Mesozooplankton composition and distribution in relation to oceanographic conditions in the Gulf of Cádiz, Spain

Composición y distribución del mesozoopláncton en relación a condiciones oceanográficas en el Golfo de Cádiz, España

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ABSTRACT

Two surveys were conducted during July 1994 and July 1995 in the Gulf of Cádiz with the aim of assessing temporal and spatial patterns in biomass (ZDV, zooplankton displacement volume) and mesozooplankton composition and their relationships with the oceanographic conditions. Differences between two successive summer seasons were found in this study. The upper water column was warmer and more saline in 1994. Mesozooplankton abundance and biomass were higher in 1994 than in 1995. However, the occurrence of several plankton species was remarkably regular. In the two summers, cladocerans (Penilia avirostris, Evadne spinifera, Evadne tergestina, Evadne nordmanni, and Podon spp) were the most abundant group followed by copepods and appendicularians. The dominance of cladocerans in the two summers was basically due to the high abundance of Penilia avirostris. The study of trends showed that the relative abundance of copepods increased throughout the summers, although this increase was significant only in the north inshore sites, where the influence of Atlantic water is higher. The mesozooplankton abundance and, specifically, Cladocera density showed a positive correlation with temperature and ZDV but showed a negative correlation with salinity and depth. ZDV, Copepoda and Appendicularia density did not show a significant relationship with oceanographic variables.

Key words: Mesozooplankton, cladocera, biomass, spatial distribution, Gulf of Cádiz

INTRODUCTION

The Gulf of Cádiz, strategically located connecting the open Atlantic Ocean with the Mediterranean Sea through the Strait of Gibraltar (Figure 1). It is an area of traditional fisheries over the shelf, but little is known about hydrology of the region (Catalán et al., 2006a; Prieto et al., 1999). The importance of fishery activity in the Gulf of Cádiz has been repeatedly addressed and is characterized by the great diversity of exploited species, which use the highly productive shelf as developing habitat for early
Surprisingly, the interest attracted by fisheries exploitation in this area was not followed by research aimed to characterize the mesozooplankton community, a key factor to the consequent fish larval survival and the fisheries yield.

The mesozooplankton plays an important role in the marine food web as a link between the micro- and macrozooplankton (Neumann-Leitão et al., 1999). However, little is known about the spatial and temporal variability of zooplankton on the shelf in the Gulf of Cádiz. There are only few studies on mesozooplankton composition (Rubín et al., 1997, 1999) and the influences of hydrodynamics on the spatial distribution of plankton (García et al., 2002; Mafalda and Rubin, 2006).

The area of the Gulf of Cádiz is characterized by an ample continental shelf, around 50 km wide, except at the west of the Guadiana river, where it is only 130 m wide (Abrantes, 1990). The most important rivers are the Guadalquivir and the Guadiana and the continental runoff reach the lowest values in summer (Garcia and Moyano, 1991). Temperature distribution and dynamic topography indicate the existence of anticyclonic circulation following the bottom contours running from NW to SE (Stevenson, 1977; Folkard et al., 1997; García et al., 2002). When prevailing winds in the Gulf are from the west, an upwelling area is found east of Cape Santa María in Portugal (Folkard et al., 1997). The upwelled waters form a cold tongue that separates from the coast, flows offshore in the SW direction towards the Strait of Gibraltar. The “Huelva Front” separates this colder water from warmer waters of the central part of the gulf (Vargas et al., 2003). Stevenson (1977) describes the “Huelva Front” as a warm-cold-warm frontal structure running in the SE-NW direction offshore, approximately between the cities of Cádiz and Huelva. Another upwelling area is also evident at the southwest of the Strait of Gibraltar (Vargas et al., 2003).

This paper presents results of the meso-scale mesozooplankton composition and its spatial and temporal variability in the Gulf of Cádiz.

