

## Seasonal fluctuations of some biological traits of the invader *Caprella scaura* (Crustacea: Amphipoda: Caprellidae) in the Mar Piccolo of Taranto (Ionian Sea, southern Italy)

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**SUMMARY:** *Caprella scaura* is an epifaunal amphipod crustacean that originates in the western Indian Ocean and has spread throughout the world, but very little is known about fundamental aspects of its biology. This paper is the first presentation of its life history traits in an invaded region. The study was conducted in the Mar Piccolo basin (southern Italy, Ionian Sea), over a one-year period. All biological parameters showed a strong seasonal pattern, breeding peaked twice during the year and the number of eggs in the ventral brood pouch ranged from 5 to 72. The sex ratio was generally close to 1:1. A strong correlation between total length of ovigerous females and number of eggs was observed. The mean length of both mature males and mature females was 10.63 and 7.70 mm, respectively. The results of this study showed that the population dynamics of this species was not dissimilar to that of other caprellids or marine epifaunal Crustacea. This caprellid has given rise to a stable population in the Mar Piccolo; it was present all year round in the study area but its density suggests that it is not yet a strong invader.

**Keywords:** *Caprella scaura*, introduced species, lagoon area, Mar Piccolo, Ionian Sea.

**RESUMEN:** FLUCTUACIONES ESTACIONALES DE ALGUNAS CARACTERÍSTICAS BIOLÓGICAS DE LA INVASORA *CAPRELLA SCAURA* EN EL MAR PICCOLO DE TARANTO (MAR JÓNICO, SUR DE ITALIA). – *Caprella scaura* es un crustáceo anfípodo originario del Océano Índico occidental, que se ha extendido por todo el mundo. Sin embargo, poco se conoce sobre la biología de la especie. Este artículo es un primera presentación de algunas características de la especie en una región invadida. El estudio se realizó en la cuenca del Mar Piccolo (sur de Italia, Mar Jónico) durante un año. Todos los parámetros biológicos mostraron un patrón estacional con picos reproductivos en dos ocasiones durante el año y con un número de huevos entre 5 y 72. La proporción de sexos estuvo en torno 1:1. Se observó una fuerte correlación entre la longitud total de hembras ovígeras y el número de huevos. La longitud media de las hembras y los machos maduros fue 10.63 y 7.70 respectivamente. Los resultados de este estudio mostraron que la dinámica poblacional de esta especie no es muy distinta al resto de crustáceos caprellidos. Se puede hablar de una población estable en el Mar Piccolo, ya que estuvo presente durante todo el año en el área estudiada, sin embargo su densidad sugiere que no parece ser un invasor fuerte aún.

**Palabras clave:** *Caprella scaura*, especies introducidas, áreas de laguna, mar Piccolo, mar Jónico.

### INTRODUCTION

Alien species continuously increase in numbers in Mediterranean waters. Invading organisms may affect marine systems by altering ecosystem processes, disrupting trophic dynamics, disturbing and degrading habitats, or directly competing, parasitizing, or prey-

ing upon native species (Ruiz *et al.* 1999). The success of introduced organisms depends on many factors, including their adaptability to new environments and survival under unfavourable conditions, linked to life-cycle features such as high reproductive potential and dispersal ability (Miglietta and Lessios 2009). Polluted or physically degraded environments are more exposed

to invasion than pristine ones (Galil 2007). For this feature, coastal lagoons and harbours are susceptible to biological invasions (Occhipinti-Ambrogi *et al.* 2011).

Along the Italian coasts, a recent update list reported 165 alien species, in many cases native of tropical regions of the world (Occhipinti-Ambrogi *et al.* 2011). The reason is surely related to the increase in human activities, such as aquaculture and recreational and commercial navigation (Occhipinti-Ambrogi *et al.* 2011).

Knowledge of the life history traits of a non-native species is a preliminary step towards understanding the invasive process and impacts on the invaded ecosystems (Krylov *et al.* 1999, Garcia-Meunier *et al.* 2001) in order to develop management practices and policies (Bollens *et al.* 2002, Allendorf and Lundquist 2003, Townsend 2003).

A small proportion of introduced species become established (Lodge 1993) and population characteristics may contribute to successful establishment (Newsome and Noble 1986, Nichols *et al.* 1990). Non-native species are generally thought to be 'r' strategists i.e. those which respond opportunistically when conditions are favourable (Lodge 1993, Van der Velde *et al.* 1998). Rapid growth, production of several generations per year, early maturity and high fecundity are crucial to the establishment of an alien species as an invader (Van der Velde *et al.* 1998, Devin *et al.* 2004). These criteria do not guarantee the success of an invader but indicate its potential to invade a suitable habitat.

According to the above, the Caprellidae are very successful as introduced species. Indeed, *Caprella acanthogaster*, *C. californica*, *C. natalensis*, *C. mutica* and *C. scaura* have all been identified outside their native range (Carlton 1979, Occhipinti-Ambrogi 2000, AMBS 2002, Ranasinghe *et al.* 2005). Unfortunately, the population biology of caprellid species has been little studied and it is not possible to complete a comparison between native and non-native species.

