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Changes in zooplankton diversity and distribution pattern under varying precipitation regimes in a southern temperate estuary

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A B S T R A C T

The influence of climate variability on the diversity and distribution patterns of zooplankton communities was investigated in the Mondego estuary (Portugal) during four consecutive years characterized by highly variable precipitation and, consequently, river flow regime. Monthly samples were collected along the estuarine gradient at five sampling stations. Seasonal, inter-annual and spatial distributions were evaluated by multivariate analyses and three diversity indices were applied (Species number, Shannon Diversity and Average Taxonomic Distinctness). A two-year drought period presented significant differences in salinity values, especially in 2005 (extreme drought event). During the study period, copepoda was the main dominant group and *Acartia tonsa* the most abundant species, with the exception of autumn 2006, where high abundances of the cladoceran *Penilia avirostris* were noticed. Multivariate analysis indicated that zooplankton communities changed from a pre- to a post-drought period indicating the influence of hydrological parameters in communities' structure. The dry period was associated with an increase in zooplankton density, a reduction in seasonality and higher abundance and prevalence of marine species throughout the year. Seasonally, winter/spring communities were distinct from those in summer/autumn. Spatially, salinity-associated differences between upstream and downstream communities were reduced during the drought years, but during the post-drought year, these differences were detected again.

1. Introduction

Under the influence of a variety of inter-related biotic and abiotic structural components and intensive chemical, physical and biological processes, estuaries are highly variable systems. Calbet et al. (2001) and Valdés et al. (2007) have shown how estuarine variability is reflected in the dynamics of the biological populations, particularly planktonic ones. Zooplankton modulates carbon-flow processes through their interactions with higher and lower trophic levels both within the water column and within the benthic community (Isari et al., 2007). Their distribution is affected by both abiotic (David et al., 2005; Marques et al., 2007a, b) and biotic parameters (e.g. predation, competition) (Isari et al., 2007). A range of studies have highlighted how plankton (and particularly zooplankton) might be an important indicator of change in marine systems (e.g. Chiba and Saino, 2003; Molinero et al., 2005) and several features point out plankton as particularly good indicators of climate change (e.g. not commercially exploited, short-lived) (Taylor et al., 2002).

In recent years, several studies have focused on the zooplankton communities of the southern arm of the Mondego estuary (e.g. Azeiteiro et al., 1999, 2000; Vieira et al., 2003) and also on the northern arm (e.g. Marques et al., 2006, 2007a, b). Salinity and temperature are the main factors influencing zooplankton distribution, which is thus directly influenced by freshwater inputs (Marques et al., 2006). Hydrological parameters are directly influenced by climatic variations and advection is one of the key mechanism explaining zooplankton distribution and abundance (Kimmerer, 2002). Fluvial contributions are variable because they reflect the seasons as well as the instability of the precipitation regime (Lam-Hoai et al., 2006). Differences in precipitation regimes have been recorded in Portugal with values 45–60% below average in hydrological year (from October to September) 2004/2005 and normal/regular precipitation values in 2003 and 2006 (http://web.meteo.pt/pt/clima/clima.jsp). Thus, this period provides a good opportunity to investigate zooplankton ecology over a wide range of precipitation. This study attempts to describe the influence of

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rainfall on the distribution of planktonic communities' in a southern European estuary.

2. Materials and methods

2.1. Study area

The Mondego estuary, located on the Atlantic coast of Portugal (40° 08′ N, 8° 50′ W), consists of two arms, northern and southern, separated by Murraceira Island (Fig. 1). The two arms exhibit different hydrological characteristics: the north arm is deeper (4–8 m at high tide) has lower residence times (<1 day) and constitutes the main navigation channel, while the south arm is shallower (2–4 m deep, at high tide) has higher residence times (2–8 days) and is almost silted up in the upper areas, forcing most of the freshwater discharge through the northern arm. In the southern arm, water circulation is mostly due to tides and the freshwater input from a small tributary, the Pranto River. Freshwater discharge of this river is small and artificially regulated by a sluice according to the irrigation needs of the Mondego valley rice fields. Environmental factors in the Mondego estuary provide a large variety of aquatic habitats for populations of marine, brackish and freshwater plankton species (Azeiteiro et al., 1999; Marques et al., 2006), mainly due to salinity and water temperature gradients.

2.2. Sample collection and analysis

Zooplankton was collected monthly in the Mondego estuary from January 2003 to December 2006, during high tide, at five stations distributed throughout both arms (Fig. 1). Samples were collected by horizontal subsurface tows (bongo net: mesh size 335 μm, mouth diameter: 0.5 m), equipped with a Hydro-Bios flow meter and preserved in a 4% buffered formaldehyde seawater solution. Additionally, at each station, water temperature (°C) and salinity were measured. Zooplankton samples were brought to the lab and split into random sub-samples for counting (individuals m^{-3}).

Monthly precipitation values were measured at the Soure 13 F/01G station and acquired from INAG – Instituto da Água (www.snirh.inag.pt) and freshwater discharge from Mondego River was obtained from INAG station Açude Ponte Coimbra 12G/01AE. Seasonal and inter-annual variability was studied and differences tested using Analysis of Variance (ANOVA) both for zooplankton and environmental parameters.

