Spatio-temporal distribution of the Caprellidae (Crustacea: Amphipoda) associated with the invasive seaweed *Asparagopsis armata* Harvey in the Southern Iberian Peninsula

Distribución espacio-temporal de los caprélidos (Crustacea: Amphipoda) asociados al alga invasora *Asparagopsis armata* Harvey en el sur de la Península Ibérica

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Palabras clave: *Asparagopsis armata*, Península Ibérica, caprélidos, fluctuaciones estacionales, distribución espacial.

ABSTRACT

The caprellid fauna associated to *Asparagopsis armata* was studied in a spatio-temporal scale at the Southern coast of the Iberian Peninsula. Fourteen stations were selected for the spatial study along the axis Mediterranean-Atlantic and five stations were studied bimonthly (Feb08-Feb09). A gradient of decreasing oxygen and increasing salinity from the Atlantic to the Mediterranean was measured. Eight caprellid species were found: *Caprella acanthifera*, *C. danilevskii*, *C. equilibra*, *C. grandimana*, *C. hirsuta*, *C. liparotensis*, *C. penantis* and *Pseudoprotella phasma*. *Caprella penantis* and *C. liparotensis* were the dominant species, and *Caprella hirsuta* was the most discriminating species between Mediterranean and Atlantic stations, reaching high abundances only in the strictly Mediterranean localities. The seaweed biomass showed higher values in April-June while water temperature was higher in August-October. Maximum caprellid densities were found in April-June (Mediterranean stations) and August-October (Atlantic stations) showing a gradient along the spatial axis. Therefore, optimal seasonal environmental conditions for caprellid cycles are reached sooner in the Mediterranean than in the Atlantic. The number of associated caprellid species in the non-native *A.armata* is very high when compared with data of other native seaweeds of the Iberian Peninsula and Northern Africa, so the toxic and unpalatable substances of this seaweed do not seem to affect negatively to the caprellid community.

RESUMEN

Se estudió la fauna de caprélidos asociados a *Asparagopsis armata* en una escala espacio-temporal en la costa sur de la Península Ibérica Se seleccionaron 14 estaciones para el estudio espacial a lo largo de un eje Mediterráneo-Atlántico, y 5 estaciones se utilizaron para el estudio bimensual desde febrero de 2008 hasta febrero 2009. Se registró un gradiente de disminución de oxígeno y aumento de salinidad desde el Atlántico hacia el Mediterráneo. Se identificaron 8 especies de caprélidos asociados a *A. armata*: *Caprella acanthifera*, *C. danilevskii*, *C. equilibra*, *C. grandimana*, *C. hirsuta*, *C. liparotensis*, *C. penantis* y *Pseudoprotella phasma*. *Caprella penantis* y *C. liparotensis* fueron las especies dominantes, y *C. hirsuta* fue la especie que más discriminó entre estaciones del Mediterráneo y el Atlántico, alcanzando densidades importantes sólo en las estaciones estrictamente mediterráneas. La biomasa del alga mostró los valores más altos en abril-junio mientras que la temperatura del agua fue mayor en agosto-octubre. Las densidades mayores de caprélidos se registraron en abril-junio (estaciones mediterráneas) y agosto-octubre (estaciones atlánticas) mostrando un gradiente a lo largo del eje espacial. Por tanto, las condiciones óptimas para el desarrollo de los caprélidos se alcanzan antes en el Mediterráneo que en el Atlántico. El número de especies de caprélidos asociados al alga no nativa *A. armata* es muy alto cuando se compara con datos de otras algas nativas de la Península Ibérica y norte de África, de forma que la sustancias tóxicas y poco palatables de este alga parecen no afectar negativamente a la comunidad de caprélidos.

INTRODUCTION

There is an increasing interest in the study of spatial distribution and seasonal fluctuations of non-native species (Ashton *et al*., 2010). Non-native seaweeds are species which have been introduced beyond its native range through human activities and has become successfully established in the new location (Williams & Smith, 2007). Although information on the life history and population dynamics of non-native seaweeds is essential to control the process of invasion, it is also important to explore the diversity patterns of associated fauna to properly understand the impact in the invaded ecosystems (Vázquez-Luis *et al*., 2009; Pacios *et al*., 2011; Guerra-García *et al*., 2012).

The marine red algal genus *Asparagopsis* has been well studied with respect to its morphology, life history, cytology, physiology, secondary metabolites, and potential applications; however, very little information is available dealing with associated fauna. To fill this gap, recent studies have been conducted at the Iberian Peninsula to characterise the crustacean communities of this invasive seaweed (Pacios *et al*., 2011; Soler-Hurtado & Guerra-García, 2011; Guerra-García *et al.,* 2012). Although *A. armata* supports a diverse crustacean assemblage along the whole year (Pacios *et al*., 2011), Guerra-García *et al.* (2012) reported an impoverishment in the peracarid community when compared with the native alga *Corallina elongata*, and a very different species composition between *A. armata* and this native seaweed.

