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Some like it hot: *Paracartia grani* (Copepoda: Calanoida) arrival in the Thau lagoon (south of France—Mediterranean Sea)

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Abstract:

Paracartia grani originates from high latitudes and has progressively been recorded in the Mediterranean Sea since the 1980s. In Thau lagoon, while *Acartia clausi* and *Acartia discaudata* present maximum peaks of abundance from January to April and in November and December, both species being perennial over the year, *P. grani* and *Paracartia latisetosa* appear in May, develop during summer, in July and August, and slowly decrease in autumn before disappearing from the water column in December. The Acartiidae populations have changed over the years at our monitoring station. Indeed, *P. latisetosa* was last recorded in August 1983 while *P. grani* appeared in the lagoon in 1998.

Keywords: *Paracartia grani* ; Mediterranean Sea ; long term changes ; *Acartia* spp.

1. Introduction

Paracartia grani (Sars, 1904) belongs to the Acartiidae family (Copepoda Calanoida) which is the most abundant family in Thau (South of France). It was reported for the first time by Sars (1904) off Western Norway and has been observed in shelf and coastal water of the North-eastern Atlantic and North Sea (Gallo, 1981; Razouls *et al*., 2009). Over the last twenty years, it has progressively appeared in the Mediterranean Sea (Rodríguez & Vives, 1984; Lakkis, 1990; Belmonte & Potenza, 2001; Daly Yahia *et al*., 2004; Pane *et al*., 2005; Razouls *et al*., 2009) (Figure 1). In 1984, *P. grani* was recorded for the first time in the western Mediterranean, in Malaga harbour close to Gibraltar strait (Rodríguez & Vives, 1984). It was observed 15 years later in Spanish and French coastal waters (references in Pane *et al*., 2005) and for the first time in Thau lagoon in 1998 (L Euzet Pers. Com.). However as this latest record was not published, it is still absent from the Thau lagoon fauna list. More recently, it has been reported in the North of the Adriatic Sea (De Olazalbal *et al*., 2006) and in the Aegean Sea (references in Pancucci-Papadopoulou *et al*., 2005). However, for the moment, there is no report of *P. grani* in the Black Sea (Belmonte & Potenza, 2001). *P. grani* is also present in polluted sites such as harbours of Malaga (Rodríguez & Vives, 1984), Barcelona and Genova (Pane *et al*., 2005) where it persists.

P. grani European biogeography was determined using a literature review as a basis to suggest hypothesis for its presence in warmer Mediterranean coastal waters. The influence of *P. grani* introduction on Thau lagoon *Acartia* spp. assemblages is also discussed.

2. Methods

2.1. *Paracartia grani* sampling

Zooplankton samples were collected twice a month between February 2008 and March 2009 at a monitoring station S1, close to Sète channel in Thau lagoon (40°03 N; 03°41 E). A WP2 plankton net with a 200µm mesh size was used to carry horizontal hauls in the surface layer (maximum 1m depth). Samples collected were fixed with formaldehyde to a final concentration of 4% and used to determine the biodiversity and abundance of planktonic populations at the station.

2.2. Long term changes

During the first half of the 20th century, several zooplankton monitoring studies have taken place at the same sampling station. However these results were never published and data were kept in the archives of the Station Méditerranéenne de l'Environnement Littoral in Sète. The main example regards the Professor Louis Euzet (Université Montpellier 2, France) who did follow the plankton population dynamics as well as temperature and salinity for his master and thesis reports in 1937 and 1938 and between 1949 and 1952. We used his notebooks to extract the population dynamics data at these periods. It has to be specified that those data are semi quantitative as the abundances, in number of organisms per unit of volume, were not expressively specified, but the proportion of each species versus the total zooplankton was indicated. An additional study published by Lam Haoi in 1985 (Lam Haoi, 1985) was also used for a long term comparison of *Acartia* spp. population dynamics during the last 60 years.

To allow a comparison between Euzet's records, Lam Haoi's study (1985) and our own data, results were all presented as percentages of a targeted species versus the total zooplankton abundance.