MATERIAL AND METHODS

During July 1994 and July 1995, a sampling grid of 10 stations was performed in the Gulf of Cádiz (Figure 1). Each station consisted of a CTD cast plus zooplankton hauls. A Bongo net, with 40 cm diameter mouth opening (Rubín, 1992), equipped with two independent flowmeters and one depth meter gauge was employed to carry out “double-oblique” trawls from the 100 m depth to surface. The samples obtained were preserved in 5% buffered formalin. Zooplankton displacement volume (ZDV) was measured for each sampling site from the catch of the 250 μm mesh bongo net (Ahlstrom and Thrailkill, 1963). ZDV values were standardized to ml per m³. Material collected with 250 μm mesh net was also used to make the taxonomic identification of the mesozooplankton. The number of organisms collected was standardized per m³. Temporal variability in mesozooplankton and oceanographic variables were

![Figure 1. Study area showing bathymetry and the sampling stations in the Gulf of Cádiz.](image-url)
tested using Welch t-Test. A MRPP (Multi-response Permutation Procedures) analysis was used in order to prove the existence of significant differences in the composition of mesozooplankton community between two summers. The Multiple Regression Analysis was employed to verified significant correlations between mesozooplankton (total abundance, copepods, cladocerans and appendicularians) and the oceanographic conditions (temperature, salinity and depth).

RESULTS AND DISCUSSION

Oceanographic conditions

According to the T-S diagram (Figure 2), there were significant differences in environmental conditions in the surface water between the two summers (Table 1). The upper water column was warmer (p < 0.05) and more saline (p < 0.05), in 1994. The water column was generally well stratified and the thermocline was located on average at 26 m. Due to mesoscale variability, the thermocline depth varied, having a tendency to move downward in anticyclonic area in the slope and continental shelf, in front of Cádiz Bay (Rubín et al., 1997; 1999).

The horizontal distribution of surface temperature and salinity showed temporal variability. During these two summers, warmer temperatures (22 – 23 °C) were observed at the inshore sites of the Cádiz Bay, at the central area. Southern area, in front of the Cape of Trafalgar and northern area, in front of Guadiana River, were generally cooler (17 – 20 °C) than the rest of surveyed area. In 1994, higher salinities (> 36.4 ups) were observed at the north area and offshore, though in 1995, higher values were observed around Cádiz bay (Rubín et al., 1997; 1999).

In 1994, higher salinities were observed at external sites, though in 1995, higher values were observed at intermediate sites, in front of Cádiz Bay. The more elevated values of salinity and temperature found in the surroundings of the bay of Cádiz, in 1995, could be explained by the fact that it is not influenced by the Atlantic current coming from Portugal and because 1995 was a particularly dry year, which supported the hypothesis of a greater solar heating and a greater evaporation (Rubín et al., 1999).

In the intermediate layers, however, the topography of 15° C isotherms suggested anticyclonic circulation near the continental slope edge (Rubin et al., 1997, 1999). This coincidence of the subsurface circulation with the edge of the continental slope would corroborate the notion that anticyclonic circulation in this area seemed to be a permanent feature in summer time (Garcia et al., 2002).

Biomass distribution

Zooplankton displacement volume (Table 1) as calculated from the Bongo catches (250 µm) varied between 0.5 – 6.2 ml/m³, in summer 1994 and 1.1 – 5.0 ml/m³, in summer 1995. Distribution of biomass followed the isotherms very clearly. A sharp decrease in ZDV was observed at the continental margin along the 200m depth line. Very low ZDV values (0.5 – 2.0) were found in areas where temperature in 3 m water depth layer did not exceed 21 °C. At higher water

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>1994</th>
<th>1995</th>
<th>Welch t Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity (psu)</td>
<td>36.33 ± 0.06</td>
<td>36.27 ± 0.11</td>
<td>P = 0.0183*</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>22.29 ± 0.79</td>
<td>21.18 ± 0.79</td>
<td>P = 0.0238*</td>
</tr>
<tr>
<td>ZDV (ml m⁻³)</td>
<td>1.9 ± 1.7</td>
<td>1.8 ± 1.0</td>
<td>P = 0.3867</td>
</tr>
<tr>
<td>Abundance (ind m⁻³)</td>
<td>6633 ± 7215</td>
<td>3553 ± 4188</td>
<td>P = 0.2624</td>
</tr>
</tbody>
</table>

Table 1. Oceanographic variables (mean ± SD) during summers in the Gulf of Cádiz, Spain and results of Welch t Test.
temperatures, as observed at the inshore sites of the Cádiz Bay, biomass ranged from 3.0 to 5.0 ml/m³. In the seas of the Mediterranean basin (Black and Azov seas) the ZDV values (Kovalev et al., 2003) were similarly low in summer (4.0 – 7.0 ml/m³) but were much higher in spring (17.0 – 29.0 ml/m³). Three peaks of biomass during a year (spring, summer and autumn) were noted in the Spanish coastal region of the Alboran Sea to the east from the Straits of Gibraltar (Caminas, 1983; Rodrigues, 1983).