Within peracarids, amphipods are considered one of the dominant groups associated with a variety of macroalgae on rocky shores (Chavanich *et al*., 2010). They can use these algae as habitat or food, and the selection of macroalgae by amphipods can be influenced by both biological and physical factors (Chavanich, 2006; Viejo & Arrontes, 1992). Among amphipods, caprellids can be among the most abundant organisms associated to algae (Sánchez-Moyano & García-Gómez, 1998; Pacios *et al*., 2011; Guerra-García *et al*., 2009a, 2011). Caprellids constitute an important trophic link between primary producers and higher trophic levels in marine ecosystems (Woods, 2009). They are particularly interesting because they have been proposed as useful marine bioindicators (Guerra-García & García-Gomez, 2001; Ohji *et al*., 2002; Guerra-García *et al*., 2009b) and as potential marine finfish aquaculture resource (Woods, 2009). Furthermore, the study of associated fauna in general, and caprellids in particular, is very relevant to properly understand the ecological patterns, biotic interactions, and competition processes.

The main objective of the present study is to characterise in detail the caprellid composition of the seaweed *Asparagopsis armata* along the Southern Iberian Peninsula and to explore the seasonal fluctuations along the whole year.

MATERIAL AND METHODS

For the spatial study, fourteen stations were selected along the Atlantic and Mediterranean coasts of the Southern Iberian Peninsula (Fig. 1). To represent a variety of environmental conditions, we chose relatively undisturbed enclaves with low human pressures (stations 1-7 and 14) and also other stations affected by anthropogenic impact, as those in Algeciras Bay (8-11), Torreguadiaro (12) and Málaga (13).

Sampling was conducted during June and July 2008. The following environmental parameters were measured in situ at each sampling site:

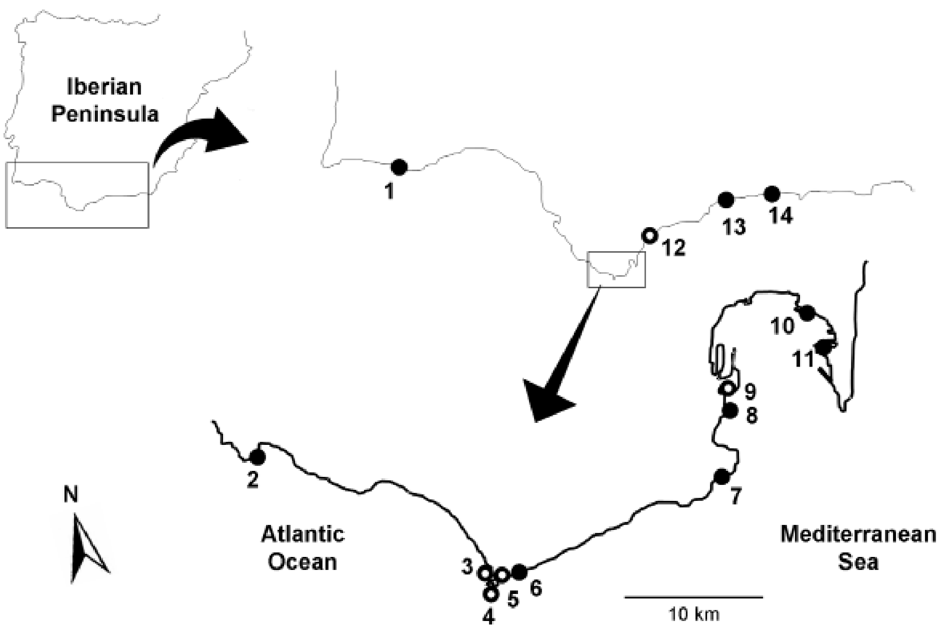

Fig. 1.—Study area showing the location of the fourteen stations sampled for the spatial study. Stations 3, 4, 5, 9 and 12 (white circles) were selected for the one-year study.
Fig. 1.—Área de estudio mostrando la localización de las catorce estaciones muestreadas en el estudio espacial. Para el seguimiento anual, se seleccionaron las estaciones 3, 4, 5, 9 y 12 (círculos blancos).

water temperature, pH, salinity and dissolved oxygen. Salinity and pH were measured using a conductivimeter-Phmeter CRISON MM40, and temperature and oxygen with an oxymeter CRISON OXI 45P. Three measurements were made for each parameter and mean values and standard deviation were calculated.

