International Journal of Lakes and Rivers.
ISSN 0973-4570 Vol.1 No.1 (2006), pp. 65-74
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http://www.ripublication.com/ijlr.htm

Comparison of the zooplankton from two different temperate tidal systems in Western Portugal: the Mondego Estuary and Ria de Aveiro Lagoon

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Abstract

This study examines the zooplankton assemblages in the Mondego estuary and Ria de Aveiro lagoon (Western Portugal) and discusses how different conditions between the two tidal systems may influence the abundance and diversity of the zooplankton. Both tidal systems are located in a warm temperate region with a basic continental temperate climate. The two systems differ in geomorphology, freshwater inputs and tidal dynamics. The statistical tested values of salinity and temperature were significantly different according to tidal, monthly and estuarine situations. The chlorophyll-*a* values were highest at low tide, in the Mondego estuary in summer months. The significant differences found are mainly explained by the different freshwater inputs in the systems. As far as zooplankton densities are concerned, the Mondego estuary presented high abundance in May in high tide and the Canal de Mira in August in low tide. Higher diversity values were found in the Mondego estuary in May, June and July in high tide and in June, July and August in low tide. Higher diversity values were found in Canal de Mira for the rest of the year. Diversity values were also significantly different in the tidal, monthly and estuarine situations. The physical and chemical (temperature and salinity) and biological (chlorophyll- *a*) differences between the two systems should explain the significant differences in the zooplanktonic densities and the diversity between them.

Key words: zooplankton, estuaries, Mondego estuary, Ria de Aveiro estuary, comparison.

Introduction

Comparison of the tidal habitats, which differ in the physical, geomorphologic and hydrographical components can be useful to identify which factors influence biological communities. This approach, due to the complexity of tidal environments, requires dynamical intensive studies in order to establish ecological relationships (Azeiteiro and Morgado, 1996).

Several studies dealing with this approach compare systems, which differ in topographic and hydrographical conditions (Kimmerer and McKinnon, 1985), oceanographic conditions (Santamaria *et al*., 1989), different water masses (Richard and Haedrich, 1991) and habitats in the same system (Azeiteiro and Morgado, 1996) and systems with different types of anthropogenic influences (Vecchione, 1989).

This study examines the zooplankton assemblages in the Mondego estuary (Azeiteiro, 1999; Azeiteiro *et al*., 1999 a, 2000) and Ria de Aveiro Lagoon (Morgado, 1997; Morgado *et al*., 2003) in Western Portugal and discusses how different conditions between the two tidal systems may influence the composition, structure and dynamics of the zooplankton. The main objectives of present paper were: i) to describe the zooplankton abundance and diversity, the chlorophyll *a* and abiotic characteristics of the two tidal systems and ii) to compare the zooplankton abundance and diversity in both tidal systems.

Study areas

Both tidal systems are located in a warm temperate region with a basic continental temperate climate. The systems differ in geomorphology, freshwater inputs and tidal dynamics (Azeiteiro, 1999; Morgado, 1997).

Mondego estuary

The Mondego estuary, located in the Portuguese west coast (40º08’N, 8º50’W), has an area of 3.3 km^2 and a volume of 0.0075 km^3. The hydrological basin of the Mondego, with an area of 6670 km^2, provides an average discharge of $8.5x10^9$ m^3s^{-1}. The estuary consists of two arms, north and south separated by an island. The two arms become separated in the estuarine upstream area, at about 7 km from the sea and join again near the mouth. These two arms of the estuary differ in their hydrographical characteristics. The north arm is deeper (5 to 10 m during high tide; tidal range about 2 to 3 m), while the south arm (2 to 4 m deep during high tide) is almost silted up in the upstream areas, which cause the freshwater of the river to flow essentially by the north arm. The circulation in the south arm of the estuary depends on the tides and in much smaller amount on the freshwater discharge from a tributary – the Pranto River, which is controlled by a sluice located 3 km from the confluence with the Mondego River. Due to differences in depth, the penetration of the tide is faster in the north arm, causing daily changes in salinity to be much stronger, whereas daily temperature changes are higher in the south arm.