**Abundance of mesozooplankton**

Mesozooplankton abundance (Table 1) was higher in 1994 (504 – 24734 ind/m³) than 1995 (1215 – 15083 ind/m³), but the statistical differences were not significant (p > 0.05). In the two summers coastal-shelf tendency was observed (Figure 2). Highest numbers of organisms were found at the shallow stations 1 and 3. The lowest mesozooplankton abundance was found at offshore stations 9 and 10. The result of the MRPP analysis showed a significant difference (p=0.0001), between two summers demonstrating an elevated temporal variability in mesozooplankton community composition (Table 2).

**Individual species distribution**

Cladocera showed temporal differences in their horizontal distribution (Figure 3). During 1994 they occurred in high abundance (average = 5766 ind/m³) in a coastal and continental shelf sites at the north and south of Guadalquivir River. In 1995 their abundance in shelf sites decreased (average = 2310 ind/m³). In the Gulf of Cádiz and Alborán sea (Souza et al., 2004; Rodrigues, 1983; Souza et al., 2005; Zagami et al., 1996). A relatively high degree of heterogeneity in zooplankton composition was found. The result of the MRPP analysis showed a significant difference (p=0.0001), between two summers demonstrating an elevated temporal variability in mesozooplankton community composition (Table 2).

**Taxonomic composition of mesozooplankton**

A total of 15 taxa (Table 2) were identified (14 taxa in 1994 and 14 taxa in 1995). The temporal difference between sites in the number of taxa was not significant (p > 0.05). In the two summers holoplankton dominated the relative abundance (98%) and was mainly represented by cladocerans followed by copepods and appendicularians. These three groups altogether made up 96.6% in 1994 and 93.9% in 1995 of the zooplankton abundance (Table 2). Meroplankton with 2% was mainly constituted by larval stages of decapods and barnacles. The relative importance of different taxa varied between sites, although cladocerans were generally dominant, with a total relative mean abundance of 75%. Copepods constituted 17% of the total zooplankton abundance. In the NW of the Alborán Sea, Copepoda and Cladocera were the most abundant group in spring, autumn and winter, while in summer cladocerans were the dominant group followed by copepods and appendicularians (Rodrigues et al., 1982; Rodríguez, 1983; Seguin et al., 1994; Souza et al., 2005). Four species and one genus of Cladocera were identified in decreasing order of abundance: Penilia avirostris, Evadne spinifera, Evadne tergestina, Evadne nordmanni, and Podon spp. Similar cladocerans’ composition was observed in other regions of the Mediterranean Sea (Fernández de Puelles et al., 2004; Rodrigues, 1983; Souza et al., 2005; Zagami et al., 1996).

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The distribution of copepods was very similar in both summers. Copepods (Figure 3) increased their abundance from 1994 (average = 526 ind/m$^3$) to 1995 (average = 901 ind/m$^3$) in the north sites (p = 0.0383) where the influence of Atlantic water is higher. The higher abundances of Appendicularia “shift” from south area (1994) to north area (1995), but abundance was the same between two summers (Figure 3). Appendicularia showed a smooth coastal-shelf decrease in density with a few spots on the shelf with irregularly high abundance.

In Mallorca Channel (Western Mediterranean) Copepoda and Appendicularia were the most abundant taxa (Fernández de Puelles et al., 2003, 2004). However, in the Biscay Bay (Cantabric Sea) copepods dominate mesozooplankton abundance (Villate and Valencia, 1997).