For the temporal study, five of the fourteen stations were selected to explore seasonal fluctuations of the caprellid community. Three stations were selected in Tarifa Island (stations 3, 4 and 5), which is a marine reserve inside the Natural Park of the Strait of Gibraltar and constitutes the most interesting enclave of the park regarding to the marine habitat (Pacios *et al.*, 2011). Tarifa Island is the most southern point of the European continent, just between the Mediterranean and Atlantic, with 21 ha and 2 km of coastline. The unique biogeographical position, the substrate heterogeneity and the military access restrictions for a long time, has contributed to maintain very diverse rocky shore intertidal ecosystems. Taking into account that Tarifa Island has enclaves with different wind exposures, we selected three stations to cover the whole range of conditions at the Island. The fourth station (sta. 9) was selected in one of the most polluted areas in Algeciras Bay, El Saladillo. Algeciras Bay, contrary to Tarifa Island, is an important industrial area, with chemical factories, refineries, thermal power plants, iron works, paper mills and shipyards, along with a major port. The fifth station selected for the temporal study was located in Torreguadiaro, with higher Mediterranean influence. This enclave is rather undisturbed during the whole year, except for summer months, when it is usually crowded with important touristic impact.

Sampling was conducted, bimonthly, from February 2008 until February 2009. In this case, only water temperature was measured bimonthly in the five stations.

In all sampling stations, both in the spatial and temporal approaches, we selected the low intertidal level, contiguous to the subtidal zone, and totally composed of *A. armata*. Samples were collected using a 20 x 20 cm quadrat (3 replicates per site) by scraping the whole surface with a trowel (see Pacios *et al*., 2011). The whole amount of the alga *A. armata* attached to the surface was collected, placed in a plastic jar and fixed in 70% ethanol.

In the laboratory, the caprellids were separated from the algae and then counted. Dry weight (24 h to 70°C) of each algal sample was also measured.

RESULTS AND DISCUSSION

Environmental variables

In the spatial study, temperature ranged from 17.7 to 22.8°C, oxygen from 7.52 to 11.06 mg/l, salinity from 35.2 to 36.4 psu and pH from 7.99 to 8.27 (Fig. 2). There is a gradient of increasing salinity from the Atlantic to the Mediterranean. This agrees with the general pattern reported by Guerra-García & Izquierdo (2010) for the whole Iberian Peninsula, where Atlantic coast is characterised by higher values of oxygen concentration and turbidity and lower values of temperature and salinity than the Mediterranean coast. We must take into account, however, that other factors can affect the values measures in the Strait of Gibraltar, such as the particular hydrodynamics in the Strait, strong winds, small scale currents, etc.

Regarding with the seasonal fluctuations, seawater temperature showed similar patterns in the five stations considered (Fig. 3), with higher values in August and October, and lower in December and February. This pattern is also in agreement with other studies conducted along the Southern Iberian Peninsula (Guerra-García *et al*., 2009c).