Ria de Aveiro lagoon

Ria de Aveiro Lagoon is a shallow bar-built estuary on the northwest Portuguese coast with a wet area of 47 km^2 at high tide and 42 km^2 at low tide. With a maximum length and width of 40 km and 10 km, respectively, the lagoon shows a rather complex topography, comprising a complex reticulate of channels radiating from the contact with the Atlantic Ocean. The tidal influence is the main factor affecting the circulation within the estuary. The volume of seawater entering the estuary in each flood is $25x10^6$ m^3 (1 m tidal range) coming up to 96 x 10^6 m^3 if the 3 m quota is reached. The sum of all freshwater entering this water body (in the same period) only amounts to 2 x 10^6 m^3. The tidal regime is semi-diurnal with a tidal range of 2.1 m at the inlet. The study site was located in the Canal de Mira (Fig. 1b) which evolves from the inlet towards the south-east, parallel to the coastline with an approximate extension of 20 km and a maximum width of 1 km. It is characterised by possessing a maximum depth of 9 m below hydrographical zero in a very narrow area near the mouth and seldom below 0.5 in its final 2/3. Freshwater is continuously imputed by a system of creeks and lagoons. The medium discharge is 7.8 m^3s^{-1}. The Canal de Mira is characterised by a positive longitudinal salinity gradient influenced by the tides and seasonal cycles. Its residual circulation can be described as a two-layer flow with vertical mixing (Morgado, 1997; Morgado *et al*., 2003).