*Caprella scaura* is a crustacean amphipod of the Caprellidae family (suborder Caprellidaea) that is distributed worldwide. It was originally described from Mauritius (western Indian Ocean) by Templeton (1836) and successively has extended its geographic distribution in the Indian Ocean (Arimoto 1976, Laubitzi 1995, Ren and Zhang 1996, Guerra-García 2004); in the Pacific Ocean (Mayer 1890, Dougherty and Steinberg 1953, Guerra-García 2003, Guerra-García and Takeuchi 2003, 2004, Guerra-García and Thiel 2001, Thiel *et al.* 2003); and in the Atlantic Ocean (Stimpson 1857, Mayer 1890, Serejo 1998). The first record of *C. scaura* in the Mediterranean Sea dates back to 1994 from the lagoon of Venice in the Northern Adriatic sea (Mizzan 1999). Further records were from the Gulf of Amvrakikos, Greece in 2002 (Krapp *et al.* 2006); from the Ravenna harbour, Italy in 2004 (Sconfiatti *et al.* 2005); from the Tyrrhenian Sea at Livorno, in 2004 (Galil 2008); from eastern Sicily in 2004 (Krapp *et al.* 2006); from the Iberian Peninsula in the 2005 (Martinez and Adarraga 2008); and

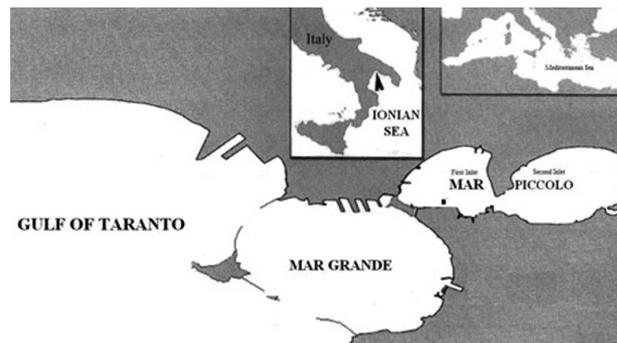


FIG. 1. – Map of the study area. Filled square indicates the sampling site in Mar Piccolo basin.

from Mar Piccolo, northern Ionian Sea, southern Italy (Eleftheriou *et al.* 2011).

Caprellids typically inhabit the littoral zone of coastal waters, but have been reported at depths of up to 4790 m (McCain and Steinberg 1970). They often represent dominant members in epibenthic communities, inhabiting macroalgae, hydroids, ascidians, anthozoans, bryozoans, sponges and sea grasses, to which they are well adapted to clinging with their hind appendages (McCain 1968, Takeuchi and Hirano 1992, Guerra-García 2001, González *et al.* 2008).

While the geographical distribution of *C. scaura* is well studied, there is still little information on its biology [Lim and Alexander (1986), Aoki (1999), Schulz and Alexander (2001)]. The aim of our study was to describe the seasonal fluctuations of some life history traits of *C. scaura* by estimating its reproductive period, fecundity, population structure, sex ratio and size-frequency. These biological traits can be the key to explaining the potential invasive success of this caprellidae in Mar Piccolo basin (Apulia region, southern Italy, Ionian Sea).

## MATERIALS AND METHODS

### Study site

The study was undertaken in Mar Piccolo of Taranto (40°28'N; 17°15'E), which is an inner, semi-enclosed basin located to the north of Taranto town (Fig. 1). It has a surface area of 20.72 km<sup>2</sup> and is divided by two rocky promontories into two inlets, the First and Second, which have a maximum depth of 13 and 8 m, respectively. The poor hydrodynamism and the reduced water exchange with the open sea cause a pronounced water stratification, mostly in summer. Tidal range does not exceed 30-40 cm. Most of the hard substrata are artificial. The soft substrata are sandy near the shore and muddy in the central zone of both the inlets. Mar Piccolo basin is subject to urbanization, industry, agriculture, aquaculture and commercial fishing: the main problems of environmental impact are due to the presence of a water scooping machine of the still industry, which uses seawater from the basin for cooling, and to the largest mussel farm (*ca.* 30000 t y<sup>-1</sup> of mussels).

## Sampling design and collection of data

A single station was considered as representative of the intertidal area (covering an area of approximately 250 m<sup>2</sup>), where the caprellids were present. Sampling was performed monthly, from January 2008 to December 2008. Samples were collected randomly, in triplicate, on seaweed beds and on the algal cover of rocky substrates, at depths of 0.5 m, using a square metal box (50 x 50 cm). Immediately after the collection, samples were fixed in a 5% formalin solution, and subsequently processed in the laboratory. The collected algae were washed through a 0.25 mm mesh sieve and the fresh weight of the samples was determined with a field balance after absorbing moisture with a blotting paper. In each sampling, water temperature, salinity, pH and dissolved oxygen were measured using a multiparametric probe (ME CTD 1500).

All organisms were identified at the taxonomic level of species. The identification of the *C. scaura* specimens was based on the morphological descriptions provided by Templeton (1936), McCain (1968), Guerra Garcia (2003), Krapp *et al.* (2006) and Martínez and Adarraga (2008). The specimens were photographed fresh before 5% formalin fixation, and then transferred to 75% ethanol for permanent preservation.

The density of individuals (N ind m<sup>-2</sup>) and length-frequency distribution of population for each sampling month were performed. Observations and measurements were made using a stereomicroscope with a graduated eyepiece. Each individual was measured from the anterior margin of the head to the posterior margin of the telson with an accuracy of 0.5 mm.

