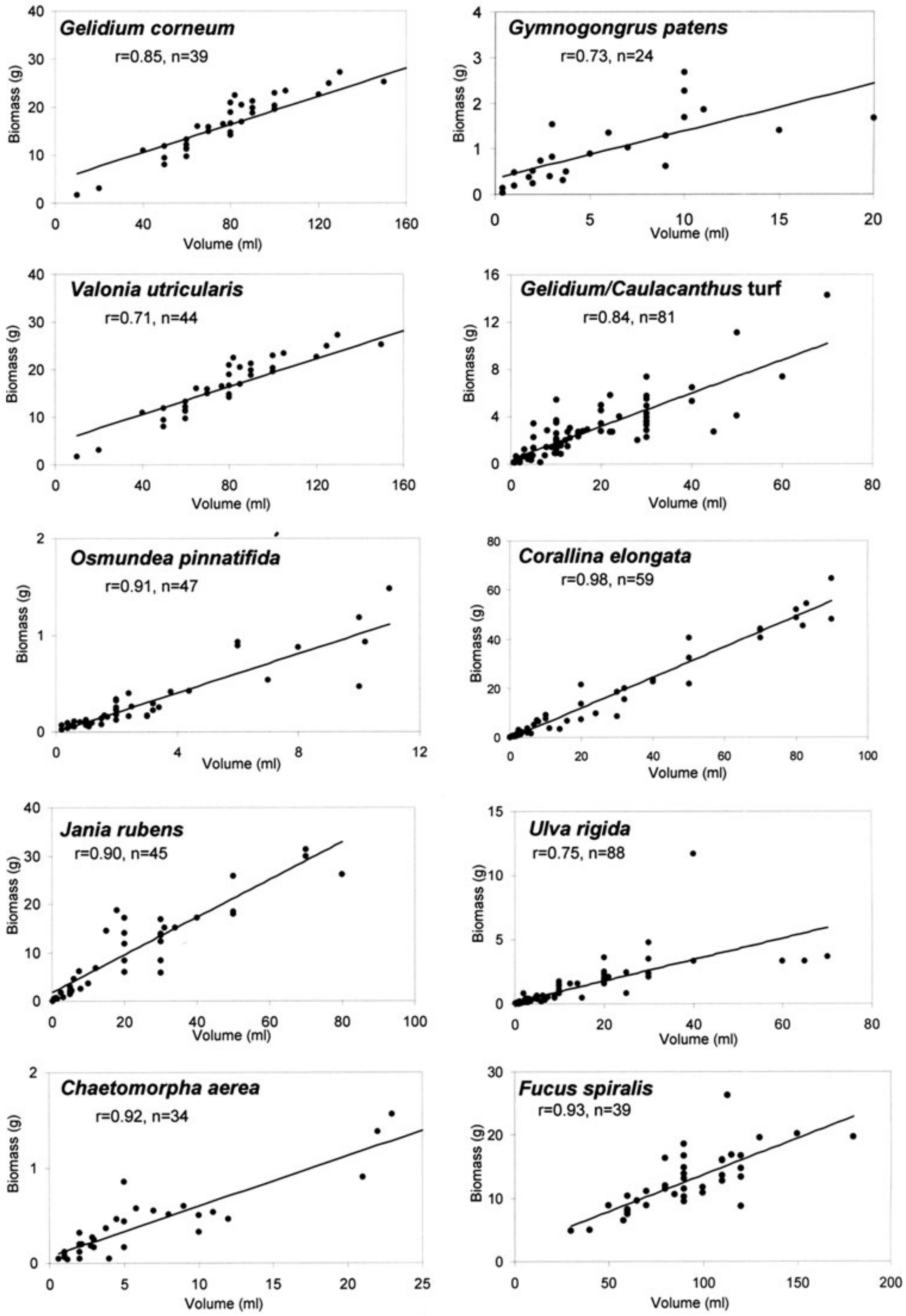

Fig. 5. Correlation plots of biomass/volume for the studied species of microalgae.

algal species. On the north-west coast of the Yellow Sea, Zhuang *et al.* (2004) reported that macroalgal biomass peaked in August, while the species diversity peaked in April. Neto (2000a) measured higher biomass of *Ulva rigida* in summer months. Ballesteros (1988) found that *Corallina elongata* from the subtidal levels at the Mediterranean coast of Spain showed its maximum biomass peak towards winter instead of spring–summer as measured in the present study for intertidal *C. elongata* from the Strait of Gibraltar. This is probably related with physical factors affecting the intertidal (mainly dessication in summer, winter storms, higher temperature range between winter and summer, etc.) which affect differently the subtidal area. *Gelidium corneum*, the other of the dominant algae of the present study together with *C. elongata*, is usually related to unpolluted areas, with low sediment loading and high exposure levels, and can be considered good indicator of undisturbed habitats (Gorostiaga *et al.*, 1998; Díez *et al.*, 1999, 2003). In fact, Tarifa Island, differently from other strongly anthropogenic areas of southern Spain, has been maintained in an excellent state of conservation. Anadón & Fernández (1986) measured higher biomass in spring–summer for this species on the