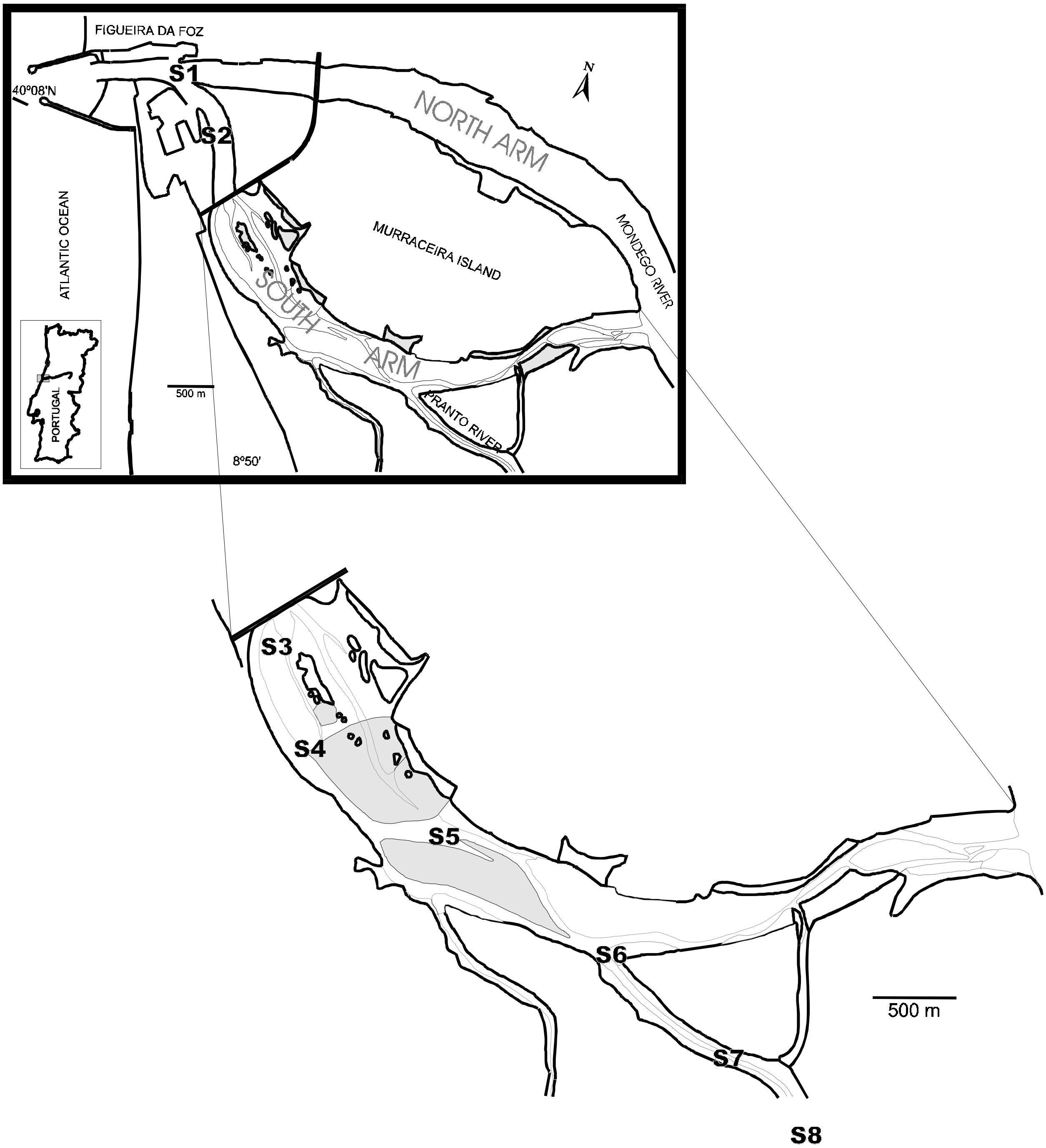

Figure 1(a)

