

## ESTUARINE MESOZOOPLANKTON DYNAMICS ON A SHORT-TERM TIME SCALE: ROLE OF SEMIDIURNAL TIDAL CYCLE

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In estuaries and coastal areas, planktonic organisms are subject to tidal, diurnal and seasonal environmental changes (MARQUES et al., 2009). Knowledge of the variability of zooplankton communities on different spatial and temporal scales is a prerequisite for the understanding of ecosystem dynamics. Tidal currents and estuarine circulation are well known phenomena that contribute to both vertical and horizontal redistribution of planktonic organisms (MORGADO et al., 2003). Moreover, biological mechanisms may also account for a significant part of the temporal variation in zooplankton community structure (MARQUES et al., 2009). Planktonic communities have presumably developed adaptations in order to compensate for or resist dispersive losses (LAM-HOAI et al., 2006), thus resulting in recurrent patterns of zooplankton distribution. The Bahía Blanca Estuary constitutes a mesotidal system with a semidiurnal tidal cycle, the tides being one of the most important sources of energy (PERILLO; PICCOLO, 1991). The temporal and spatial dynamics of the mesozooplankton in this estuary have been extensively investigated (e.g. HOFFMEYER 2004; HOFFMEYER et al., 2008) but none of these studies has considered the short-term variability associated with tidal cycles. The objectives of the present study were to describe the influence of the tidal cycle on mesozooplankton variability and to compare the mesozooplankton distribution of two zones in the main channel of the estuary: its northern margin and the deeper central zone.

The Bahía Blanca Estuary is a coastal plain system (38°45'S; 62°22'W) on the Atlantic coast of Argentina (Fig. 1). It is formed by several NW to SE tidal channels separated by extensive intertidal flats, low marshes and islands (PICCOLO; PERILLO, 1990). The tides and winds have been considered the main factors controlling the water turbulence processes (PICCOLO; PERILLO, 1990), especially in the inner zone where the tidal height is maximal (tidal

range of up to 3.6 m). Tidal currents are reversible with maximum surface velocities of about 1.3 m s<sup>-1</sup> and maximum vertically averaged values of 1.2 and 1.05 m s<sup>-1</sup> for ebb and flood conditions, respectively (CUADRADO et al., 2005). The inner zone of the estuary is relatively shallow (4-7 m at the channel margin and a mean depth of 10 m in the central zone of the channel), well mixed and highly turbid as a result of the combined effect of winds, tidal currents and river discharge. Sampling was carried out on 12th May 2006, during a transition from spring to neap tides (Fig. 1). Samples were taken over a 14-h period at two stations (S1, S2) located in the inner zone of the estuary (Fig. 1). S1, Puerto Cuatros, coincides with the northern margin of the principal channel and S2 is located in the central zone of the main channel, approximately 200 m away from S1 (Fig. 1). Zooplankton samples were collected during the daytime every 3 h (from a boat in S2), beginning at high tide. Two submersible pumps were used to obtain simultaneous surface and bottom samples and a PVC hose linked the pumps to 200 µm pore size plankton nets. Water was filtered through the nets for 10-20 min, for a total sample volume between 1.5 and 2.9 m<sup>3</sup>. The collected material was preserved in a buffered solution of 4% formaldehyde. To estimate the water volume sampled, the flow rate of the pumps was calculated before and after each sampling time by recording the time taken to fill a known volume of water. Vertical profiles of temperature and salinity were obtained with a digital multisensor Horiba U-10 and additional surface and bottom water samples (through pumping water) were taken to determine suspended particulate matter (SPM). Measurements of current velocity were made using a 1.5 MHz Acoustic Doppler Profiler (ADP) located near S2. The tidal height was continuously measured by means of a tidal gauge and all data concerning winds were obtained via a meteorological base installed on the pier. Zooplankton samples were sub-sampled (1/10) and all

individual taxa were counted. The abundance of taxa was expressed as the number of individuals per cubic meter ( $\text{ind. m}^{-3}$ ). The SPM was determined filtering 250 ml of water through previously dried and weighed Whatman GF/C filters ( $0.45 \mu\text{m}$ ). Filters were then dried at  $60^\circ\text{C}$  for 24 h and weighed for SPM estimation.