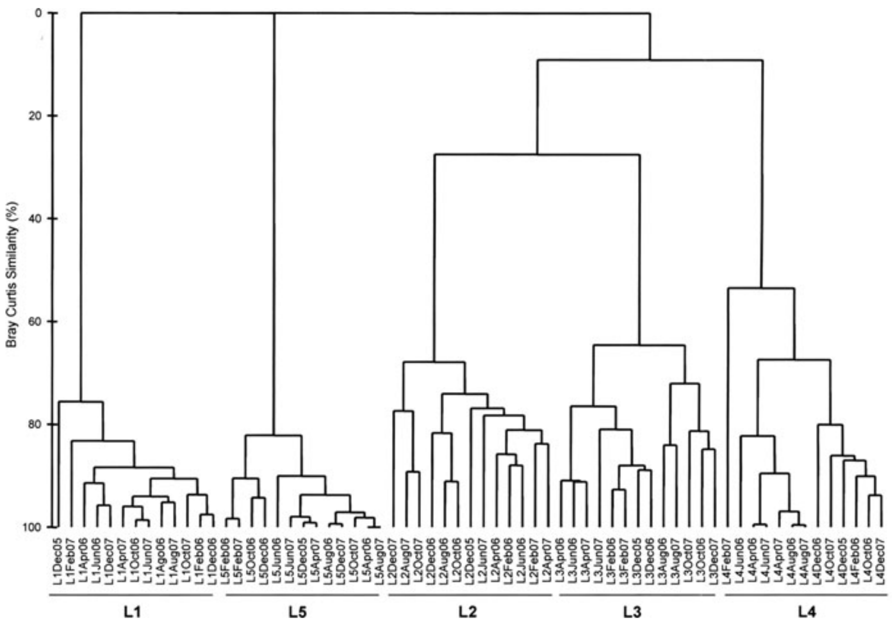

Fig. 6. Dendrogram resulting from the cluster analysis based on the seaweeds matrix of biomass values.