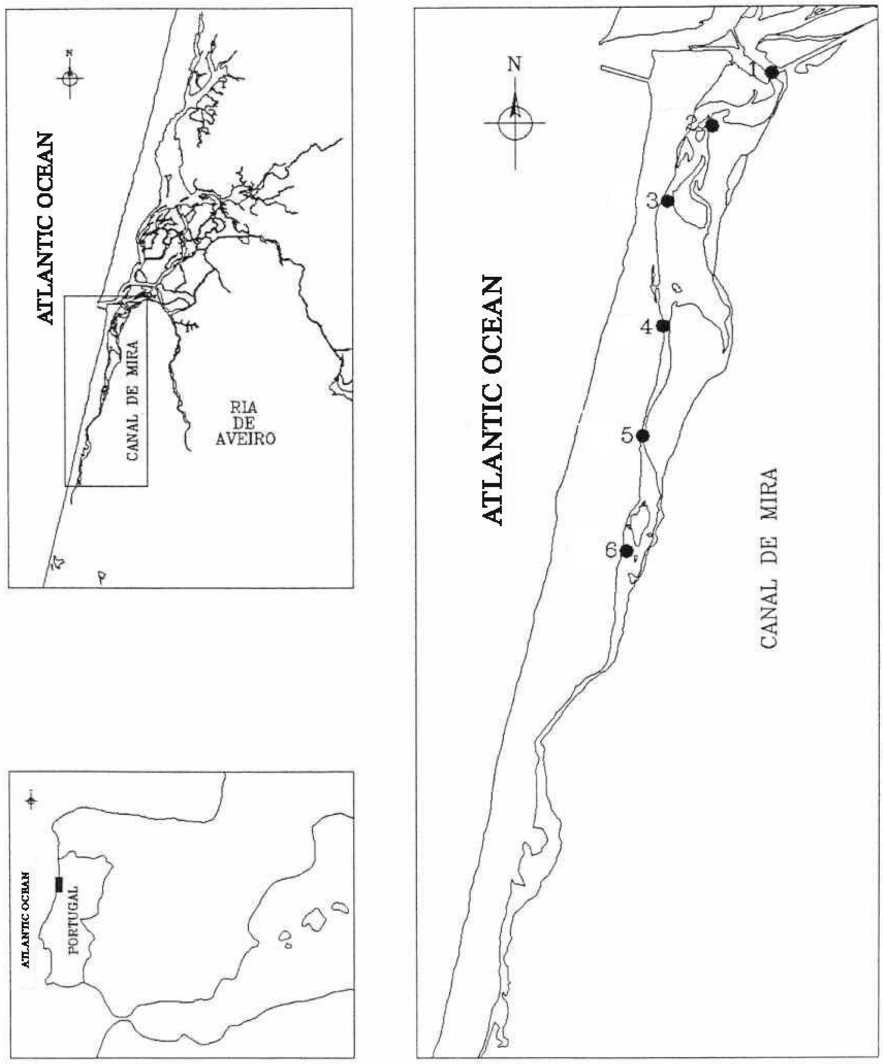

Figure 1(b)