Temperature data were available for the years 1949, 1950, 1951, 1952, 2008 and 2009. In 2008 and 2009, salinity measurements were also done. Relationships between copepods abundance and temperature or salinity were investigated by testing the significance of the Pearson correlation coefficient.

3. Results

During our study in Thau lagoon (February 2008- March 2009), *P. grani* was detected in zooplankton samples in summer and autumn (June –December 2008 which year). During this period, the temperature ranged between 22.4°C in June to 8.3 °C in December 2008 which year with a mean value of 18.0°C.

An ecological succession of the different *Acartia* species can be noticed at the monitoring station, with *A. clausi* occurring in average from January until March in high abundance (ranging from 8.1% of the total zooplankton abundance in March 1950 up to 65.5% in February 2008) followed by *A. discaudata* from February to April (highest contribution in March 2009: 36.2%). Both *P. grani* and *P. latisetosa* appear to have their maximum abundances, 53.1% in 2009 and 13.6% in 1952 respectively, in August. A second peak of abundance (up to 32.8% in December 2008) of *A. clausi* is observed from November to December (Figure 2).

Acartia populations have undertaken changes since the 1950ies (Figure 2). Both *A. clausi* and *A. discaudata* contribution to the total zooplankton abundance have increased over the study period. *P. latisetosa* has disappeared from the monitoring station since 1985 while *P. grani* is now encountered since 2008.

4. Discussion

4.1. *P. grani* population dynamics

P. grani is the most abundant *Acartia* species in August (2008) where it contributes up to 53% of total zooplankton (2040 ind m^{-3}). This peak is followed by a drastic decline and *P. grani* disappears in January (2009) as it has been reported by Rodriguez *et al*. (1995) who described it as the dominant *Acartia* species in summer in Malaga bay. Similarly, Pane *et al.* (2005) indicated *P. grani* occurrence in autumn (from September to December with a peak in October) in the Western Harbour of Genova (Ligurian Sea), supporting the results reported by Guerrero (1993) at a coastal station in the Alboran Sea. Alcaraz (1977) described *P. grani* as an opportunist species as it is commonly found in coastal waters but can also be spotted in brackish waters and polluted sites (Rodriguez & Vives, 1984; Pane *et al*., 2005) where it persists.

4.2. Long term changes in *Acartia* spp. populations

Studies on *P. latisetosa* are rare (Belmonte, 1992; Belmonte, 1998; Siokou-Frangou & Papathanassiou, 1991; Siokou-Frangou *et al*., 2005). However, this species is known to be encountered generally at high abundances in very confined environments with fresh waters inputs and especially in summer (Siokou-Frangou & Papathanassiou, 1991). It was described in Thau until the 50ies, as abundant during summer and in low abundances in winter and spring (Fatemi, 1937; Mathias & Euzet, 1951, 1962). Last record at our sampling station was in August 1985, in low abundance (less than 1%) (Lam Haoi, 1985). Our monitoring station is mainly under sea water influence and consequently it does probably not represent the ideal environment for *P. latisetosa* development. However, *P. latisetosa* might still be present in Thau lagoon in areas closer to the river mouths.

In addition, *P. grani* appearance in Thau might be responsible for *P. latisetosa* drastic decrease. Indeed, its presence in the lagoon might be older than 1998, and *P. grani* is occurring during the warm period meaning that it could be occupying the same ecological niche that *P. latisetosa*. *P. latisetosa* disappearance might therefore be a consequence of a competition with *P. grani*. The fact that the latest remains in the ecosystem while the native species has disappeared might be explained by recent studies showing that non native *Acartia* species are able to colonize coastal areas and estuaries (Seuront, 2005; David, 2007) and that they are modifying the status of native species which are subject of competitive pressure (Lakkis, 1994).