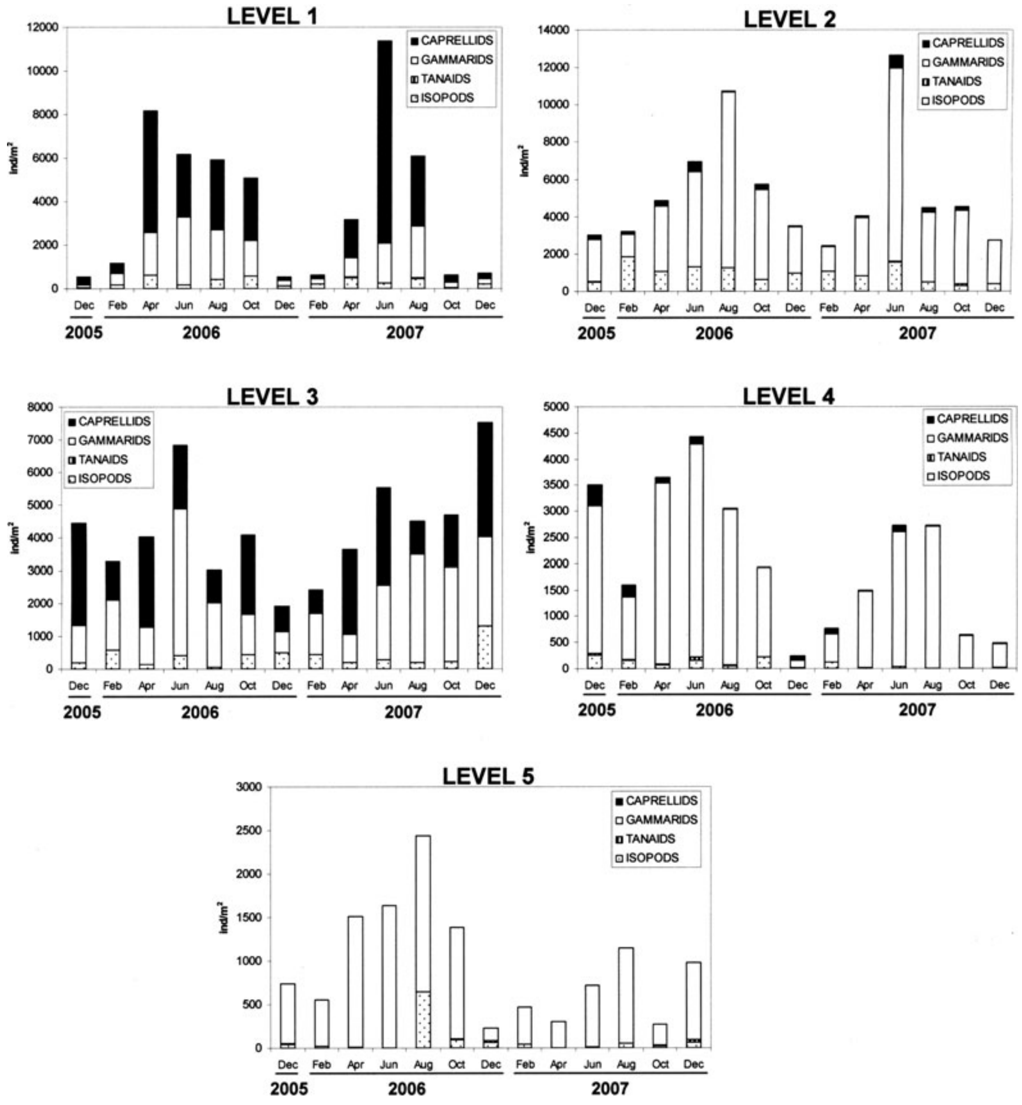

Fig. 7. Seasonal fluctuations of crustacean densities (ind/m^2) in each intertidal level.

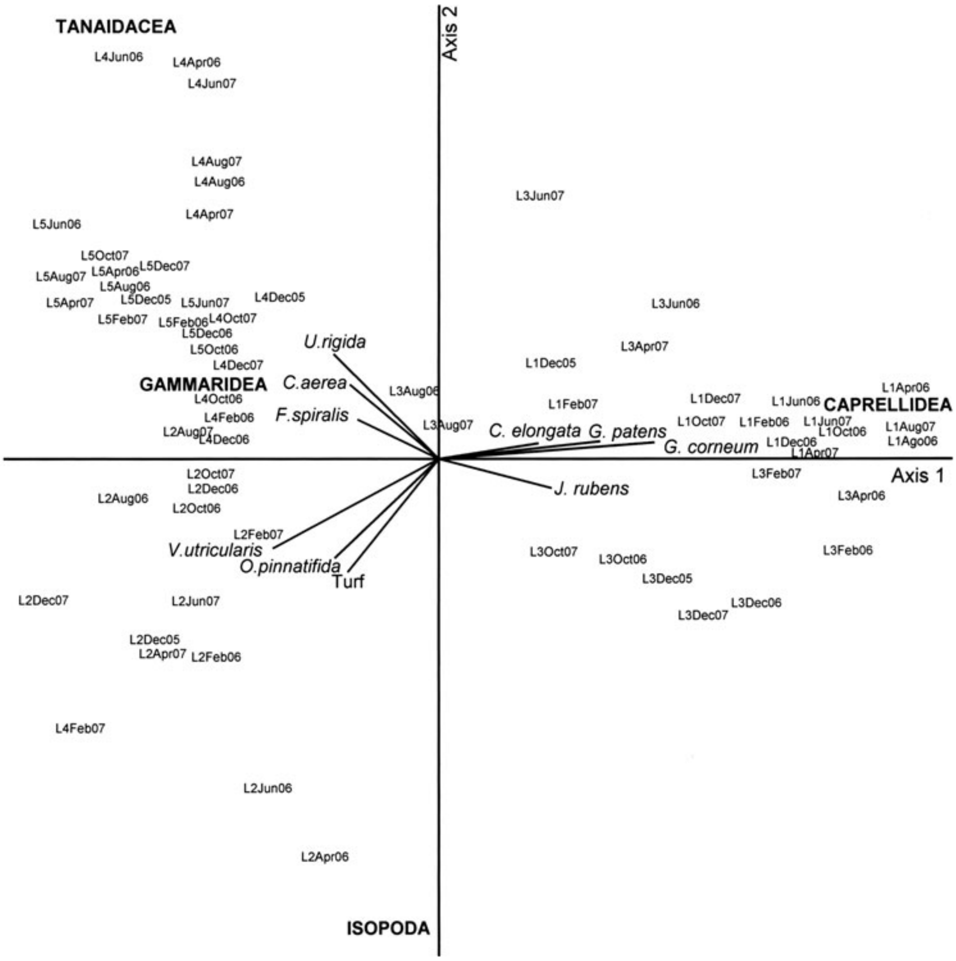

Fig. 8. Graph representation of the samplings, crustacean group and seaweeds with respect to the first two axes of the canonical correspondence analysis.

northern coasts of the Iberian Peninsula, similarly to the results obtained in the present study. *Gelidium corneum* is the main raw material used for agar production in Morocco and the industrial exploitation of this alga is an important part of the economy of this country; however the species is in danger of being overexploited (Mouradi-Givernaud *et al*., 1999; Zidane *et al*., 2006). Probably, the collections of these algae for industrial purposes should be conducted in summer months, when algae are more developed, although their presence is maintained along the whole year.