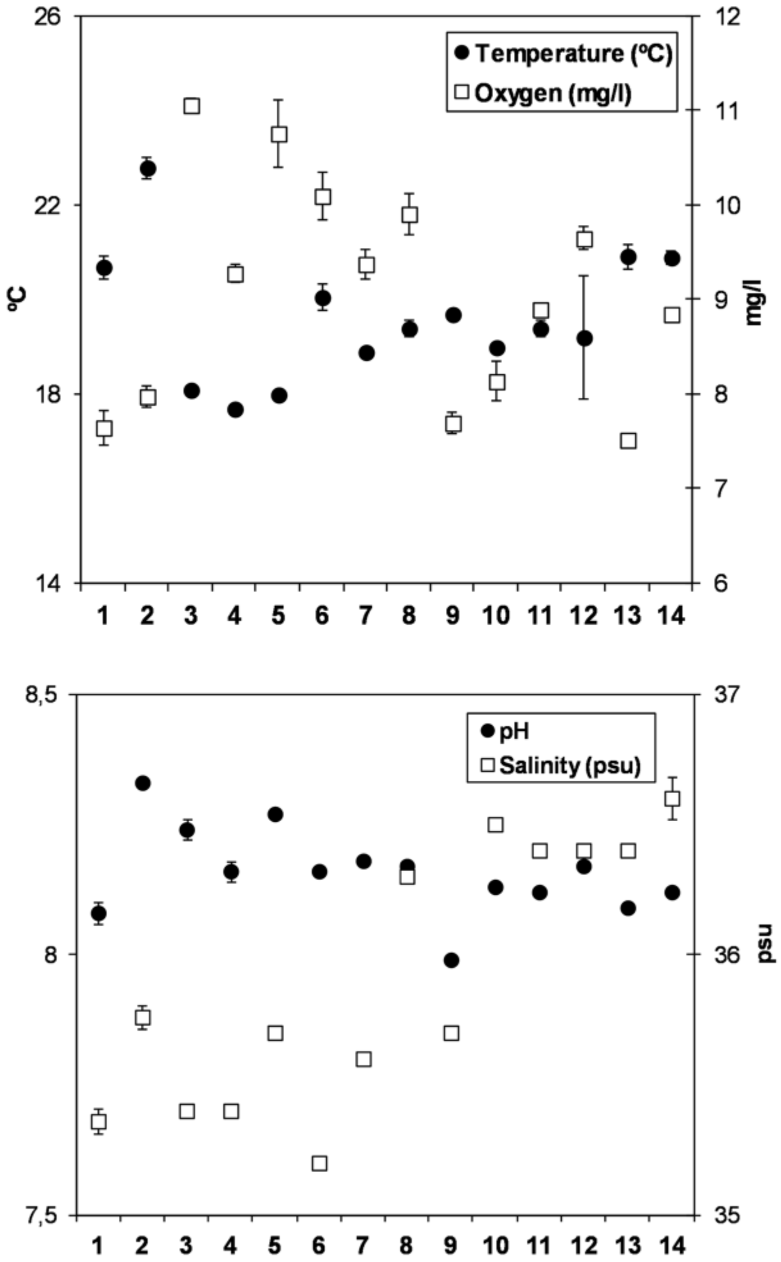

Fig. 2.—Water temperature, dissolved oxygen, pH and salinity measured in the fourteen stations considered. Values are mean ± standard deviation.
Fig. 2.—Temperatura del agua, oxígeno disuelto, pH y salinidad medidos en las catorce estaciones consideradas. Se incluyen valores medios ± desviaciones estándar.

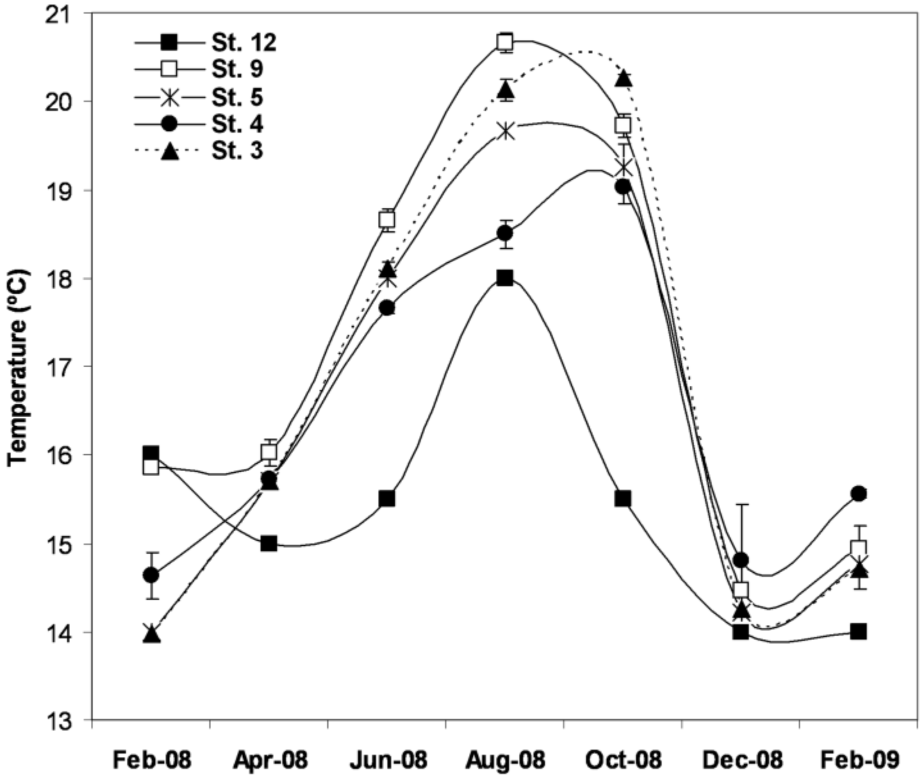

Fig. 3.—Water temperature measured in the five stations considered for the temporal study throughout the year. Values are mean ± standard deviation.
Fig. 3.—Temperatura del agua medida en las cinco estaciones consideradas en el estudio temporal a lo largo del año. Los valores representan la media ± desviación estándar.

Caprellids associated to A. armata: spatial patterns and seasonal fluctuations

Eight caprellid species were found associated to *A. armata* in the 14 stations considered (Fig. 4). The dominant species were *Caprella penantis* and *C. liparotensis*, while *C. equilibra*, *C. grandimana* and *Pseudoprotella phasma* were rare. *Caprella danilevskii* were registered only in the stations with Atlantic influence, whereas *C. hirsuta* was distributed only along the Mediterranean sites. Most of the species found associated to *A. armata* are also common species in other littoral seaweeds of the Iberian Peninsula, such as *Corallina elongata* (Guerra-García & Izquierdo, 2010) or *Halopteris scoparia* (Guerra-García *et al.,* 2009d). Consequently, it seems that the

