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

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

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Received: 02/27/2007 First reviewing ending: 05/09/2007 First review received: 09/11/2007
Second reviewing ending: 09/24/2007 Second review received: 09/25/2007 Accepted: 10/10/2007

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

RESUMEN

Dos campañas de verano fueron realizadas en los meses de julio de 1993 y de 1994 en el Golfo de Cádiz, con el objetivo de discernir patrones temporales y espaciales en la biomasa y composición del mesozooplâncton y investigar su relación con las condiciones oceanográficas. Variabilidad temporal entre los dos veranos ha sido observada. La columna de agua ha sido más caliente y salina en 1994 y también ha presentado una mayor densidad y biomasa de mesozooplâncton. A pesar de estas variaciones temporales la presencia de varias especies planctónicas fueron notablemente regulares. En los dos veranos los cladóceros (*Penilia avirostris*, *Evadne spinifera*, *Evadne tergestina*, *Evadne nordmanni*, y *Podon* spp) fueron el grupo más abundante seguido por los copépodos y apendicularias. La dominación de cladóceros en verano es básicamente debido a la alta abundancia de *Penillia avirostis*. El estudio de tendencias demostró que la abundancia relativa de copépodos aumentó tras los veranos, aunque este aumento solamente ha sido significativo en las estaciones occidentales, donde es más elevada la influencia del agua Atlántica. La densidad de mesozooplâncton and Cladocera demostró una correlación positiva con temperatura y biomasa pero demostró una correlación negativa con salinidad y profundidad. La biomasa y la densidad de Copepoda y Appendiculata no han presentado correlación con las variables oceanográficas.

Palabras clave: Mesozooplancton, cladocera, biomasa, distribución espacial, Golfo de 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 life stages (Catalán *et al*., 2006b, Drake *et al*., 2002; Mafalda and Rubin 2006).

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 m^3. 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 m^3. Temporal variability in mesozooplankton and oceanographic variables were

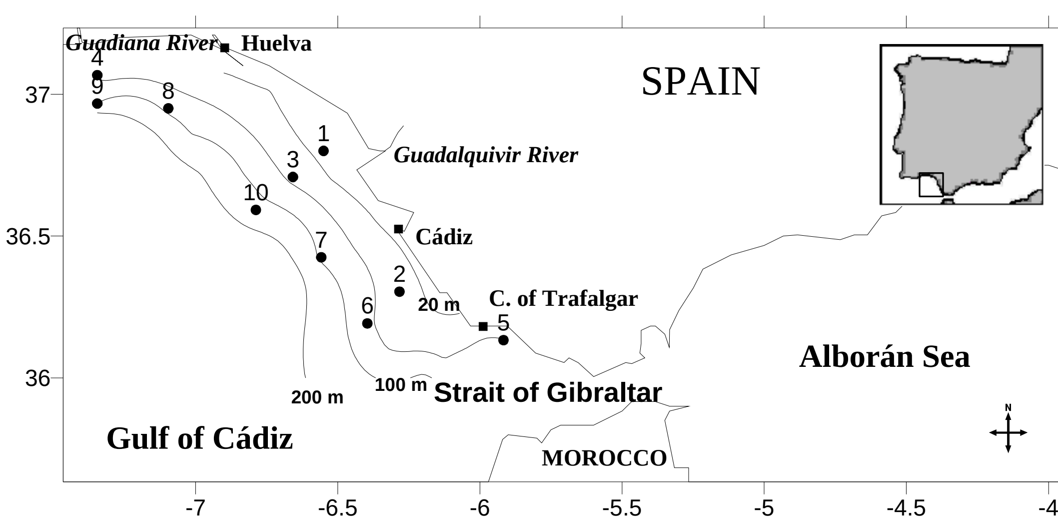

Figure 1. Study area showing bathymetry and the sampling stations in the Gulf of Cádiz.