Figure 1. Map of the Mondego estuary (a) and the Ria de Aveiro lagoon (b) showing the locations of the two sampling stations in the south arm.

Material and Methods

The south arm of Mondego estuary was surveyed every month from April 1995 to April 1996. Sampling was carried out at eight stations, as shown in Fig.1a (Azeiteiro, 1999) . In order to eliminate differences due to the depth variability, as well as tidal and vertical migrations, sampling was performed in sub-surface waters and between 8:00 and 18:00 h. The eight stations were visited during ebb and flow spring tides. The zooplankton was collected with a 60 cm diameter Bongo net having 335 μm mesh nets. The volume of water filtered by the net was measured with a HydroBios flowmeter mounted in the mouth of the nets. The zooplankton samples were preserved in 4% neutralized formalin after collection. Each zooplankton sample was sub sampled by taking aliquots, which were sufficiently large to provide several hundred organisms for counting. The numbers of each taxon were converted to densities, *i.e*. numbers m^{-3} (Azeiteiro, 1999; Azeiteiro *et al*., 1999 a, 2000).

Sampling was carried out in Ria de Aveiro Lagoon at six stations in the Canal de Mira. Longitudinal subsuperficial hauls were made from January to December 1993 during spring tides, both during flood and ebb, with a 335 µm plankton net. Zooplankton samples were preserved in a 4 % buffered formalin. Chlorophyll- *a* was estimated, using the method described by Strickland and Parsons (1972). Temperature and salinity measurements were also taken during all sampling procedures using an YSI t-s instrument. Samples containing excessive number of organisms were sub sampled with a Folsom plankton splitter. The densities of organisms were expressed ind.m^{-3} (Morgado, 1977; Morgado *et al*., 2003).

The Shannon-Wiener diversity index was used for the estimation of community diversity (Azeiteiro, 1999; Azeiteiro *et al*., 1999 a, 2000; Morgado, 1997; Morgado *et al*., 2003).

For statistical analysis purposes, the overall effect of the area of study, the phase of tide and period of study on densities of the organisms were investigated, using a one-way analysis of variance (ANOVA). All collected samples were considered as replicates. Prior to analysis, in order to normalise data, densities were submitted to a Log (n+1) transformation, which homogenised the variances in all cases (Morgado, 1997; Morgado *et al*., 2003).

Results and Discussion

In recent years several studies on zooplankton ecology (Gonçalves, 1991; Azeiteiro, 1999; Azeiteiro *et al*., 1999 a, 2000; Vieira *et al*., 2003) and dynamics (Azeiteiro *et al*., 1999 b; 2002; Pastorinho *et al*., 2003; Vieira *et al*., 2002) of the Mondego estuary have increased our knowledge about this system. Canal de Mira was also studied in details as far as zooplankton ecology is concerned (Morgado, 1997; Morgado *et al*., 2003). The methodologies used in these studies (Azeiteiro, 1999; Morgado, 1997) allowed us to compare data from these. The differences found (that leaded to significant statistical differences) are mainly explained by the different freshwater inputs in the systems. Both systems are tidally controlled but the circulation in the southern arm of the Mondego estuary is related to the freshwater discharge from a tributary – the Pranto River, which is controlled by a sluice located 3 km from the confluence with the Mondego River. In the winter months the sluice is open and a considerable volume of freshwater flows to the system altering the salinity gradient. In Canal de Mira, the freshwater is continuously imputed by a system of creeks and lagoons. Both tidal systems exhibited a similar annual pattern of variation in salinity and temperature values. In high tide, salinity showed higher values in the Mondego estuary than in Canal de Mira (exception in September and February). During low tides, salinity was much higher in January, February and March in Canal de Mira than in the Mondego estuary. The pattern of variation of the temperature values was almost similar for both systems and for both tidal situations. In high tide, the temperature was almost always higher in the Mondego estuary than in Canal de Mira (except for September and January) (Fig. 2). The statistical tested values of salinity and temperature were significantly different in the tidal, monthly and estuarine situations (Table 1). The chlorophyll *a* values were highest at low tide, in the Mondego estuary in summer months (Fig.3 and Table 1).