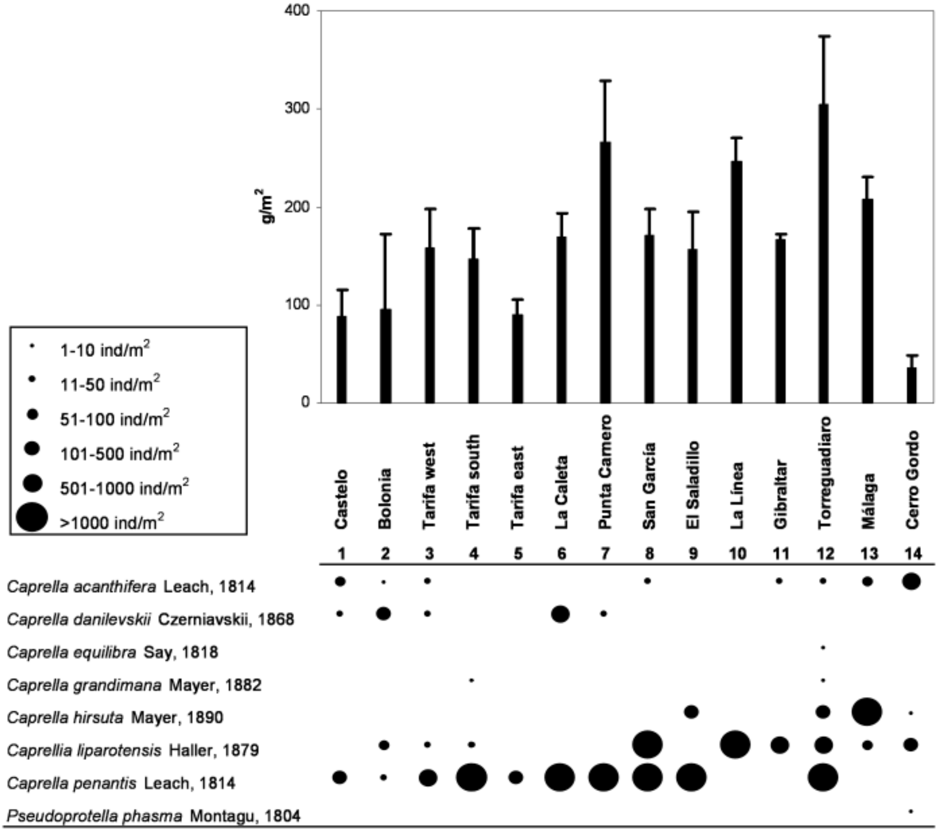

Fig. 4.—Caprellid densities measured in the fourteen stations considered. The histogram represents the *A. armata* biomass (g/m^2) in each station. Values of biomass are mean ± standard deviation.
Fig. 4.—Densidad de caprélidos medida en las catorce estaciones consideradas. El histograma representa la biomasa de *A. armata* (g/m^2) en cada estación. Los valores representan la media ± desviación estándar.

dominant caprellid community of intertidal and shallow water seaweeds is rather unspecific for its substrate. The biomass of *A. armata* measured as g/m^2 (Fig. 4) did not correlated with the number of caprellid species found in each station (r=0.078, p=0.792). Punta Carnero or La Línea showed a low number of caprellid species in spite of having high values of algal biomass, and Cerro Gordo hosted 4 caprellid species being the station with lowest values of algal biomass. However, the maximum number of species per station (6 species) was found in the station with higher biomass of seaweed. This station (Torreguadiaro), although Mediterranean, has a strong