Sexual differentiation and maturity of females, i.e. the development of oostegites on the ventro-lateral margin of pereonites III and IV and the development of eggs in the ovaries, were recorded. Using a modification of Takeuchi and Hirano (1991), female stages were classified as immature and mature. The immature females could be distinguished from males by the development of oostegites on pereonites 3 and 4. Females were identified as mature when the oostegites were fully developed, forming the brood pouch (often with eggs/embryos inside). Although there is no morphological character to identify maturation in males, it is known that large males have elongated pereonites 2, base of gnathopod 2 and propodus of gnathopod 2, while females lack these characteristics. Smaller individuals lacking characteristics of either sex were defined as juveniles. The sex ratio ( $\frac{\text{♂}}{\text{♀}}$ ) of the population was estimated and deviations from unity were assessed by a  $\chi^2$  test.

Different stages of embryonic development were identified following the classification of Weygoldt (1924) and Skadsheim (1982), with some modifications. In stage 2 the hyaline membranes have disappeared, the egg is homogeneous internally and the egg membrane fits tightly around the egg mass. In stage 3 a ventral cleft is visible, extending into a horseshoe-

shaped furrow and separating the future abdomen from the cephalothorax. In stage 4 the differentiation of appendages and embryo organs have appeared, the embryo is characterized by its comma-like shape and the dorsal organ is formed. In stage 5 the antennae of the cephalothorax have developed, appendages are segmented and the eye is clearly visible. Finally, in stage 6 the juvenile released from the egg membrane.

## Data analysis

Results are presented as mean values  $\pm$  standard deviation (SD). Prior to statistical analysis, the data were tested for homogeneity of variances and normal distribution (SPSS, Version 12.0). Normal distributed data were tested with parametric methods. Multiple regression analysis was applied to evaluate the influence of environmental variables and algal biomass on number of individuals (Statgraphics® Version 2.1). Abundance data were analysed for significant temporal variability by one-way ANOVA. If the ANOVA test was significant, differences in density between adjacent sampling periods were tested for significance using the Tukey HSD test. A significance level of  $p < 0.05$  was used for all tests.

The partial fecundity index, defined as mean brood size/mean breeding female size and relative size when reaching maturity index ( $M_{\text{ind}}$ ), defined as minimal/mean breeding female size, were determined. The relationship between total length of females and the brood size was evaluated using linear regression analysis (Statgraphics®, version 2.1).

## RESULTS

The sampling site of *Caprella scaura* was characterized by extensive beds of *Chaetomorpha linum* throughout the year, while during the summer months *Hypnea cornuta* was the most abundant species (Cecere and Petrocelli pers. comm.). Moreover, *C. scaura* was found associated with several species common in the Mediterranean shore fauna, most of which were the gastropods *Gibbula adansonii* and *Tricolia tenuis*, the isopod *Cymodoce truncata*, the amphipods gammaridea *Gammarus aequicauda*, *Elasmopus rapax* and *Gammarella fucicola* and the amphipods caprellidae *Caprella equilibra* and *Phtisica marina*.

All environmental parameters considered in this study varied through time, exhibiting a temporal pattern typical for a temperate region (Fig. 2). The temperature varied strongly, reaching the maximum value in August (30°C) and a minimum in February (7°C); the annual range in salinity was 36.85‰ to 38‰; pH values varied in a range of estuarine water (7.88-8.42) and oxygen concentrations ranged from 6.89 mg/l in September to 8.33 mg/l in February.

The monthly population analysis of *C. scaura* was performed to give a single representative year. A total of 617 individuals of *C. scaura* were collected in the sampling area during the whole study period. Multiple

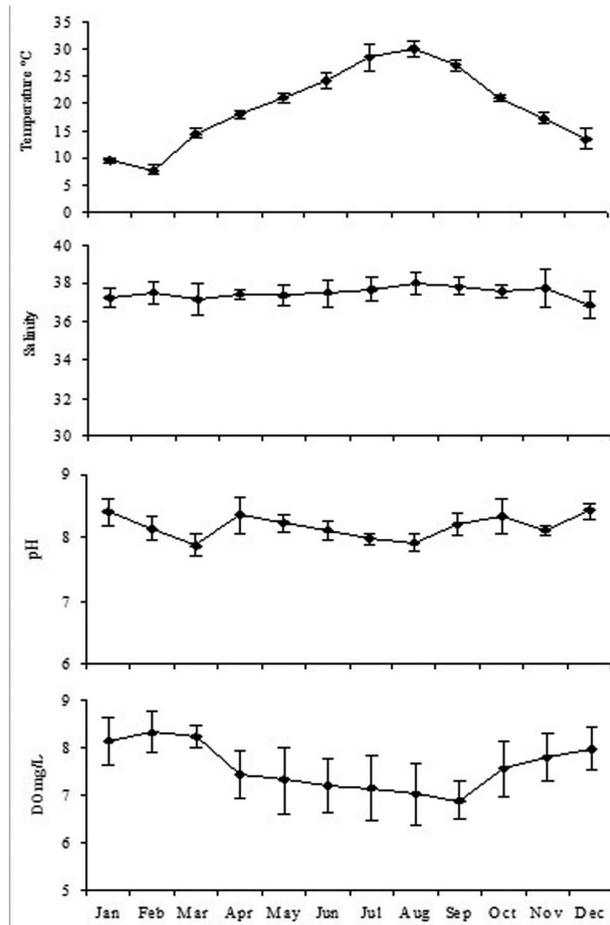


Fig. 2. – Temporal distribution of environmental parameters investigated in the area during the study period.

regression analysis indicated that the density was not influenced by environmental parameters measured and by algal biomass ( $F=1.20$ ;  $p>0.05$ ) (Table 1, Fig. 3).