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 ºC) 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 ºC) 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 (Rubín *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/m^3, in summer 1994 and 1.1 – 5.0 ml/m^3, 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

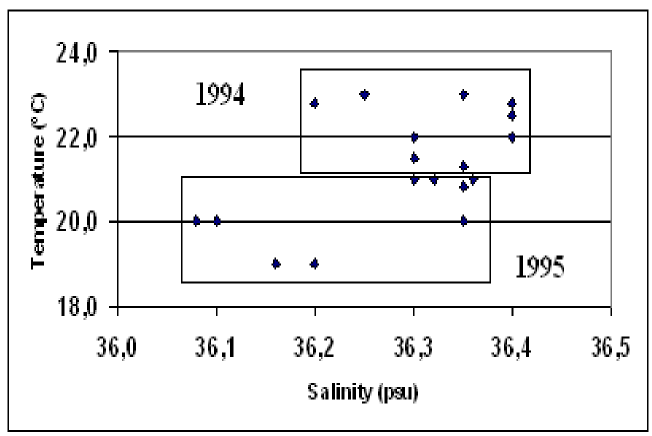

Figure 2. T–S diagrams for the oceanographic stations in the Gulf of Cádiz, Spain.

Table 1. Oceanographic variables (mean ± SD) during summers in the Gulf of Cádiz, Spain and results of Welch t Test.

	1994	1995	Welch t Test
Depth (m)	63.60 ± 34.4	63.10 ± 34.7	P = 0.9708
Salinity (psu)	36.33 ± 0.06	36.27 ± 0.11	P = 0.0183*
Temperature (°C)	22.29 ± 0.79	21.18 ± 0.79	P = 0.0238*
ZDV (ml m^{-3})	1.9 ± 1.7	1.8 ± 1.0	P = 0.3867
Abundance (ind m^{-3})	6633 ± 7215	3553 ± 4188	P = 0.2624

temperatures, as observed at the inshore sites of the Cádiz Bay, biomass ranged from 3.0 to 5.0 ml/m^3. 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/m^3) but were much higher in spring (17.0 – 29.0 ml/m^3). 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/m^3) than 1995 (1215 – 15083 ind/m^3), 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 with concentrations of 500 to 2000 ind/m^3, showing densities more than ten times less than at high density station. In 1994 the total mesozooplankton was most abundant in south area of Guadalquivir River. However, north area between Guadiana and Guadalquivir rivers was most abundant in 1995. In the Gulf of Naples, in summer, densities ranged between 223 – 11148 org/m^3 (Mazzocchi and Ribera d´Alcala, 1995), but in the Mallorca channel, influenced by the Atlantic waters, the spring mesozooplankton abundance was lower (400 – 1200 org/m^3) than in the Gulf of Cádiz (Fernández de Puelles *et al*., 2004). The same was observed during summer, in tropical shelf waters of North-Eastern Brazil, where the average density of mesozooplankton was lower than the Gulf of Cádiz, with 1731 ind/m^3 (Neumann-Leitao *et al*., 1999). These results demonstrate the most productive pattern in the Gulf of Cádiz temperate waters.

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 apendicularians (Rodrígues *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).

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).

Individual species distribution

Cladocera showed temporal differences in their horizontal distribution (Figure 3). During 1994 they occurred in high abundance (average = 5766 ind/m^3) 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/m^3). In the Gulf of Cádiz and Alborán sea (Souza *et al*., 2005), the dominance of cladocerans in summer was basically due to the high abundance of *Penilia avirostris*, a biological indicator of warmer waters. In the Gulf of Naples, in the inshore station (0-50m layer), zooplankters forming the summer peak were mainly composed of cladocerans (Mazzocchi and Ribera d´Alcala, 1995). The importance of cladocerans in summer is a typical pattern of Mediterranean waters (Della Croce and Bettain, 1965; Thiriot, 1972; Siokou-Frangou, 1996; Calbert *et al*., 2001; Ribera d´Alcala *et al*., 2004. 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).

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

	1994			1995		
Taxa	Order	A%	F%	Order	A%	F%
Cladocera	1°	86.90	100	1°	65.00	100
Copepoda	2°	7.90	100	2°	25.40	100
Appendicularia	3°	1.80	100	3°	3.50	100
Cirripedia	4°	0.78	90		0.00	0
Chaetognatha	5°	0.70	90	9	0.51	90
Decapoda	6°	0.58	100	5°	0.85	100
Echinodermata	7°	0.54	100	8	0.59	90
Siphonophora	8°	0.26	100	7	0.65	100
Doliolidae	9°	0.21	80	4°	2.00	100
Mollusca	10°	0.10	90	12°	0.10	50
Foraminiferida	11°	0.10	80	6°	0.75	100
Euphausiacea	12°	0.05	50	10°	0.40	90
Polychaeta	13°	0.03	60	13°	0.06	60
Hydromedusae	14°	0.02	70	11°	0.21	90
Ostracoda		0.00	00	14°	0.02	30

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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).