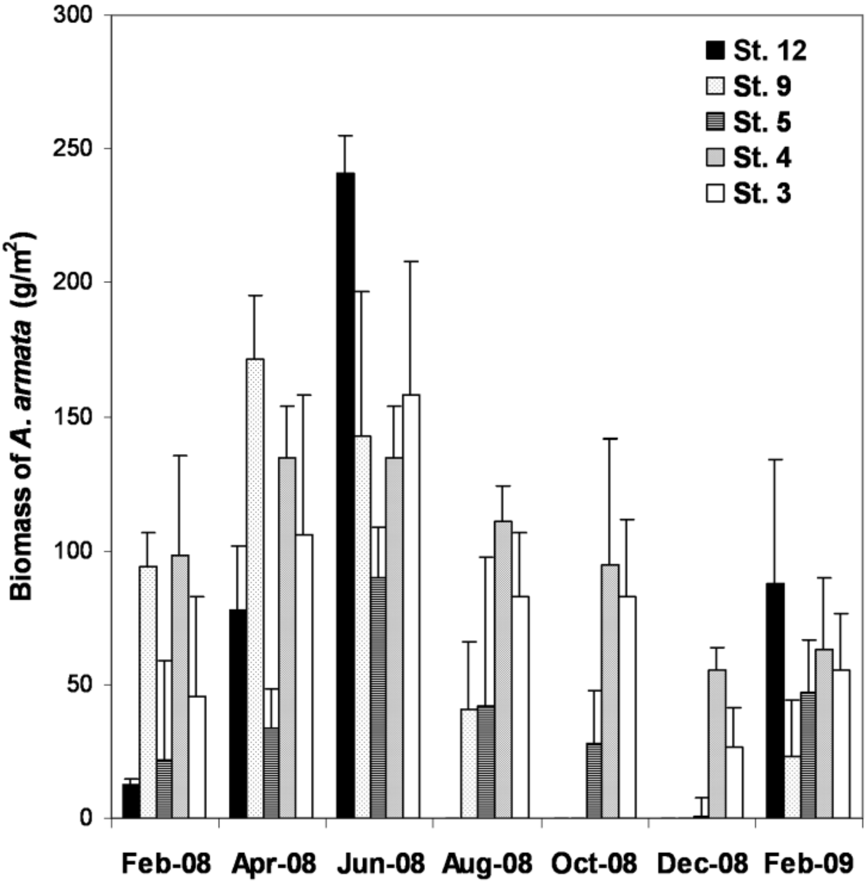

Fig. 5.—Biomass of *A. armata* throughout the year in the five stations considered for the temporal study. Values are mean ± standard deviation.
Fig. 5.—Biomasa de *A. armata* a lo largo del ciclo anual en las cinco estaciones consideradas en el estudio espacial. Los valores representan la media ± desviación estándar.

Atlantic influence due to the current coming from the Atlantic which goes parallel to the coast of Malaga (Arévalo & García, 1983). Consequently, the diversity of the species in this station could also be affected by these factors, and not only by the algal biomass.

In connection with the temporal study, the highest values of *A. armata* biomass were measured in April-June (Fig. 5) while water temperature was higher in August-October. In stations 3, 4, 5 located in the marine reserve Tarifa Island, *A. armata* was present during the whole year. However, in stations 9 and 12 with more Mediterranean influence, the species disappeared during August-December (station 12) or during October-December (station 9), probably due to the high temperatures reached during the summer season, together with the antropogenic impact on summer. The most abundant species throughout the year was *Caprella penantis* (Fig. 6), and *C. hirsuta* (Figs. 4 & 6) was the most discriminating species between the Mediterranean and Atlantic stations, as shown by other studies conducted in different algae (Guerra-García *et al*., 2009d; Guerra-García & Izquierdo, 2010).

Maximum caprellid densities seem to be found in April-June (Mediterranean stations) and August-October (Atlantic stations) showing a slight gradient

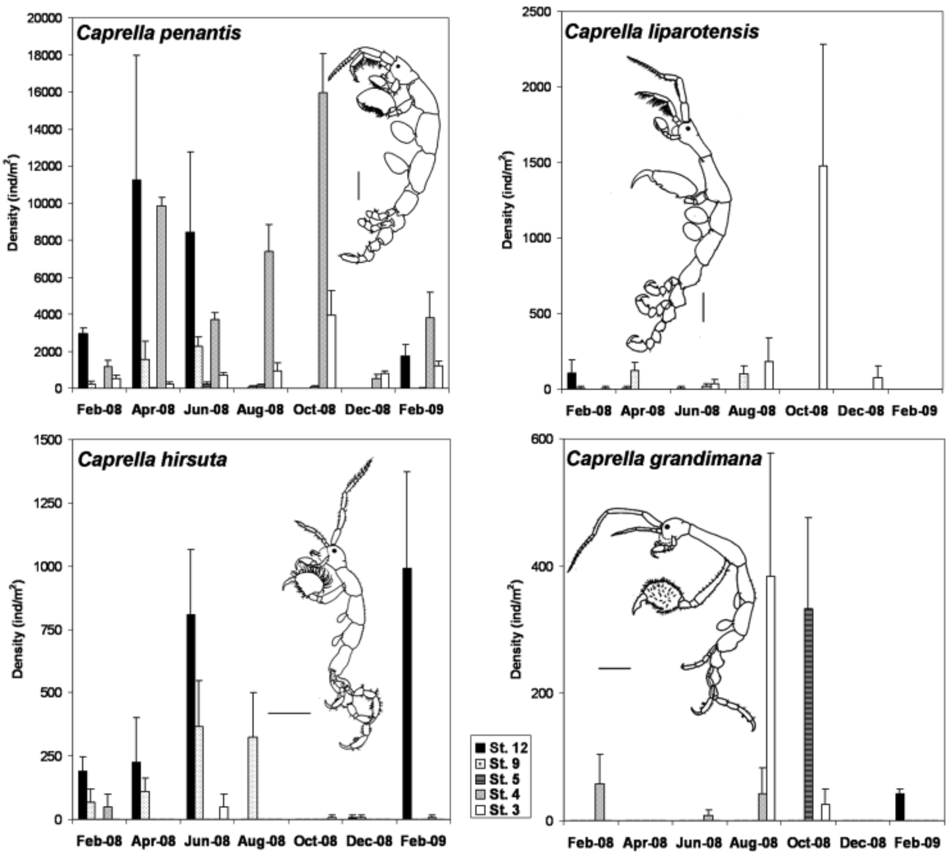

Fig. 6—Density of the dominant caprellids throughout the year. Values are mean ± standard deviation.