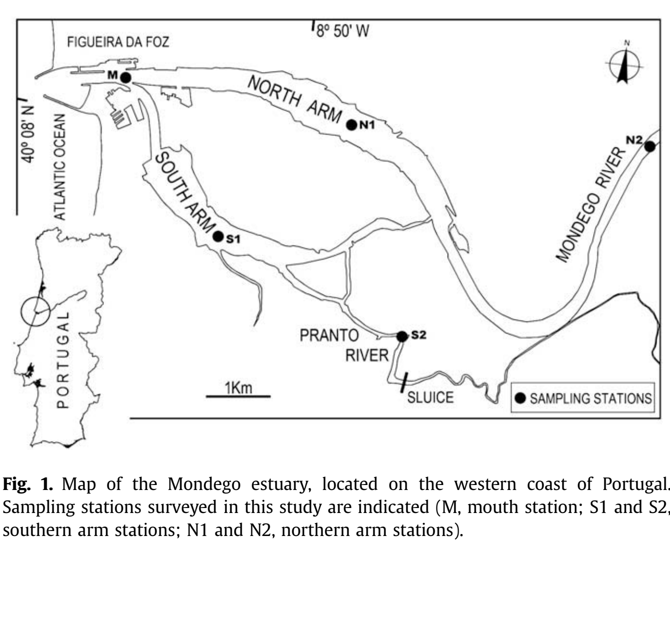

Fig. 1. Map of the Mondego estuary, located on the western coast of Portugal. Sampling stations surveyed in this study are indicated (M, mouth station; S1 and S2, southern arm stations; N1 and N2, northern arm stations).

Spatial and temporal patterns in community structure were examined by multivariate techniques using PRIMER software package (version 5.2.6, PRIMER-E Ltd.) (Clarke and Warwick, 2001). Species abundance data were fourth-root-transformed to balance the contributions from the few very abundant species with the many rare species (Clarke and Warwick, 2001). Bray–Curtis similarity was used to construct a similarity matrix which made-up the basis for a 2-D ordination plot using the non-metric multidimensional scaling (NMDS). Samples were grouped in years, seasons and sampling stations and differences tested by a one-way ANOSIM test (Clarke and Warwick, 2001).

Three biodiversity indices were calculated for each sample: number of species, the Shannon Diversity Index (log2) (H') and the Average Taxonomic Distinctness Index (Delta*). Delta* reflects the taxonomic spread of species among samples and is based in the taxonomic distances between every pair of individuals. This index removes the effect of dominant species and reflects more purely the taxonomic hierarchy. High Delta* values (maximum 100) reflect high taxonomic diversity in the assemblage (Clarke and Warwick, 2001). For each diversity index, differences between seasons were tested using a one-way ANOVA (the Newman–Keuls post-hoc test) or the Kruskal–Wallis ANOVA (the Dunn post-hoc test).

3. Results

3.1. Environmental parameters

In the Mondego estuary a clear seasonal pattern of rainfall and freshwater discharge was observed during the four-year period, with the highest values observed in winter (Fig. 2A).

Compared to the mean precipitation regime for central Portugal during 1933–2000, the year of 2003 corresponded closely to an average precipitation year except for some above-mean precipitation in October leading to flooding events. As in 2003, 2006 had precipitation values closer to average but in October 2006 another flooding event occurred (Fig. 2A). The years of 2004 and 2005 showed periods with below-mean precipitation (January–May and October–December) causing, in 2005, one of the biggest droughts of the 20th century in Portugal. Freshwater discharge in 2005 was significantly lower than in 2003 and 2006 (Kruskal–Wallis ANOVA: $H = 15.287$, df = 3, $p < 0.05$).

Generally, water temperature and salinity had a similar variation pattern during the sampling period, with lower salinity values and lower temperatures in winter months. However, in 2004 and 2005 salinity values were higher in spring and autumn months, respectively (Fig. 2B). Year 2006 showed the highest annual mean water temperature (16.5 ± 3.81 °C) but generally, differences in water temperature were not statistically significant between years. Moreover, sampling stations also did not present significant temperature differences between years.

Annual mean salinity in 2005 (28.7), was significantly higher than in 2003 (17.8) or 2006 (16.1) (One-way ANOVA: $F = 8.166$, $p < 0.001$). No significant differences were found for the remaining period. At all sampling stations, salinity presented significantly higher values in 2005 than in 2003 and 2006 (Kruskal–Wallis ANOVA, df = 3, $p < 0.01$).

3.2. Seasonal and inter-annual zooplankton variability

Mean monthly zooplankton abundance was highly variable within the study period ranging from 21 (January 2005) to 1102 ind. m^{-3} (November 2006) (Fig. 3). The highest value was recorded in November 2006, but peaks occurred in different months in the other years. In the year 2003 the maximum value (587 ind. m^{-3}) was observed in December, in 2004 it was observed