In this study, the wind effect was almost negligible throughout the sampling period: with mean wind velocities of  $6.7 \text{ km h}^{-1}$  in the morning (mainly from the NNE) and  $14.9 \text{ km h}^{-1}$  in the afternoon (mainly from the NW). Therefore, the short-term variability observed in the measured variables was mainly due to the semidiurnal tidal influence. Tidal height varied between 1.18 and 5.1 m, low water slack occurred at 13:00 h and high water slack at 6:30 and 19:00 h (local time). Instantaneous tidal currents ranged from  $<0.2$  to  $0.8 \text{ m s}^{-1}$  according to the semidiurnal tidal cycle (Fig. 2). Maximum velocities were observed during the ebb,  $\sim 3$  h after high tide, while minimum velocities ( $<0.2 \text{ m s}^{-1}$ ) corresponding to slack water occurred at high and low tide (Fig. 2). Tidal flows were asymmetrical so the ebb currents had a shorter duration, but were stronger than at the flood ( $\sim 0.5 \text{ m s}^{-1}$ ). In both ebb and flood phases, velocities were higher near the surface (Fig. 2). Temperature values seemed to follow the course of the tide, with maximum temperatures around high tide ( $12.5$ – $12.8^\circ\text{C}$ ) and minimum during the ebb or low tide

( $11.6$ – $12.1^\circ\text{C}$ ). Water salinity (33.8–36) co-varied with tidal height, showing the lowest salinity at low tide, according to the expected result of the advection of the lateral salinity gradients typical of an estuary with major freshwater input at the head (GUINDER et al., 2009). The water column was always vertically mixed as indicated by temperature (mean gradient:  $0.015$  and  $0.011 \text{ }^\circ\text{C m}^{-1}$  for S1 and S2, respectively) and salinity vertical profiles ( $0.035$  and  $0.043$ ). SPM varied between  $26.8$  and  $94.8 \text{ mg L}^{-1}$  and showed similar temporal patterns at the surface and at the bottom of the water column (Fig. 3). The highest SPM concentration was around ebb tide at both sampling stations although in S2, high concentrations were also detected during flood tide (Fig. 3). Considering that bottom sediment resuspension is controlled by the near-bed shear stress (which is a function of current speed) (VELEGRAKIS et al., 1997), the maximum SPM concentrations observed in association with the energetic ebb currents indicate that bottom sediment resuspension is likely to account for the observed changes in SPM concentration. Other researches related to SPM tidal variability in estuaries have reported different patterns associated not only with resuspension but also with advective processes and river discharges (CLOERN et al., 1989; WEEKS et al., 1993; VAN DE KREEKE et al., 1997; VELEGRAKIS et al., 1997).