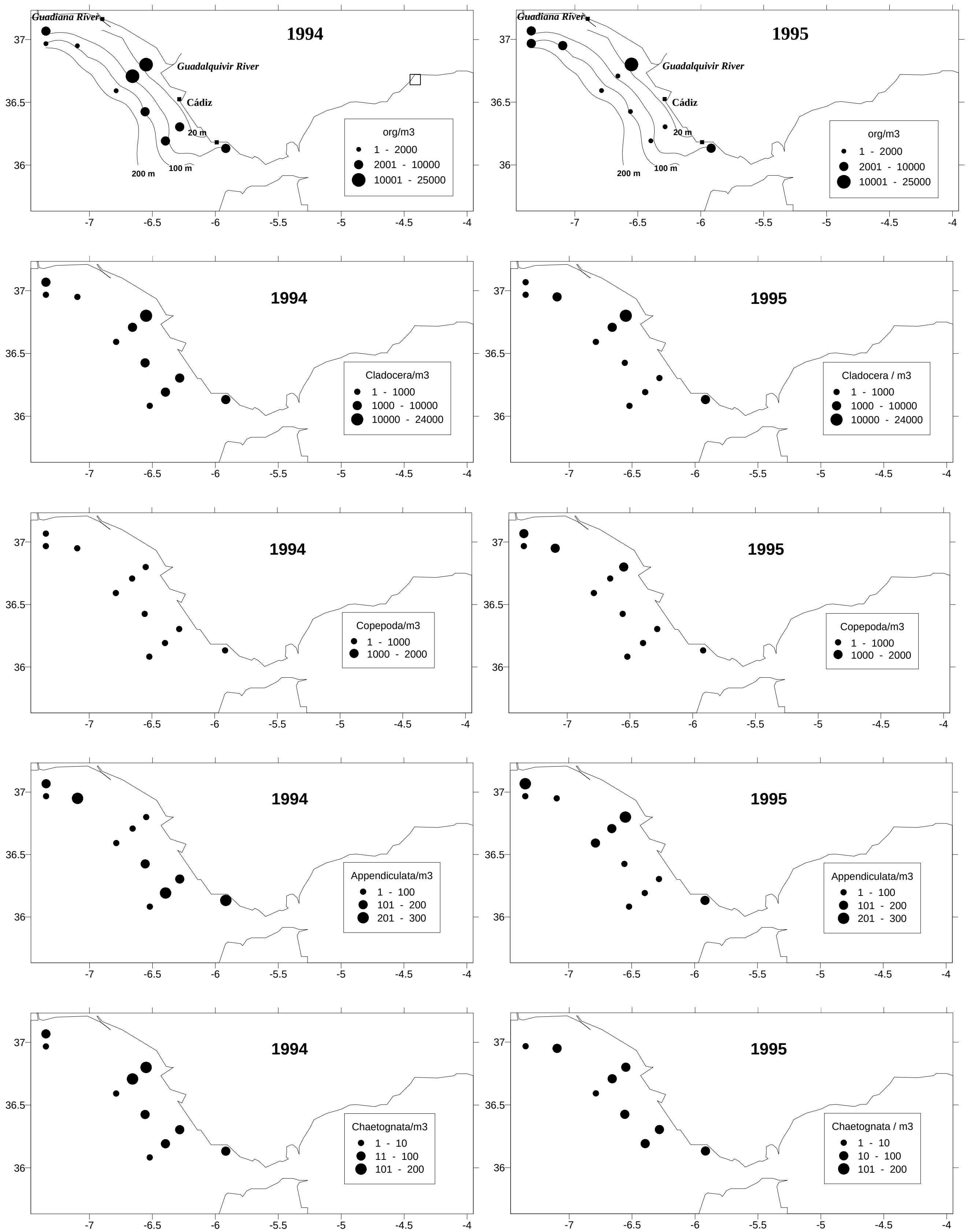

Figure 3. Temporal and spatial distribution of mesozooplankton taxa in the Gulf of Cádiz, Spain.