Figure 3 shows the population density (ind.  $m^{-2}$ , mean [SD]) and the total macroalgal biomass (g wet wt  $m^{-2}$ ) during the study period. There was a conspicuous seasonal fluctuation of macroalgal biomass, with higher values in March-April and lower ones in summer (Fig. 3). Population density of *C. scaura* in the Mar Piccolo basin also varied significantly during the year (ANOVA;

TABLE 1. – Multiple regression analysis of individual numbers, with environmental variables and algal biomass (number of cases = 12).

	N° ind. $m^{-2}$	
	Beta	<i>p</i>
adj. $R^2$	0.31	
F	1.20	
<i>p</i>	>0.05	
T°C	1.31	>0.05
S‰	0.21	>0.05
pH	0.62	>0.05
DOmg $l^{-1}$	2.36	>0.05
Algal biomass (g $m^{-2}$ )	-1.02	>0.05

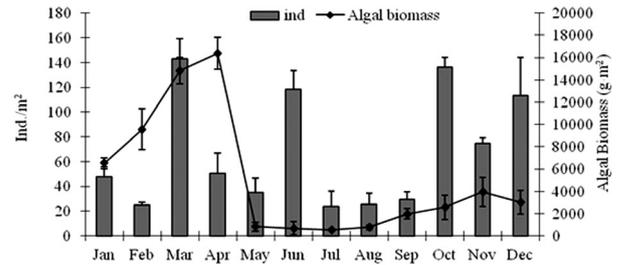


Fig. 3. – Monthly variation in population density (ind.  $m^{-2}$ , mean [SD]) and total algal biomass (g wet wt  $m^{-2}$ , mean [SD]) during the study period.

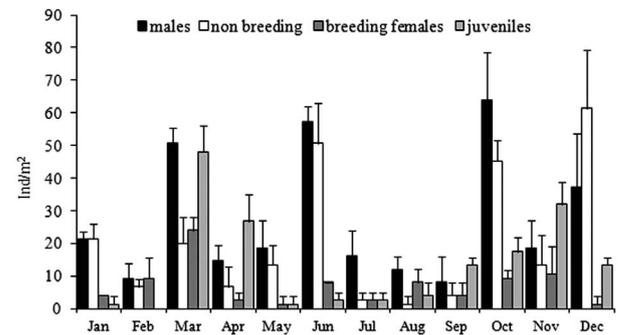


Fig. 4. – Monthly variation of the demographic categories density (ind.  $m^{-2}$ , mean [SD]) during the study period.

$F=33.97$ ,  $p<0.001$ ). It was highest in March ( $142.8 \pm 16.16$  ind.  $m^{-2}$ ), followed by October and June, while in May, February and summer months (July, August and September) the population reached minimum density (24-35 ind.  $m^{-2}$ ) (Tukey test;  $p<0.05$ ) (Fig. 3). Therefore, in general terms, population density showed a pattern similar to that of the macroalgal biomass, but the statistical analysis revealed that fluctuation of *C. scaura* density was not influenced by biomass of algae ( $p<0.05$ ).

The demographic structure of the population underwent considerable fluctuations during the study period (Fig. 4). All demographic categories were present all year round (except juveniles in February). The juveniles represented 20% of the total population, with low values in summer and during the late winter months (January and February). The proportion of juveniles increased in March/April and from September to November (Fig. 4).

The breeding females represented only 10% of the total population during the year. The highest number of breeding females occurred in March, February and November and the lowest in mid-spring (April/May), July and December (Fig. 4). However, if we take into account the percentage of breeding females with respect to the total number of females, the highest percentage was observed in August (86% of all females) (Fig. 5).

The population structure of *C. scaura* is shown with the size-frequency histograms (Fig. 6). For each month, the four demographic categories are represent-

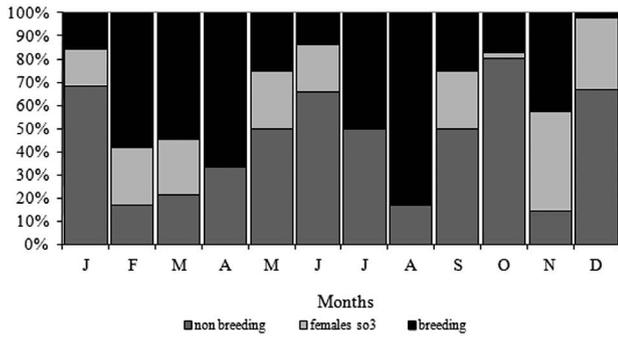


Fig. 5. – Proportion of breeding vs non-breeding females of *C. scaura* during the sampling period.

ed by their frequency in each of the 9 size classes. The sizes of the individuals ranged from 2.74 to 23 mm and the highest abundance corresponded to the range sizes (TL) of 6.1-8 and 8.1-10. *C. scaura* males were longer than females, the uppermost length classes being constituted exclusively of males. In particular the length of the largest male was 23 mm, while that of the largest female was 9.68 mm. From the data size of the different categories (Table 2), it can be inferred that males and females mature at about the same body size, but the average size of males (10.63 mm) is also greater than that of all the female categories. There are no breeding females less than 5.64 mm in size. The largest female category is that of the breeding female (7.70 mm). The juveniles are 3.86 mm in average length.