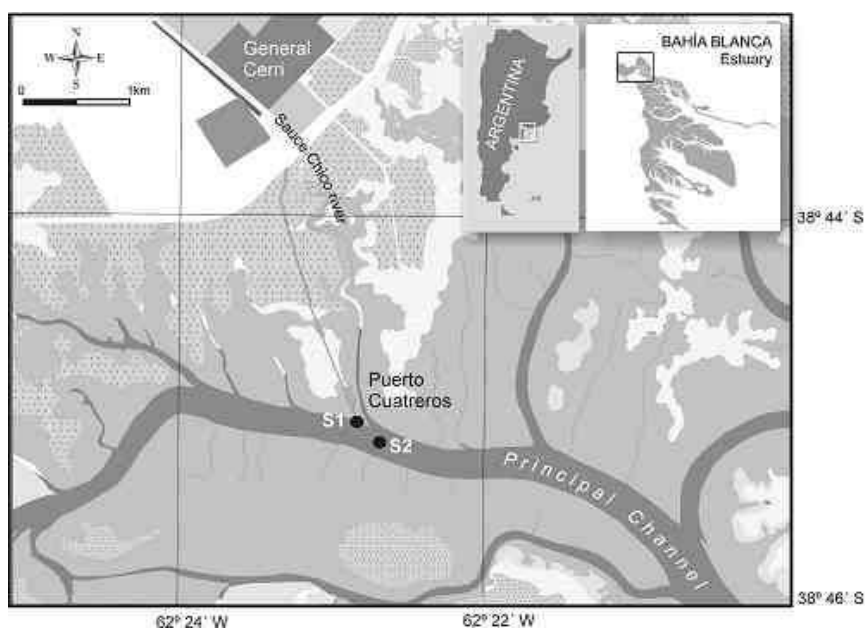


Fig. 1. Inner zone of the Bahía Blanca Estuary and location of the two sampling stations (S1, S2). S1: Puerto Cuatros, northern margin of the main channel. S2: central main channel, 200 m away from S1.

After analyzing all the samples, a total of 23 taxa were identified in this survey, 17 of which were observed at both sampling sites. The holoplankton fraction represented 39.1% of the total taxa observed whereas the remaining percentage corresponded to meroplankton (34.8%) and adventitious organisms (26.1%). Copepods occurred at all tidal phases and were the dominant group at both stations. The calanoid copepod *Acartia tonsa* dominated the mesozooplankton community numerically, accounting for more than 95% of the total zooplankton abundance. Lower densities of *Paracalanus parvus*, benthic harpacticoids, estuarine larvae of polychaetes and the amphipod *Corophium* sp. were also found at both sites. Some individuals of *Labidocera fluviatilis* and the cladoceran *Bosmina longirostris* were only registered at S2 and their contribution to the total mesozooplankton was very small. On the other hand, bivalve larvae, foraminifera and the amphipod *Caprella* sp. were only present in the margin area.

*A. tonsa* abundances registered at the channel margin (S1) were in general higher near the surface throughout the tidal cycle and fluctuated between 11.34 and 2941.34 ind. m<sup>-3</sup> at the surface and between 56.77 and 661.88 ind. m<sup>-3</sup> at the bottom (Fig. 4). The abundance of this species was markedly higher during ebb tide (2853.6 ind. m<sup>-3</sup>) than during flood, low or high tide events (Fig. 4). *A. tonsa* abundances in the central main channel (S2) ranged from 222.81 to 987.50 ind. m<sup>-3</sup> at the surface and from 298.78 to 1533.01 ind. m<sup>-3</sup> at the bottom (Fig. 4). Contrary to what occurs in the margin area, the abundances in the central main channel were higher near the bottom during the entire tidal cycle and no marked increase of the abundance was detected during ebb tide (Fig. 4). These results showed a daytime scenario in which the short-term temporal variability of the dominant species *A. tonsa* was strongly affected by tidal dynamics. The interdependence of planktonic organisms' exchanges with water circulation in order to control the seaward transport arises mainly from differences in the density between flood and ebb tides (MORGADO et al., 2003). Thus, the distributional pattern observed for *A. tonsa* could be related to a retention mechanism of this species in the inner zone of the Bahía Blanca Estuary. The increase of the abundance during ebb tide only at S1 may be associated with a lateral movement of this species to areas of decreased flushing such as the channel margins. This option has been suggested for different copepod species in order to enable them to resist the seaward net flow during the ebb (CRONIN et al., 1962; RODDIE et al., 1984; CASTEL; VEIGA, 1990), but until now there are few data illustrating this. In this study, we have always registered the highest abundances of *A. tonsa* in a zone of net residual landward flow. This may be interpreted as a

mechanism that prevents individuals from being washed out of the estuary considering that landward residual currents help to maintain the populations in the estuaries (CASTEL; VEIGA, 1990). In the central channel, the greater proportion of the population near the bottom would reduce the advective losses considering that the residual flow is landward near the bottom (PERILLO; PICCOLO, 1991). Additionally, the net transport is completely landward in the shallower parts such as the margins (PERILLO; PICCOLO, 1991).