Quantitative data on *Acartia* sp. showed that the species abundances are not significantly correlated with temperature or salinity in Thau lagoon between February 2008 and March 2009 ($p>0.05$). Similarly, for each year of the long term series, the contributions of each species to the total zooplankton abundance are not correlated with temperature variation ($p>0.05$). Therefore, while climate changes have been shown to modify seasonality and period of dominance of *A. tonsa* in Narragansett Bay (Sullivan *et al*., 2007), in Thau lagoon, changes in *Acartia* spp. community structure have another origin than temperature. In addition, if climate change was to be blame, it is likely that temperature would have increased, favouring the thermophile species *P. latisetosa* (Kritchagin, 1873) which is a dominant species in summer (Fatemi, 1937; Mathias & Euzet, 1962; Lam Haoi, 1985). Surprisingly enough, *P. latisetosa* has currently totally disappeared from the plankton community at this station.

4.3. Introduction in the Mediterranean Sea

The introduction of *Paracartia grani* in the Mediterranean Sea might first be explained by a natural migration *via* Gibraltar strait (i.e. Yebra *et al*., 2011). Indeed, several studies, focused on copepods ecology, have underlined the fact that even though the Strait of Gibraltar and the Almeria-Oran Front are considered important phylogeographic barriers in many marine species there is some evidence of transport of copepods across the Gibraltar Strait and the Almeria-Oran Front and for some species, populations are not genetically differentiated between the NE Atlantic and the W Mediterranean (Tyrrhenian) based on 16S data (e.g. Yebra *et al*., 2011). An involuntary introduction could also be the result of human activities: for example transport *via* ship ballast waters (Belmonte & Potenza, 2001; Pane *et al*., 2005) or bivalve transfers between the Atlantic Ocean and Mediterranean Sea can be suggested as sources of introduction. However, several arguments favour the latest hypothesis:

-*P. grani* ecology has been closely linked with bivalve production (i.e. *Ostrea edulis*, Audemard et al. 2001, 2002, 2004), as it has been suggested to be one of the intermediate hosts of the protozoan paramyxean parasite *Marteilia refringens* responsible for marteiliosis, a major disease for bivalve production in Europe which requires mandatory notification to the OIE (the World Organisation for Animal Health) and to the EU (European Union) when detected. During the cultivation of bivalves, the organisms might be transferred several times (see details for *Crassostrea gigas* cycle in Mineur *et al*., 2007). Such transfers are permitted within the European Community and there is no obligation to report them (Mineur *et al*., 2007).

-In Thau lagoon, Mineur *et al.*'s results (2007) support the hypothesis that oyster transfers are effective as primary and secondary vectors of macroalgal introductions.

-Many species have been accidentally introduced in association with bivalve transfers, but there is little direct evidence. As most records of *P. grani* are correlated with shell farms sites (Figure 3), we suggest that shell transfers between the Atlantic and the Mediterranean Sea might be responsible for its introduction into the Mediterranean.

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Figures

Figure 1. Biogeography (literature record) of *Paracartia grani* (Copepoda: Calanoid) in Europe in 2011. Records of *P. grani* was based on Rodríguez & Vives, 1984; Lakkis, 1990; Belmonte & Potenza, 2001; Daly Yahia *et al*., 2004; Pancucci-Papadopoulou *et al*., 2005 ; Pane *et al*., 2005; De Olazalbal *et al*., 2006 ; Razouls *et al*., 2009.