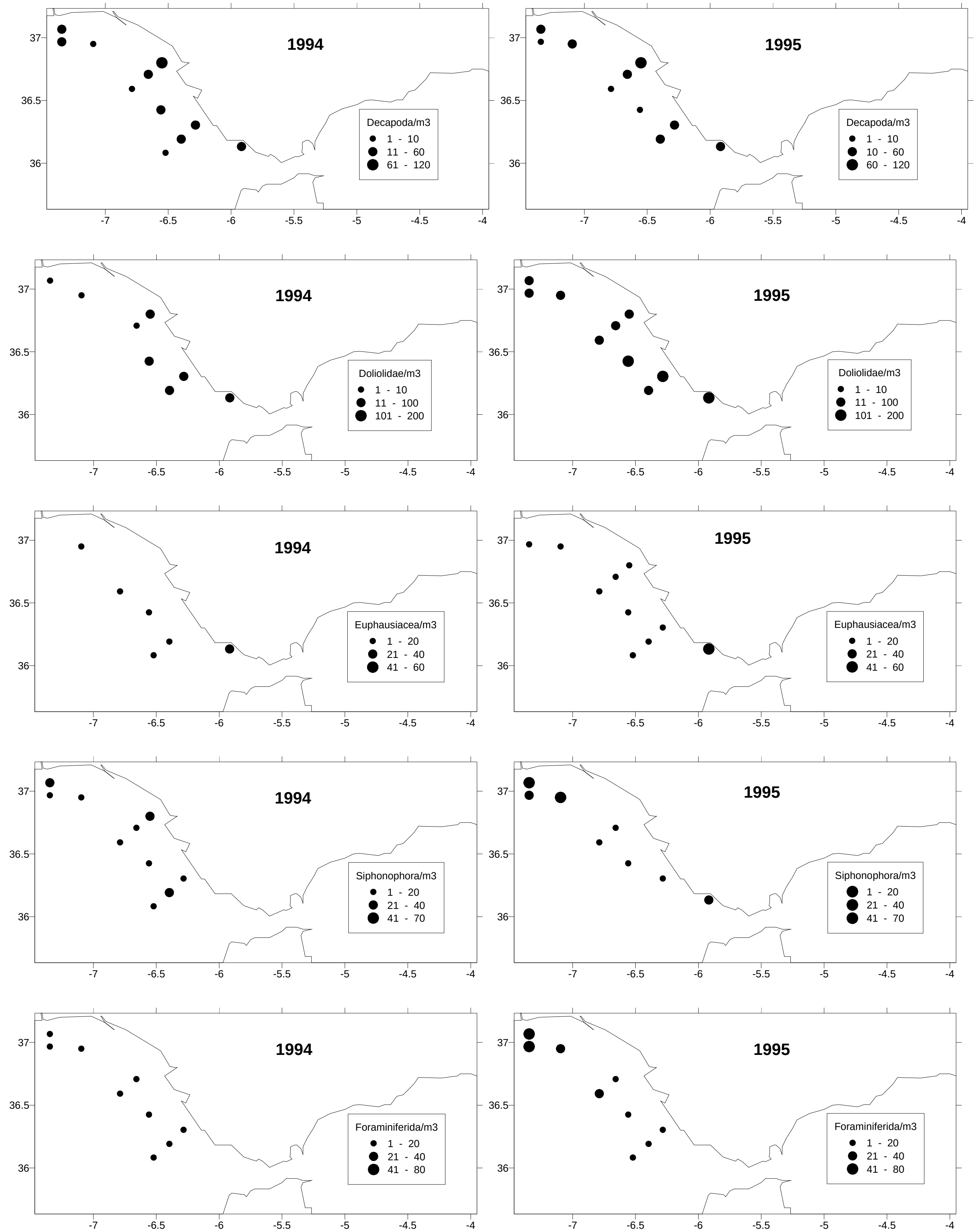

Figure 4. Temporal and spatial distribution of mesozooplankton taxa in the Gulf of Cádiz, Spain.