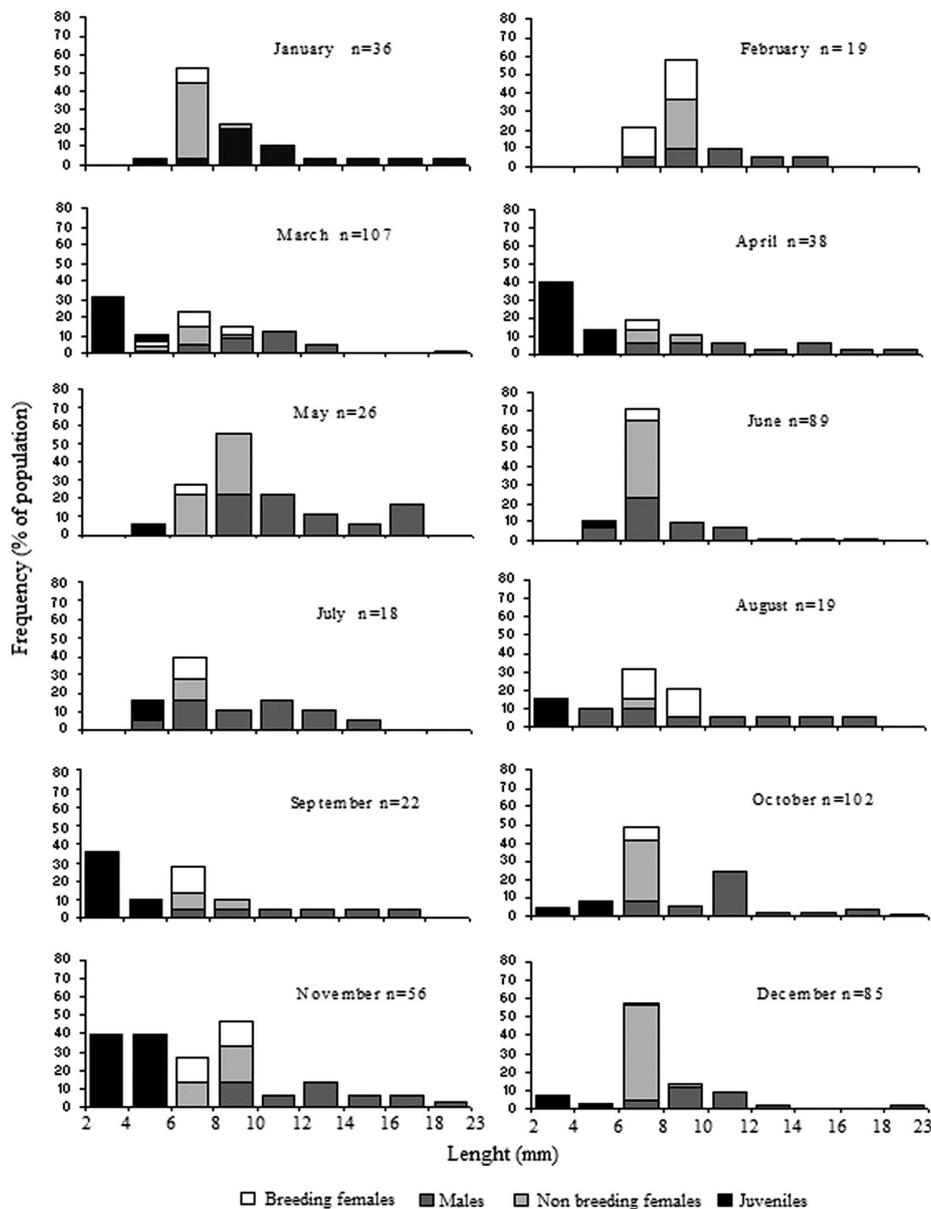


Fig. 6. – Population structure (histograms of the monthly size-class distribution) of *C. scaura* in Mar Piccolo.

TABLE 2. – Mean (SD), maximum and minimum total length (TL) of the four categories of *C. scaura*.

TL (mm)	Males	No-breeding females	Breeding females	Juveniles
Minimum	5.20	5.05	5.64	2.74
Maximum	23.00	9.68	9.57	4.82
Mean (SD)	10.63 (3.36)	7.08 (0.93)	7.70 (0.97)	3.86 (0.59)

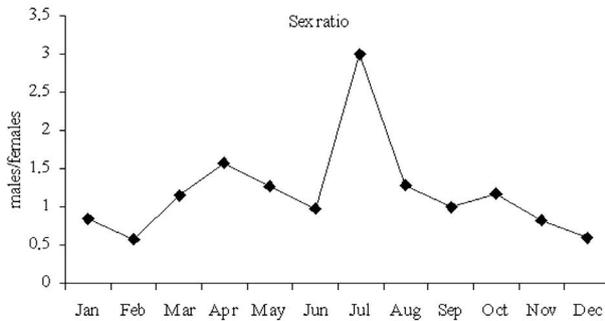


Fig. 7. – Sex ratio in studied population of *C. scaura* over entire sampling period.