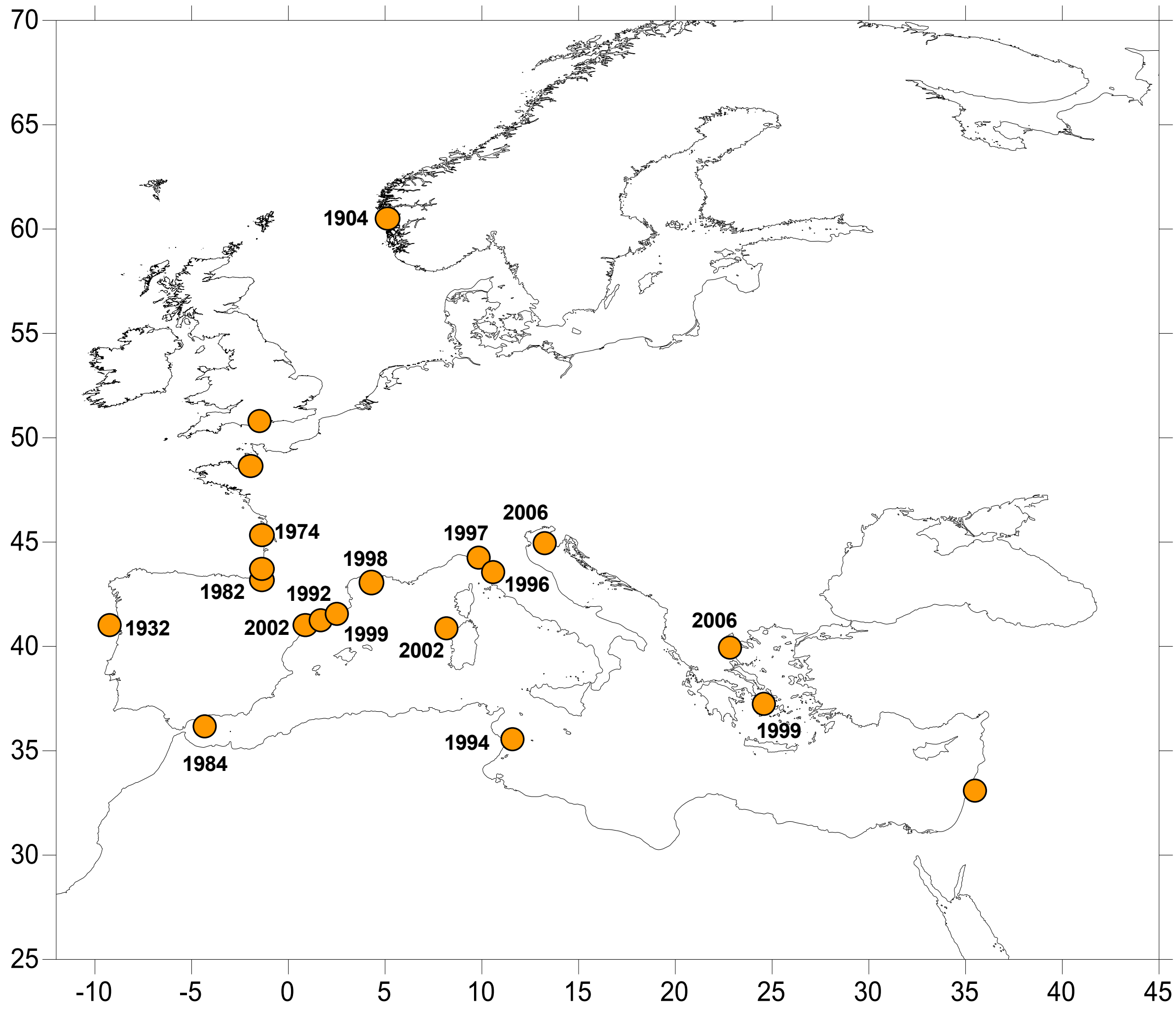

Figure 2. *Acartia* spp. long term contribution to the total zooplankton abundance (%) at S1 in Thau lagoon. a- *A. clausi*, b- *A. discaudata*, c- *P. latisetosa* and d- *P. grani*.