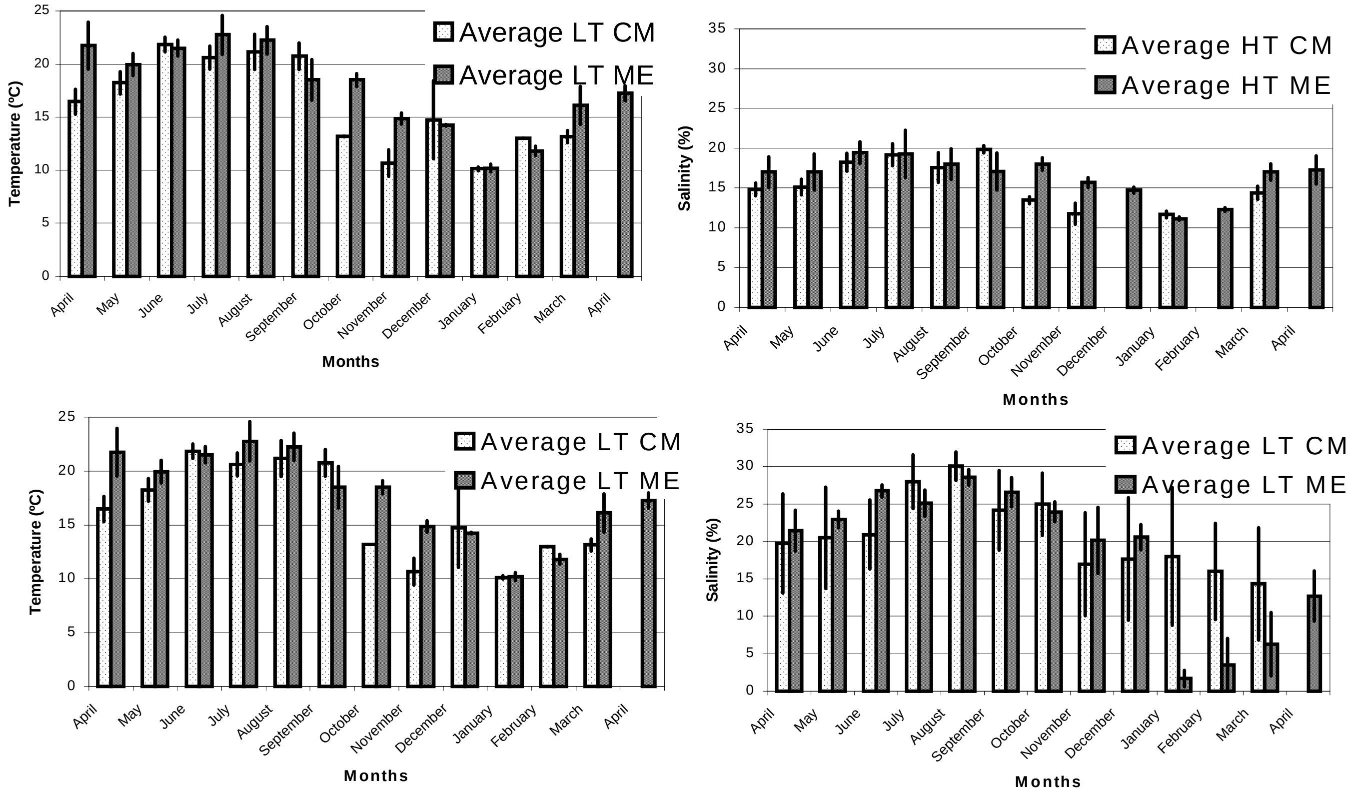

Figure 2. Average temperature and salinity values distribution in high and low tide for both systems.