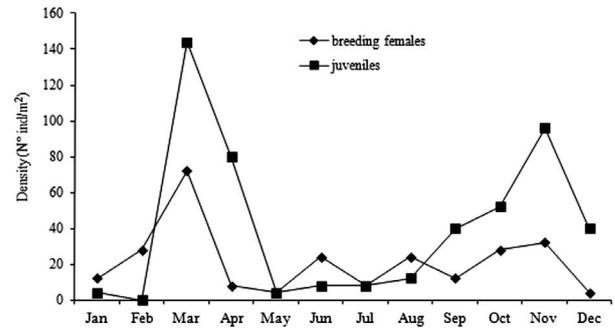


Fig. 8. – Monthly variation in density of *C. scaura* breeding females and juveniles.

The total body length (LT) of breeding females is at a maximum in autumn-winter months, with a peak in November (8.52 mm); it decreases significantly in spring and early summer, with a significant minimum in May (6.14 mm) ( $F = 4.06, p < 0.05$ ).

The sex ratio was generally close to 1:1 ( $\chi^2=0.018; n=12; p>0.05$  (Fig. 7). There were significantly more females in December than in July, when males were significantly more abundant in the population ( $p<0.05$ ) (Table 3).

Although breeding and newly hatched individuals occurred in the population almost throughout the year, two pronounced peaks of newly hatched individuals were recognizable in the population of *C. scaura*: one in March, when juveniles accounted for 34% of the population and one in autumn, when they accounted for 26% of the population (Fig. 8). After spring breeding, the proportion of juveniles decreased rapidly, whereas the proportion of males and females increased. The post-spawned adult males and females disappeared after spring breeding. Maximum body length was attained in April and May by the overwintering

individuals, indicating a probable greater longevity for the autumn recruits.

Multiple regression analysis indicated that breeding of *C. scaura* was not influenced by the environmental parameters measured ( $F=3.64; p>0.05$ ), but breeding occurred mainly at intermediate temperature values.

The mean body length of breeding females was 7.70 mm. The smallest gravid female had a body length of 5.64 mm in March, while the largest one had a body length of 9.57 mm in September. The maturity index (minimal size/mean size of gravid females) was low (0.76), which may be because females reach maturity at a relatively young age. The mean brood size was 42 and ranged from 5 to 72 eggs per brood. Partial fecundity reached a fairly high value of 5.71.

The fecundity index (the number of eggs divided by the female body length) was calculated to account for possible size differences in breeding females, as in Ladewig *et al.* (2006). The highest values were obtained in October and November (mean [SD] of 6.99 [1.11] and 6.33 [0.33], respectively) and the lowest in May, June and July (mean value and standard deviation of  $4.13 \pm 0.10, 4.92 \pm 0.32$  and  $4.47 \pm 1.05$  respectively).

The linear regression indicated a strong correlation between the length of ovigerous females and their brood sizes ( $r=0.84, n=60, p<0.001$ ) (Fig. 9).

Ovigerous females were present each month, indicating that the breeding period occurred continuously throughout the year. However, despite the presence of females of reproductive size, breeding almost ceased during the summer months and the production of offspring did not take place until September-October, when recruitment was resumed. Moreover, the fact that the smallest breeding females were observed in late spring-early summer indicates that the fastest developing individuals born in March/April may have attained reproductive size and matured within 1-2 months.

TABLE 3. –  $\chi^2$  and sex ratio (males to females).

Month	$\chi^2$	Sex ratio
January	0.25	1:1.16
February	1.3	1:1.42
March	0.35	1:0.86
April	0.89	1:0.64
May	0.53	1:0.70
June	0.011	1:1.2
July	4.0*	1:0.33
August	0.25	1:0.78
September	0.00	1:1
October	0.55	1:0.85
November	0.50	1:1.17
December	4.81*	1:1.40

Asterisks refer to significant  $p$  values. \*  $p<0.05$

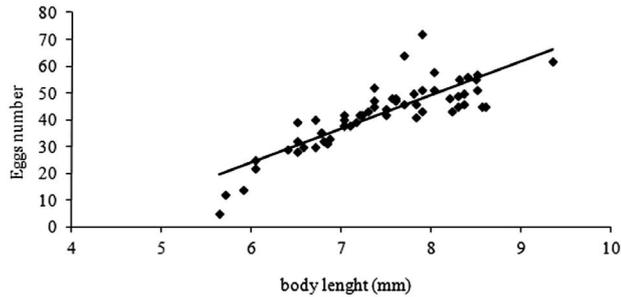


Fig. 9. – Relationship between female body length (mm) and number of eggs.

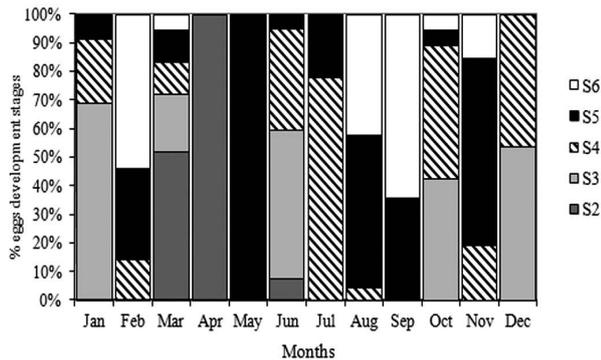


Fig. 10. – Proportion of females of *C. scaura* carrying embryos in different development stages (S).