Other holoplanktonic taxa, such as Chaetognatha (*Sagitta* spp) and meroplankton, such as Decapoda larvae, did not show any marked temporal differences in their abundance and horizontal distribution (Figures 3 and 4). During 1995, Doliolidae, Euphausiacea, Siphonophora, Foraminiferida and Hydrozoa (Figure 4 and 5), enlarged their distribution and abundance in coastal and shelf sites. In 1995, Echinodermata, Mollusca and Polychaeta (Figure 5), showed the same distribution pattern and decreased their abundance in south coastal and shelf sites. Cirripedia larvae were present only in 1994, with most abundance in the coastal sites, but Ostracoda were present only in 1995 at the north area (Figure 5). In the Guadiana estuary, decapod larvae were among the most abundant taxa (Esteves et al., 2000). In the Mondego estuary the occurrence of larval stages of benthic invertebrates, such as decapod larvae, was mainly restricted to the summer months (Marques et al., 2006) where this pattern is related to the release of larvae into the water column during warmer months, when the environmental conditions are favourable (Gonçalves et al., 2003).

Table 2. List of mesozooplankton taxa identified, their order, relative abundance (A%) and frequency of occurrence (F%) in the Gulf of Cádiz, Spain.

<table>
<thead>
<tr>
<th>Taxa</th>
<th>1994</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Order</td>
<td>A%</td>
</tr>
<tr>
<td>Cladocera</td>
<td>1°</td>
<td>86.90</td>
</tr>
<tr>
<td>Copepoda</td>
<td>2°</td>
<td>7.90</td>
</tr>
<tr>
<td>Appendicularia</td>
<td>3°</td>
<td>1.80</td>
</tr>
<tr>
<td>Cirripedia</td>
<td>4°</td>
<td>0.78</td>
</tr>
<tr>
<td>Chaetognatha</td>
<td>5°</td>
<td>0.70</td>
</tr>
<tr>
<td>Decapoda</td>
<td>6°</td>
<td>0.58</td>
</tr>
<tr>
<td>Echinodermata</td>
<td>7°</td>
<td>0.54</td>
</tr>
<tr>
<td>Siphonophora</td>
<td>8°</td>
<td>0.26</td>
</tr>
<tr>
<td>Dolioiidae</td>
<td>9°</td>
<td>0.21</td>
</tr>
<tr>
<td>Mollusca</td>
<td>10°</td>
<td>0.10</td>
</tr>
<tr>
<td>Foraminiferida</td>
<td>11°</td>
<td>0.10</td>
</tr>
<tr>
<td>Euphausiacea</td>
<td>12°</td>
<td>0.05</td>
</tr>
<tr>
<td>Polychaeta</td>
<td>13°</td>
<td>0.03</td>
</tr>
<tr>
<td>Hydromedusae</td>
<td>14°</td>
<td>0.02</td>
</tr>
<tr>
<td>Ostracoda</td>
<td>0.00</td>
<td>00</td>
</tr>
</tbody>
</table>
Figure 3. Temporal and spatial distribution of mesozooplankton taxa in the Gulf of Cádiz, Spain.
Figure 4. Temporal and spatial distribution of mesozooplankton taxa in the Gulf of Cádiz, Spain.
Figure 5. Temporal and spatial distribution of mesozooplankton taxa in the Gulf of Cádiz, Spain.
Correlations between the abundance of mesozooplankton and oceanographic variables

Abundance of copepods and appendicularians did not show a significant relationship with oceanographic variables (temperature, salinity, ZDV and depth) (Multiple Regression Analysis, give the results). Although abundance of the total mesozooplankton and cladocerans in 1994 (p < 0.0005) and 1995 (p < 0.0001) showed a positive correlation with temperature and biomass but showed a negative correlation with salinity and depth. In the Alborán Sea the density of copepods decreased while cladocerans showed a positive correlation with temperature (Souza et al., 2005). In the Mallorca channel the high zooplankton abundance, mainly due to copepods, was found where the coolest and more saline waters were observed, and the lowest abundance, mainly represented by siphonophores, chaetognaths and doliolids, was in the warmer and less saline waters, indicating the input of Atlantic waters (Fernández de Puelles et al., 2004). In the coastal zone of other Mediterranean seas the differences in zooplankton abundance are attributed to changes in temperature regime (Kovalev et al., 2003).

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