Mechanisms by which estuarine mesozooplankton enhance retention in particular regions have been subjected to different interpretations including behavioral responses as well as purely hydrological mechanisms. CASTEL and VEIGA (1990) suggested that *Eurytemora affinis* populations in the Gironde Estuary, France, are maintained through the same hydrological processes that trap and concentrate suspended particles. Similar results were mentioned by MORGAN et al. (1997) for *Coullana canadensis* in the Columbia River Estuary, USA, where the abundance distribution mirrors that of SPM. Hough and Naylor (1991, 1992), however, observed tide-related vertical migrations of *E. affinis* in the mid-estuary region of the Conway River Estuary in Wales. In our study, patterns of abundance and distribution of *A. tonsa* did not match those of SPM, suggesting that additional mechanisms beyond hydrodynamic processes would maintain the populations in the inner zone of the Bahía Blanca Estuary. The high abundances of this species observed during ebb tide at the margin and near the bottom in the central channel, where there are landward residual currents, provide evidence about the existence of some mechanism that allows the species to avoid stronger surface currents during the receding tide. Determination of whether such a retention mechanism operates for *A. tonsa* in the Bahía Blanca Estuary awaits further studies not only considering other sampling stations but also complementary observation of the behavior of individual copepod species.

This study represents a contribution to the knowledge of the mesozooplankton dynamics over tidal time scales. The results highlight the role of tides as forcing agents on the mesozooplankton community structure and emphasize the importance of the biological-physical interactions on a short-term time scale in coastal systems. In addition, and although this study is restricted to samples collected during a short period of time, the results show how variable the mesozooplankton community structure can be over short time scales in mesotidal temperate estuaries. This variability should be taken into account for any mesozooplankton monitoring program conducted in a temperate system with a high-tidal regime.

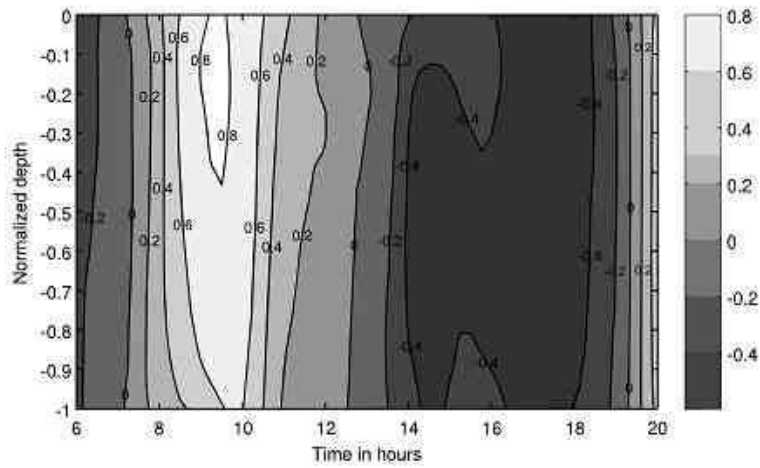


Fig. 2. Longitudinal component of the velocity ( $m s^{-1}$ ) in the central point of the main channel (S2) as a function of normalized depth for a complete tidal cycle. Positive values of water velocity represent the ebb tide and negative the flood tide.