The analysis of data presented in Figure 10 allowed us to estimate the length of egg development time. More than 45% of all examined breeding females were carrying embryos in early developmental stages. Moreover, the eggs in the marsupium of a female were not always at the same development stage. Reproductive synchrony was higher in April, May, when 100% of the examined embryos were of the same developmental stage. Maximum egg production (number of breeding female  $\times$  average brood size) occurred during February/March and in autumn months. Juveniles were also found inside the marsupium, sometimes together with earlier developmental stages of eggs.

## DISCUSSION

*Caprella scaura* was present all year round in the study area, suggesting that the population had successfully established at this location, albeit with great density fluctuations. Several authors, including Martínez and Adarraga (2008), reported *C. scaura* as a strong invader that can colonize a wide geographical range. However, these authors based their results on the high densities measured in Roses Bay (Gerona, Spain; 12925 ind.  $m^{-2}$ ).

In Mar Piccolo basin, the species displayed a strong seasonal pattern in the biological parameters analysed. The density showed a peak in March ( $142.8 \pm 16.16$  ind.  $m^{-2}$ ), a decline in summer months, and then an increase again in October ( $136 \pm 8$  ind.  $m^{-2}$ ). The latter peak represented the starting point of the overwintering

generation, which grew during the colder months and reached larger sizes.

The decreased density of the adult population during the summer months can be explained by two most likely reasons: the death of adult individuals (most large-sized individuals disappeared after May), and predation, which is a major factor in amphipod population regulation (Savino and Stein, 1982). Indeed, the species is an important source of food for other benthic animals and fishes of commercial value (Beare and Moore, 1996; Woods, 2009).

The Mar Piccolo basin plays an important role in supporting the growth and survival of juveniles of fish species that periodically colonize this transitional ecosystem, showing peaks of juvenile abundance during the spring-summer months (Prato, unpublished data). Individuals of *C. scaura* that survived fish predation may continue to grow and then reproduce in the next breeding periods.

The maximum density of *C. scaura* found in the Mar Piccolo was below the density recorded in the abovementioned Roses Bay (12925 ind.  $m^{-2}$ ) (Martínez and Adarraga 2008), in the Canary Islands (3080 ind.  $m^{-2}$ ) and in Cadiz (35945 ind./1000 g of *Bugula neretina*) (Guerra-García 2011). In Mar Piccolo basin, *C. scaura*'s density was also quite low compared with that of some native amphipod species (Prato and Biancolino 2003, 2006).

It was found associated with seaweeds (*Chaetomorpha linum* and *Hypnaea cornuta*), which were present throughout the year at the study site, although maximum values of biomass were recorded in March-April and minimum values during the summer months, probably due to the higher temperatures. This fact probably led the associated caprellids to be also present throughout the year with a similar seasonality to that of seaweeds. However, the seasonal fluctuation of *C. scaura* density was not significantly influenced by the biomass of algae. Guerra-García *et al.* (2010, 2011), in a study conducted at Tarifa Island (Strait of Gibraltar), reported that the seasonal fluctuation of peracarids was directly related to the seasonality of the main seaweeds with which they were associated and also to external factors, such as hydrodynamism, oxygen and weather conditions.

The physiological ability of a species to reproduce and establish sustainable populations in a new area depends primarily on abiotic environmental parameters (Lennon *et al.* 2001, Sakai *et al.* 2001, Stachowicz *et al.* 2002, Füreder and Pöckl 2007), but in this study the density of *C. scaura* population was not influenced by the environmental parameters measured.

Although incubating females were present all year round in the population, recruitment that occurred in spring almost ceased during the summer, peaked in autumn and decreased in winter (Fig. 4).

The common pattern of caprellid reproduction is continuous throughout the year, with peaks in spring and late summer-autumn (Caine 1979, Takeuchi and Hirano 1992).

The shortest ovigerous female was 5.64 mm long with 5 eggs in the brood pouch; the longest reached 9.57 mm and carried 62 eggs. There was a positive correlation between female length and number of eggs of *C. scaura*, also found for *C. mutica* and other caprellids in previous studies (Caine 1979, Vassilenko, 1991); this feature is a common trend in amphipods (Sainte-Marie 1991, Prato and Biandolino 2006).

The positive relationship between female body size and brood size indicates a higher fecundity in autumn–winter, because of the larger body size of mature females in these cohorts.

The number of eggs in females of this study was  $42 \pm 12.2$ ,  $n=59$ , similar to that found in Cádiz ( $41.4 \pm 12.8$ ,  $n=22$ ) by Guerra-García *et al.* (2011). Vassilenko (1991) found the fecundity of 6 *Caprella* species to range from 4 to 322 eggs per female.

The fecundity of *C. scaura* females of a similar size was quite variable. This could be due to constraints during sampling and sorting in the laboratory (e.g. variable egg loss from the marsupium). Fecundity of caprellids varies seasonally, being a function of female size (Vassilenko 1991). Female caprellids breeding in spring were much larger and more fecund than those breeding in summer (Vassilenko 1991). Bacela *et al.* (2009) underlines that the invasive species are characterized by very high fecundity, fast growth and attaining the maturity early. According to the above, the *Caprellidae* should be very successful as introduced species. Indeed, *Caprella acanthogaster*, *C. californica*, *C. natalensis* and *C. mutica* have all been identified outside their native range (Carlton 1979, AMBS 2002, Ranasinghe *et al.* 2005, Ashton *et al.* 2007). Unfortunately, the population biology of caprellid species has been little studied and it is not possible to make a comparison between native and non-native species.