Table 1: ANOVA analysis results.

		ESTUARY			
source of variation	df	MS	F	P	
Chlorophyll *a*	2	31,71866	140,8411	0,01	**
Salinity	2	74,40421	46,10738	0,001	***
Temperature	2	12,17001	301,905	0,01	**
Diversity	2	0,027285	181908,7	0,01	**
Density	2	0,844667	5751,252	0,01	**
		TIDE			
source of variation	df	MS	F	P	
Chlorophyll *a*	2	29,46156	162,4718	0,01	**
Salinity	2	66,90612	67,24438	0,001	***
Temperature	2	12,03712	306,8115	0,01	**
Diversity	2	0,050799	97622,03	0,01	**
Density	2	0,786675	6188,534	0,01	**
		MONTH			
source of variation	df	MS	F	P	
Chlorophyll *a*	12	28,00414	30,5486	0,01	**
Salinity	12	42,43969	32,19364	0,01	**
Temperature	12	4,081154	197,9529	0,01	**
Diversity	12	0,047828	17283,97	0,01	**
Density	12	0,736145	1105,119	0,01	**

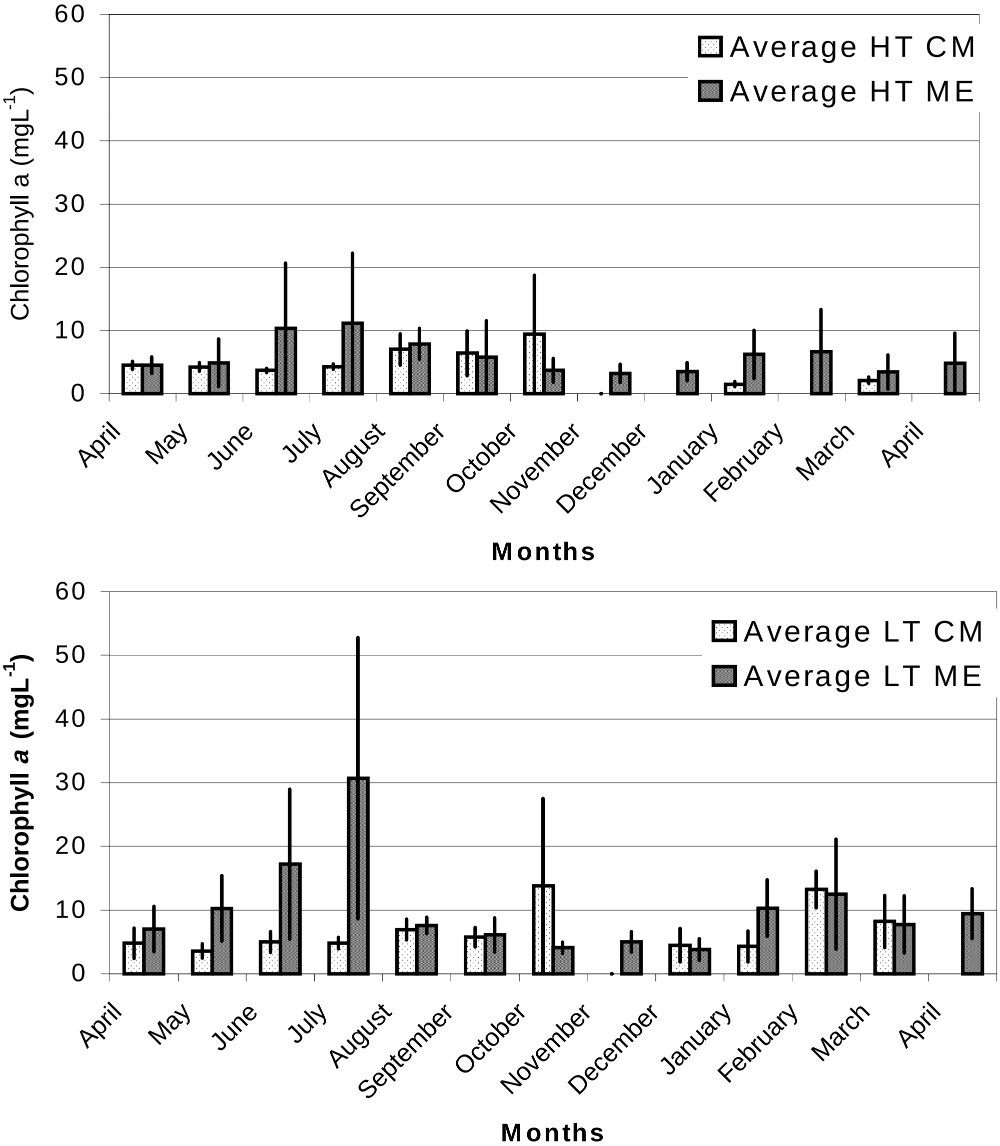

Figure 3. Average Chlorophyll *a* values distribution in high and low tide for both systems.

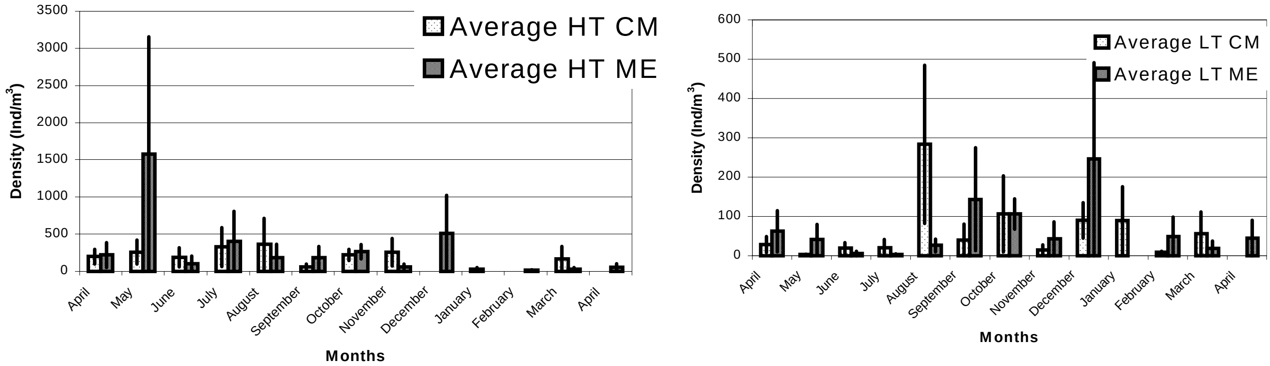

Figure 4. Average zooplankton abundance values distribution in high and low tide for both systems.