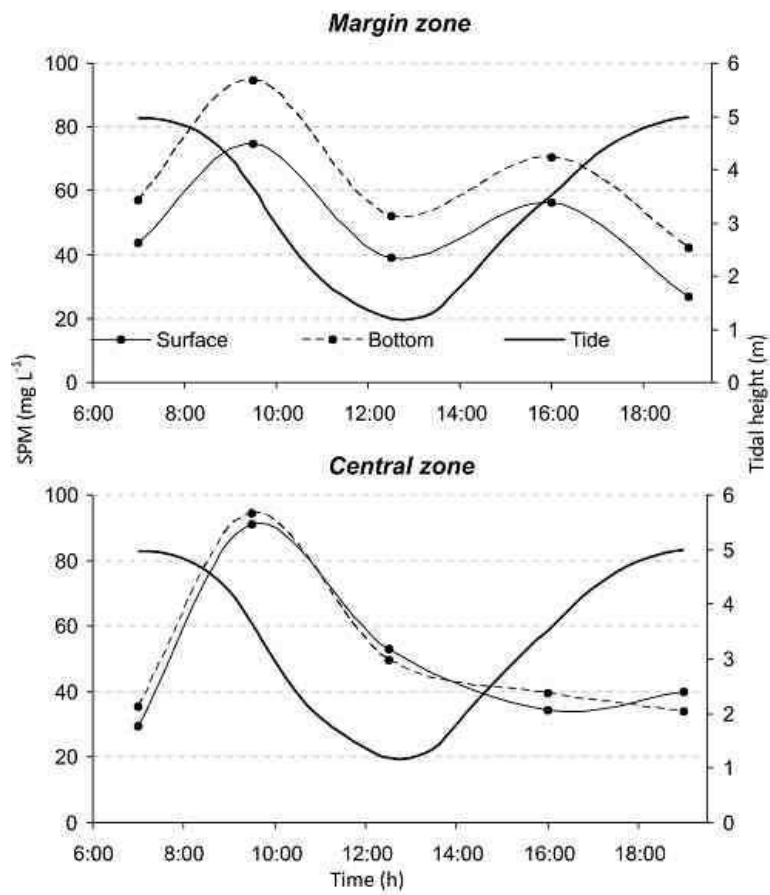


Fig. 3. Temporal distribution of SPM in the two sampling stations of the main channel.

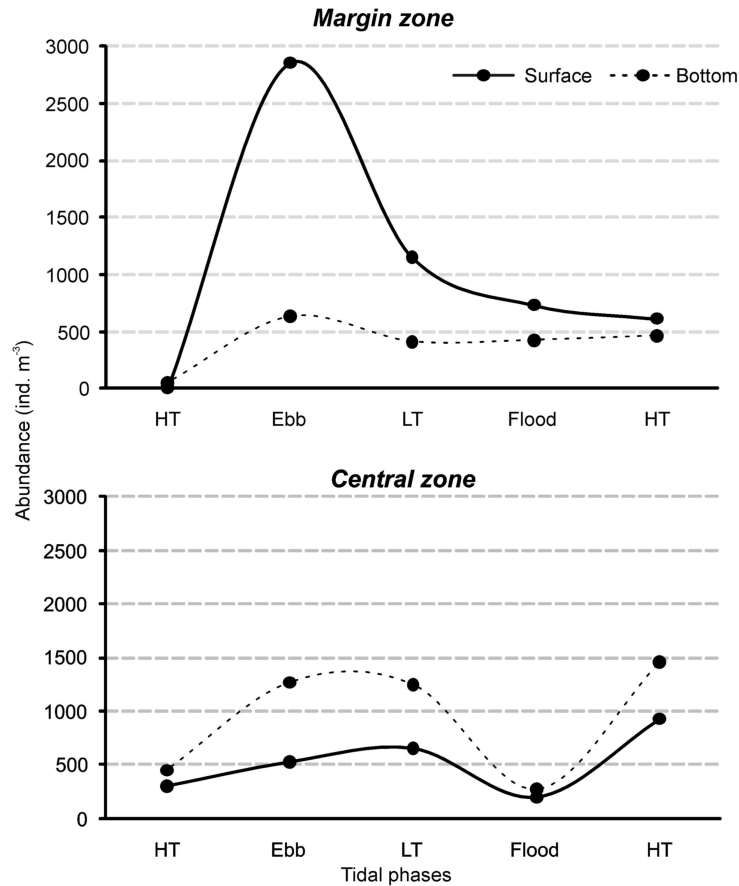


Fig. 4. Abundance distribution of *A. tonsa* in the two sampling stations of the main channel. HT: high tide, LT: low tide.

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