Table 1. Summary of the results of the canonical correspondence analysis: $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.31	0.03	0.01
Species–environment correlation	0.91	0.56	0.19
Percentage of species variance	64.8	6.0	0.1
Correlation with environmental variables			
Gelidium corneum	-0.71^{***}	–	–
Gymnogongrus patens	-0.47^{**}	–	–
Valonia utricularis	–	-0.48^{**}	–
Turf	–	-0.65^{**}	0.39^{*}
Osmundea pinnatifida	–	-0.55^{**}	–
Corallina elongata	0.42^{**}	–	-0.41^{**}
Jania rubens	0.47^{**}	–	–
Ulva rigida	–	0.57^{**}	–
Chaetomorpha aerea	–	–	-0.48^{**}
Fucus spiralis	-0.44^{**}	–	-0.49^{**}

Seasonal fluctuations of crustaceans were, in general terms, coincident with seasonality of seaweeds, having higher biomass from April to August. However, in spite of the important biomass decrease of level 3 algae (mainly due to *Corallina elongata*) in summer because of the high temperatures, crustacean densities maintained values above 2000 ind/m^2. On the other hand, *Gelidium corneum* at level 1 maintained a similar biomass throughout all the year (200–500 g/m^2 approximately) and crustacean associated, mainly caprellids, showed important fluctuations with more than 5000 ind/m^2 in April–October and less than 500 ind/m^2 in December–February. These patterns indicate that crustacean density in the intertidal is not only influenced by distribution and abundance of algae as substrate, but also by external factors, such as hydrodynamism, oxygen, weather conditions, competition or predation, including the particular population dynamics for each species. Probably, the level 1, very close to the subtidal, is more exposed to wave action, and is more sensitive to winter storms, affecting negatively the associated crustaceans, which reduces its density during winter period. Oppositely, crustaceans from level 3 were able to maintain high densities in the platforms of *Corallina elongata*. Level 3 is not so affected by waves during winter storms. Prathep *et al.* (2003), during a study of spatial and temporal variations in sediment accumulation in an algal turf and their impact on associated fauna, found that most organisms were most strongly influenced by sediment accumulation and temporal changes in the turf plants. In the present study *Corallina elongata* and *Jania rubens*, the dominant species which shared niche at platforms of intermediate levels, showed an opposite behaviour, probably to avoid competence: *C. elongata* showed higher biomass in April–June and lower values in August–October–December, while biomass of *J. rubens* was higher in December–February and lower in April–August. Probably, this particular trend of *J. rubens*, with different peaks of biomass than most of other seaweed, also positively contributed to maintain high densities of crustaceans in level 3 throughout the whole year, even when *C. elongata* biomass decreased.

Collecting data over a series of years is rare in ecological literature because it is time-consuming, costly and often not possible (Simkanin *et al.*, 2005). However, knowledge of seasonal fluctuations of seaweeds and associated macrofauna is essential for future monitoring, conservation and for making reliable management decisions, especially in protected areas such as Tarifa Island in the Strait of Gibraltar. The present study constitutes the first baseline approach to the seasonal fluctuations of biomass of the main seaweed at the Strait of Gibraltar, a most interesting biogeographical area between the Mediterranean Sea and the Atlantic Ocean.

ACKNOWLEDGEMENTS

Financial support of this work was provided by the Ministerio de Educación y Ciencia (Project CGL2007-60044/BOS) co-financed by FEDER funds, and by the Consejería de Innovación, Ciencia y Empresa and Junta de Andalucía (Project P07-RNM-02524). Special thanks to the directors of the Parque Natural del Estrecho (Jesús Cabello and Esther Gordo) and to the Comandancia General de la Guardia Civil for providing authorizations and facilitating access to the marine reserve Isla de Tarifa. M. Corzo (Consejería de Medio Ambiente and Junta de Andalucía) kindly provided the data for air temperature measured at the study site. Thanks are also due to M.M. López, M.J. Jiménez, D. Vázquez, I. Pacios, A. García, D. González and J.J. Díaz for assistance in the field and laboratory.

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Correspondence should be addressed to:
J.M. Guerra-García
Laboratorio de Biología Marina, Departamento de Fisiología y Zoología
Facultad de Biología, Universidad de Sevilla
Avenida Reina Mercedes 6, 41012
Sevilla, Spain
email: jmguerra@us.es