Fig. 6.—Densidad de los caprélidos dominantes a lo largo del ciclo anual. Los valores representan la media ± desviación estándar.

along the spatial axis Atlantic-Mediterranean. Probably, optimal seasonal environmental conditions for caprellid cycles are reached sooner in the Mediterranean than in the Atlantic and this pattern could explain the differences in caprellid abundance. For the dominant species, *C. penantis*, the peak of abundance in Tarifa Island (sta. 3, 4 and 5) was in October while in Algeciras (sta. 9) was in June and in Torreguadiaro (the station with more Mediterranean influence) was in April. It is interesting that, in the case of *C. penantis* associated to *Gelidium corneum*, another alga from the low intertidal region of Tarifa Island, the peaks are also in April and June (Guerra-García *et al.*, 2009c), as in the Mediterranean sites, indicating a different seasonal pattern of *C. penantis* abundance depending on the algae. A possible reason to explain why the highest abundances are reached sooner in *G. corneum* than *A. armata* at Tarifa Island, could be related with the fact that *A. armata* has more influence of subtidal zone, and *G. corneum* is more exposed to the emersion periods during low tides in the intertidal, and, consequently, more affected by the higher temperatures than *A. armata*. Anyway, we can assess that the highest abundances for caprellids clinging to *A. armata* were, in general terms, measured from April to October, with the exception of *Caprella hirsuta* which showed a peak in June and other in February. The abundance peaks recorded for *C. penantis* in April and October are in total agreement with the breeding peaks in spring and early autumn reported by Bynum (1978) in the study of the life history of *C. penantis* in North Carolina, USA. Regarding with other substrates and species, the highest abundance of *C. grandimana* associated to *Corallina elongata* has been measured from April-June at Tarifa Island (Guerra-García *et al.*, 2009c) and March-July in Tunisian coast (Zakhama-Sraieb *et al.*, 2011). Conradi *et al.* (2000) found that *Caprella equilibra* and *P. marina* associated to the bryozoan *Bugula neritina* in Algeciras bay showed the highest abundance in September-October for *C. equilibra*, and January and June for *P. marina*. Sconfietti & Luparia (1995) also found for *C. equilibra* in the Northern Adriatic Sea, peaks in Abril and September and a decrease in summer due to high temperatures. In the present study, *C. equilibra* is only occasional in *A. armata*.

Caprellid diversity in native and non-native seaweeds

Considering that the alga *A. armata* is a non-native seaweed that produce toxic substances and is highly unpalatable, we could expect that this invasive substrate could present lower number of species in comparison with other native seaweeds. Indeed, although Pacios *et al.* (2011) demonstrated that, in general, *A. armata* maintains a diverse crustacean community along the whole year, Guerra-García *et al.* (2012) showed an impoverishment in the peracarid community when compared with the native alga *Corallina elongata*. However, this trend measured for peracarid diversity in general, seems to be different for caprellid diversity in particular (Fig. 7). In fact, *A. armata* host high caprellid diversity when compared with other algae along the coast of the Iberian Peninsula and Northern Africa. It has similar values than *Halopteris scoparia* and *Cladostephus spongiosus*, which are the two native seaweeds with the highest caprellid diversity, and also similar caprellid diversity than species of the genus *Cystoseira*. The values registered for *A. armata* are even higher than those measured for *Corallina elongata* or *Jania rubens*. Other invasive species, *Caulerpa racemosa*, do not imply neither an impoverishment in the caprellid number of species of the ecosystems. Nevertheless, in the case of the non-native *Sargassum muticum*, the number of caprellid species is low, but of the same order than in the native *Sargassum vulgare*. In summary, it seems that most of caprellids associated to the native seaweeds in the surrounding of patches of *A. armata*, can also use this non-native seaweeds as a substrates to cling in. Furthermore, we have observed juveniles of *C. penantis* feeding on branches of *A. armata* in spite to the toxic and unpalatable substances present in the seaweed, so the alga could be also a source of food and not only a place to cling on. On the other hand, although there is a lack of studies dealing with the fauna associated with the other invasive species of the genus in the Iberian Peninsula, *A. taxiformis*, preliminary observations seem to indicate a very poor associated fauna. Therefore, exploring chemical composition of the species is necessary to understand possible differences in faunal composition. Consequently, further research is necessary to study how caprellids and other invertebrates solve the problem of toxicity in *A. armata* and which mechanisms are affecting the interactions. It is important investigate not only the spatial patterns and seasonal fluctuations of the seaweed *per se*, but also the associated epifaunal community to properly understand the global interactions in the ecosystems and address correctly the control and management of this invasive seaweed.