Comparing *C. scaura* to other invasive species of gammarids, the reproductive performance of *C. scaura* was high with a maximum eggs number of 72 produced by a single female. This result was very low compared with that reported by Cook *et al.* (2007) for *Caprella mutica*, which showed a maximum of 316 eggs in a single brood pouch (Cook *et al.* 2007). On the other hand, Takeuchi and Hirano (1992) reported an egg number of 50 and 32 for *C. danilevskii* and *C. okadai*, respectively and Bynum (1978) reported an egg number of about 55.8 for *C. penantis*. However, it should be stressed that fecundity and size of mature individuals may differ largely among sites.

The maturity index of *C. scaura* was 0.76. It can be interpreted that it reaches maturity later than other alien invasive species of gammarids occurring in European fresh waters, such as *Dikerogammarus villosus* (0.57), *D. haemobaphes* (0.57–0.70), *Gammarus tigrinus* (0.50) and *Obesogammarus crassus*. (Bacela *et al.* 2009). It is difficult to compare the number of eggs carried by caprellids with the number carried by gammaridean amphipods because their body shapes are so different, but if total length is taken as a rough

measure, *C. scaura* reached maturity later than most gammarideans.

Statistical analysis indicated that breeding was not influenced by the environmental parameters measured ( $p < 0.05$ ), but breeding occurred mainly at intermediate temperature values. Extreme temperatures during the winter and summer probably deterred breeding of *C. scaura*, while moderate temperatures during the spring and autumn were apparently favourable for reproduction. Male Caprellidae are typically larger than females. Caine (1979) suggested several explanations for this difference: adult females have a higher rate of unsuccessful moultings due to the encumbrance of a brood pouch; intraspecific aggressive behaviour among males reduces the number of smaller-size males; the different sexes have different levels of camouflage, the brood pouch of ovigerous females being visually obvious. The smaller size of females was also explained by Dias and Sprung (2004) in terms of greater investment of energy in reproduction, making it difficult for them to continue to grow at the same pace as males. This also accounts for the pattern of size-frequency distribution of *C. scaura*: juveniles dominated the smaller size classes (0–4 mm) and were much more abundant than males and females, summation led to a peak in females (6–8 mm), and males dominated the larger size classes (10–23 mm).

The largest female recorded in this study had a length of 9.68 mm. Martínez and Adarraga (2008) and Krapp *et al.* (2006) found a maximum length of 13 to 13.5 mm for females recorded in Roses Bay (Girona, Spain) and Venice lagoon, while McCain (1968) reported females of 12 mm.

The maximum male length recorded (23.0 mm) was similar to that recorded by McCain (1968) in the western North Atlantic (21.0 mm). Foster *et al.* (2004) reported males and females collected in Charleston Harbour with a length of 18 mm and 8 mm, respectively, in winter and 10 and 5 mm, respectively, in summer and suggested that these size differences may be due to seasonal effects. For example, these authors reported that individuals, especially males, in winter populations reach much larger sizes than those observed during the summer months in coastal waters of Georgia. They attributed these apparent ecophenotypic differences in size to the decrease in predation during the colder months, in conjunction with the dampening effects of low temperature on reproductive activity.

However, lengths recorded in the present study were greater than those recorded in studies on the eastern Atlantic coast (Martínez and Adarraga 2008, Guerra-García *et al.* 2011) and in the central and eastern Mediterranean (Krapp *et al.* 2006). The presence of *C. scaura* individuals of a large size throughout the study could give it a year-round competitive advantage over native conspecifics.

In this study the sex ratio was close to 1:1. It is worth underlining that a female-biased sex ratio is a common feature for amphipods. Sex-ratio fluctuations can be attributed to several factors, including differential rates

of production, growth, longevity or mortality (Naylor *et al.* 1988, Beare and Moore 1996). The influence of these factors has not been studied here, although the larger size of males could result in an increased susceptibility to predation (suggested for *Dikerogammarus villosus*; Devin *et al.* 2004). In an invasion process, a female-biased sex ratio could be advantageous because it increases the reproductive capacity of the population (Devin *et al.* 2004).

The results of this study provide background information as to how *C. scaura* might function in a new habitat, even if the seasonal fluctuations of this species were not dissimilar to those of other caprellids or marine epifaunal Crustacea. This caprellid has given rise to a stable population in the Mar Piccolo, since it was present all year round in the study area, but its density suggests that it is not a strong invader.

It is highly probable that *C. scaura* has been introduced, either from eastern Mediterranean or Indo-Pacific populations, by a combination of vectors including independent natural dispersal, attachment to driftweed via ship traffic and shellfish transfers (aquaculture practices). Taking into account previous investigations, *C. scaura* can be considered as having been introduced recently, as it was not recorded in the area before, and was collected for the first time in the vicinity of potential introduction sources (e.g. mussel farms, naval harbours) (Prato and Biandolino 2005).

This situation highlights the need to monitor this environment in order to determine a possible expansion of this species to other areas of the Taranto Gulf, as well as a potential ecological impact on the assemblages of the resident species of the Mar Piccolo basin.

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