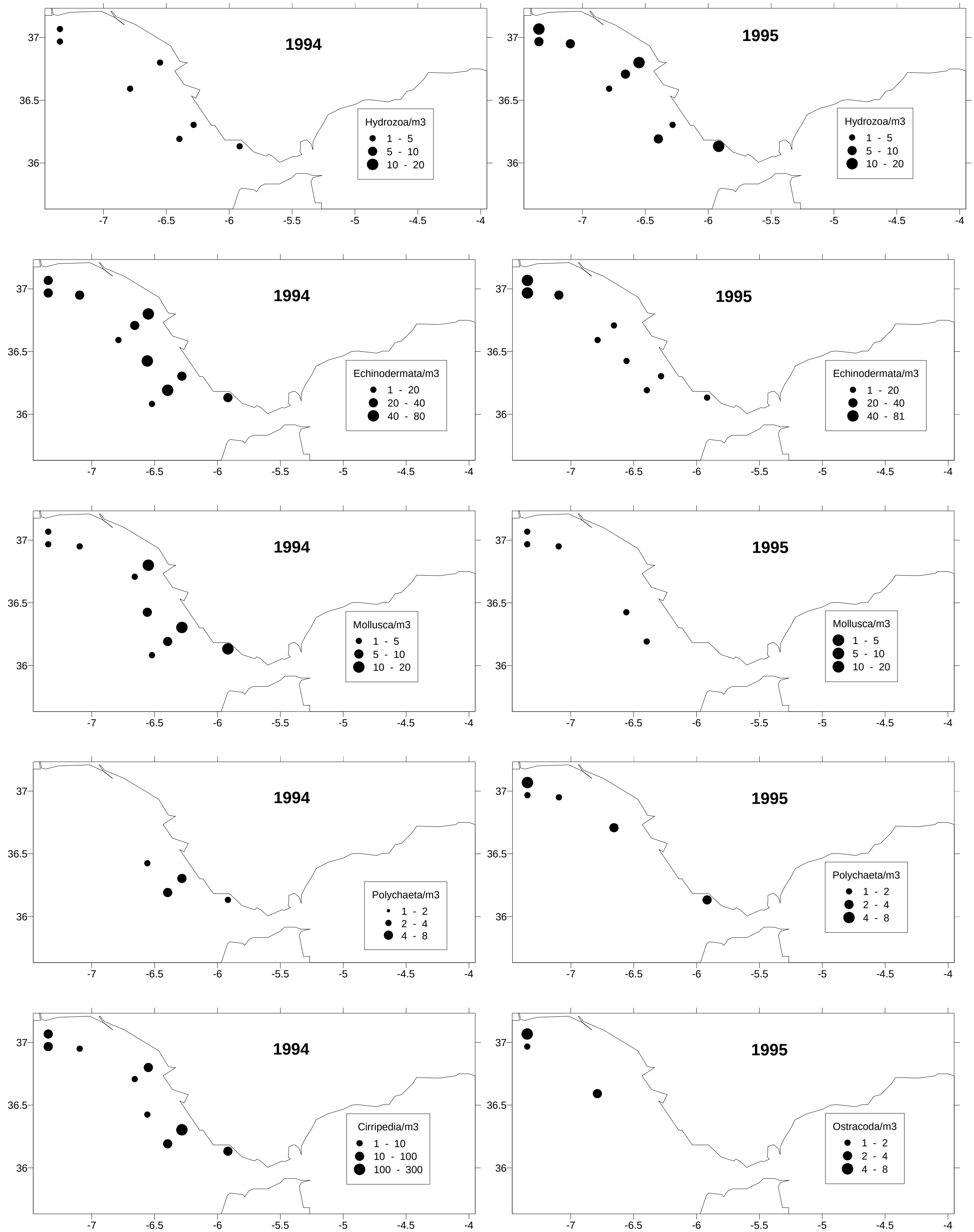

Figure 5. Temporal and spatial distribution of mesozooplankton taxa in the Gulf of Cádiz, Spain.

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).

ACKNOWLEDGEMENTS

The authors would like to thank the crew of R/V Francisco de Paula Navarro and many scientists who assisted in collecting samples at the sea and sorted the mesozooplankton. This study was partly supported by CAPES (Ministry of Education, Brazil) as part of the post doctoral grant (BEX 0762-03-2). Financial support was received from the Instituto Español de Oceanografia (IEO) within the framework of the “Ictio.Alboran–Cádiz” project.

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