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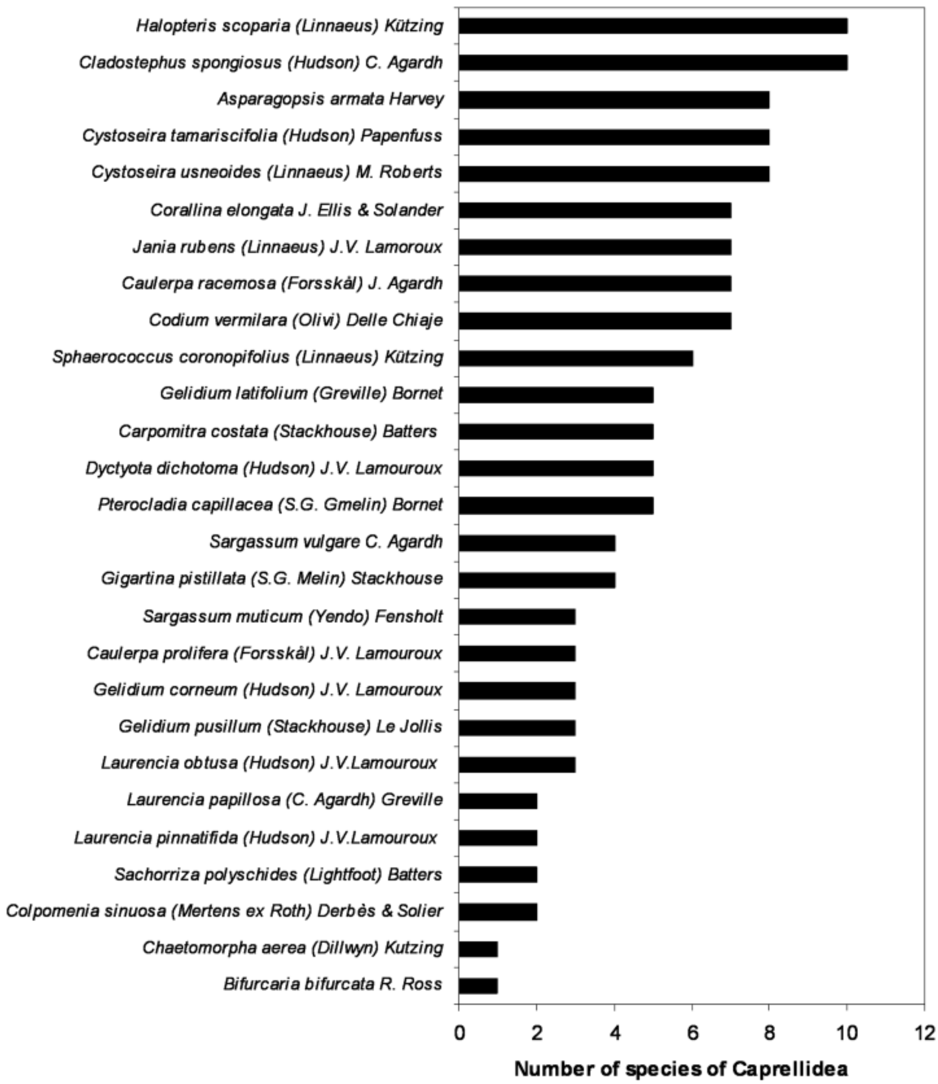

Fig. 7—Comparison of the caprellid species richness in different seaweeds inhabiting the coast of the Iberian Peninsula and Northern Africa. Data taken from: Jimeno & Turón (1995), Sánchez-Moyano & García-Gómez (1998), Guerra-García (2001), Guerra-García & García-Gómez (2001), Guerra-García *et al.* (2002; 2009d; 2010), Vázquez-Luis *et al.* (2009), Guerra-García & Izquierdo (2010), Zakhama-Sraieb *et al*. (2011).

Fig. 7.—Comparación de la riqueza de especies de caprélidos en distintas algas de la costa de la Península Ibérica y norte de África. Los datos se han tomado de: Jimeno & Turón (1995), Sánchez-Moyano & García-Gómez (1998), Guerra-García (2001), Guerra-García & García-Gómez (2001), Guerra-García *et al.* (2002; 2009d; 2010), Vázquez-Luis *et al.* (2009), Guerra-García & Izquierdo (2010), Zakhama-Sraieb *et al*. (2011).

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