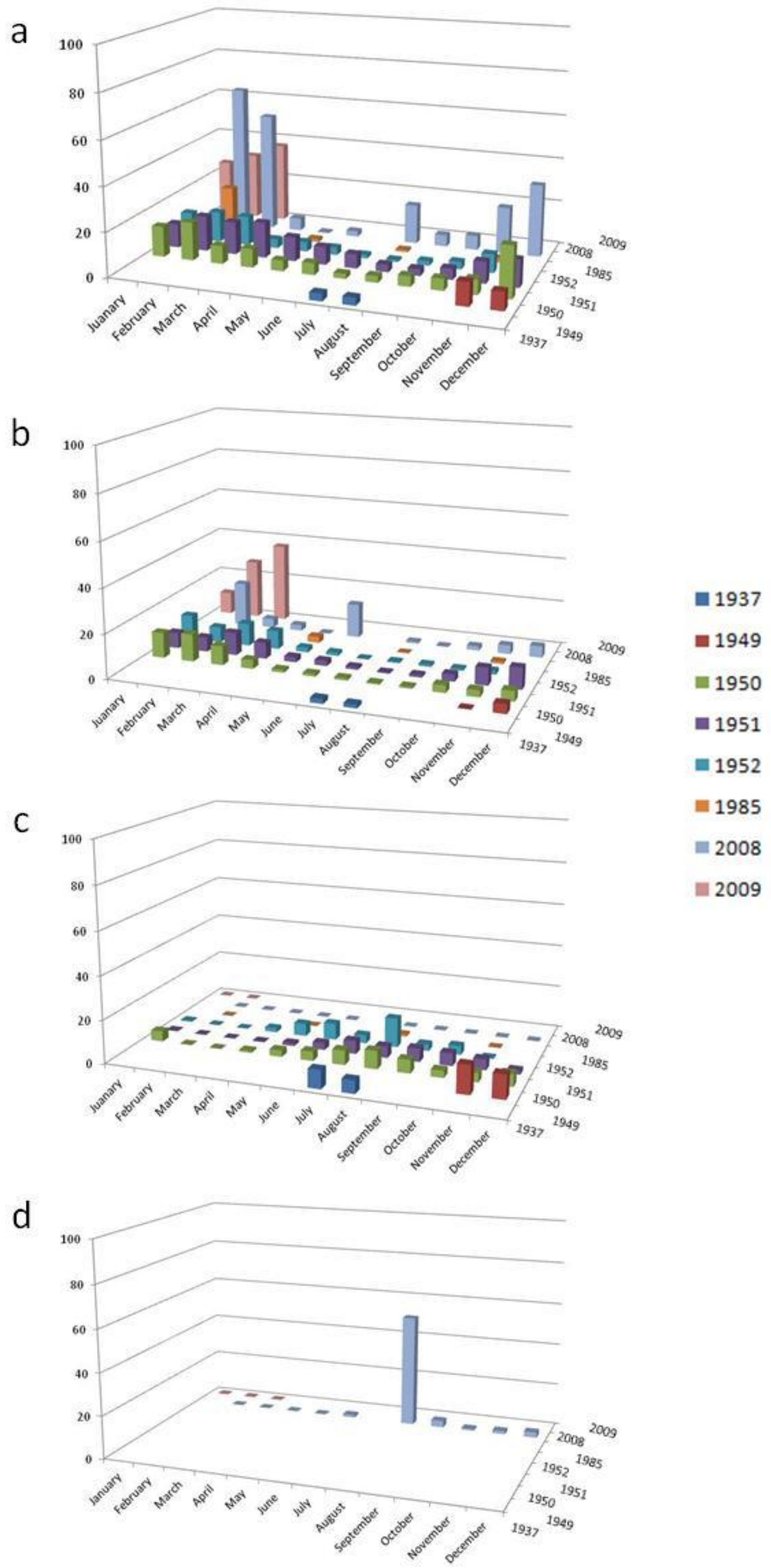

Figure 3. Records of *Paracartia grani* and several bivalves exploited species in Europe.

● : *P. grani* ★: Oyster farms ✦: mussel farms and ✸: : clam farms Sars (1904) ; Gallo (1981); Rodríguez & Vives (1984); Lakkis (1990); Belmonte & Potenza (2001); Daly Yahia *et al*. (2004); Pancucci-Papadopoulou *et al*. (2005) ; Pane *et al*. (2005) ; De Olazalbal *et al*. (2006); Razouls *et al*. (2009)