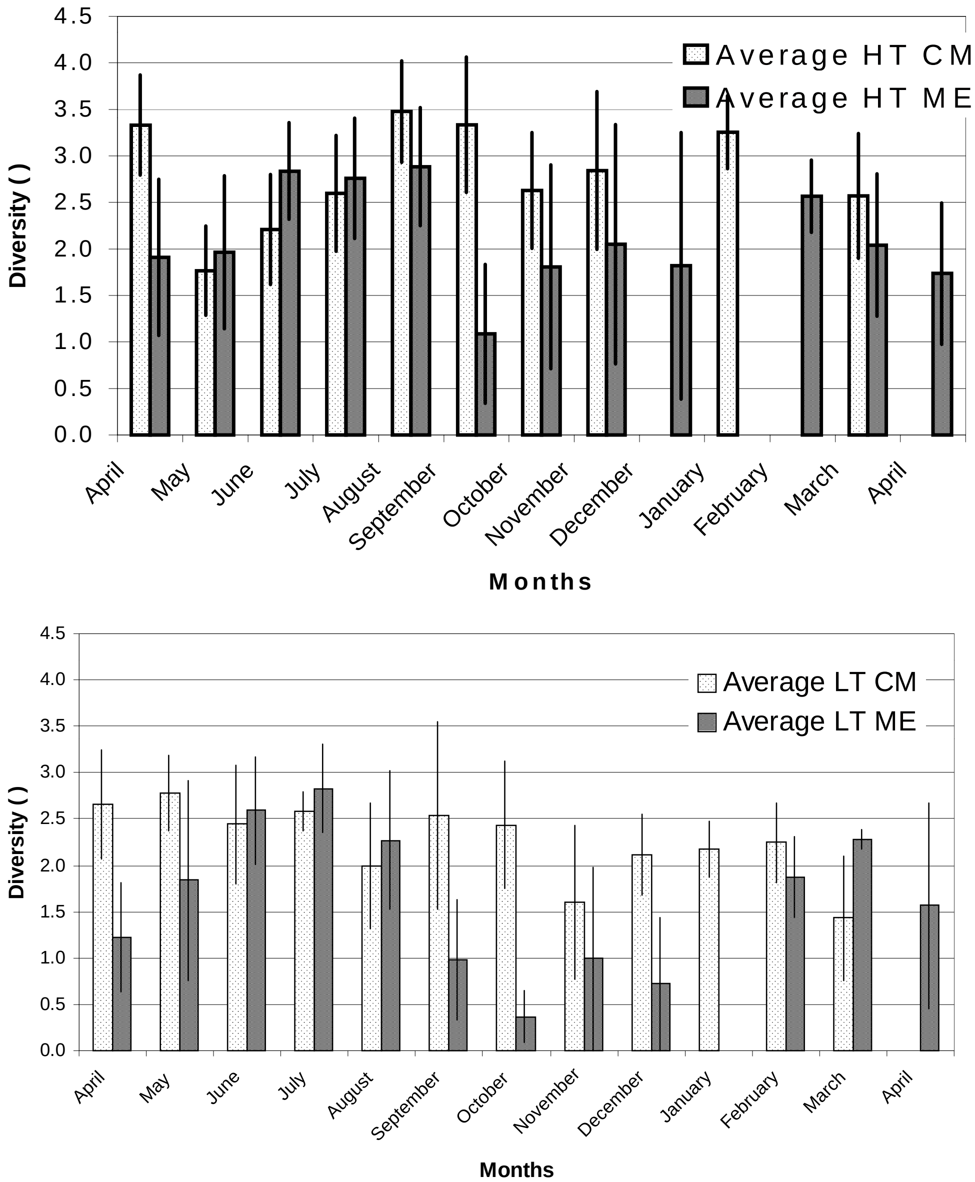

Figure 5. Average diversity values distribution in high and low tide for both systems.

As far as zooplankton densities are concerned, the Mondego estuary presented high abundance in May in high tide and Canal the Mira in August in low tide (Fig. 4). Higher diversity values were found in the Mondego estuary in May, June and July in high tide and in June, July and August in low tide. Higher diversity values were found in Canal de Mira during the rest of the year (Fig. 5). Diversity values were, also, significantly different in the tidal, monthly and estuarine situations (Table 1). Seasonal fluctuations in zooplankton densities and diversity in temperate climates have been known for a long time and the numerous studies conducted have identified a vast number of factors responsible for these phenomena. Explanations provided have varied in accordance with the prevalent combination of environmental /biological parameters present at each study site. Available papers, concerning the interpretation of seasonal cycles, usually present a set of conclusions contemplating a complex conjunction of those factors although only a limited numbers of them are identified as prime responsible, being modelled, in a somewhat limited way, by the remaining others. In this situation are the environmental parameters such as temperature and salinity (Castel and Courties, 1982; Ryan *et al*., 1986; Mallin, 1991; Mackas, 1992; Gaughan and Potter, 1995), food (Fulton, 1984) and hydrology (Kouwenberg, 1994). The significant differences between the two systems in those parameters (temperature, salinity and chlorophyll *a*) should than explain the differences found in the densities and diversity of the zooplankton in both systems.

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