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Spatial and Temporal Variability of Suspended Sediments Concentration in Ria de Aveiro Lagoon and Fluxes between the Lagoon and the Ocean

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ABSTRACT

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The measurements of suspended sediment concentration in different parts of the Ria de Aveiro coastal lagoon during four tidal cycles show a significant spatial and temporal variability. Fluxes of water and suspended sediments between the lagoon and the coastal ocean were estimated for each tidal cycle applying a hydrodynamic two-dimensional numerical model and using the values measured at the lagoon mouth. The hydrodynamics of the lagoon are essentially dominated by tidal forcing. Tides are predominantly semidiurnal and are present in the entire lagoon The differences in suspended sediments concentration within the lagoon seem to be largely determined by the magnitude of the currents and by the bottom properties. As in other estuarine systems, the suspended sediments concentration fluctuated with tidal amplitude. In almost all stations, higher mean values occur during spring tides due to the strength of the tidal currents. Anomalous higher mean values observed in stations close to the tidal inlet during winter neap tide suggest that wind-induced resuspension and horizontal advection from the adjacent coastal area is taking place during that period of the year. Semidiurnal variations are explained, especially during the summer, by tidal-current velocity asymmetry (ebb dominance). Seasonal variability, with winter higher suspended sediments concentration, is probably related with wind climate, biological activity and coastal wave regime. In general, the fluxes of water and of suspended sediments between the lagoon and the coastal ocean showed a seaward flux that is consistent with the ebb dominance. Under winter neap tide conditions external factors allowed retention of suspended sediments in the lagoon.

ADDITIONAL INDEX WORDS: *Resuspension, deposition, advection.*

INTRODUCTION

Located in the transition between the Vouga river basin and the Atlantic Ocean, the Ria de Aveiro coastal lagoon is influenced by marine and fluvial processes that print their signature in the fine-grained sediment dynamics.

Investigations about fine-sized matter in estuaries and coastal lagoons show that the suspended sediments concentration is extremely variable and may vary regionally, with season and with tidal amplitude and phase (FETTWIS *et al*., 1998; RIDDERINKOF *et al*., 2000). Seasonal fluctuations may result from variations in rivers discharge, wave and wind climate. Under tidal influence estuarine fine sediments are moving forward and backward, participating in processes of deposition and resuspension, which are dependent on tidal currents strength (VAN LEUSSEN, 1996).

Semidiurnal variations in the concentration of the Ria de Aveiro suspended sediments have already been reported by SILVA (1994) and PEREIRA (1995), but just for the northwestern channels of the lagoon. A two-dimensional depth-integrated transport model for cohesive suspended sediments has also been applied to simulate tidal evolution of suspended sediments in the lagoon by LOPES *et al*. (2000) and indicated that sediments concentrations show spatial, semidiurnal and fortnightly variability.

The purpose of this work is to study the suspended sediments concentration spatial and temporal variability in the central area of the Ria de Aveiro lagoon and to determine the magnitude and sign of water fluxes and suspended sediments between the lagoon and the ocean.

SETTING

Ria de Aveiro is a shallow well-mixed estuary-coastal lagoon, located in the northwest of Portugal. The lagoon is 45 km long and has a maximum width of 10 km (Figure 1), covering an area of 83 km^2 and 66 km^2, at the highest and lowest tide, respectively. The average depth in the lagoon is about 1 m, with exception for the navigation channels where dredging operations maintain a depth of about 7 m (DIAS *et al*., 2000).

This lagoon, which is connected with the Atlantic Ocean through a narrow entrance (1.3 km long, 350 m wide and 20 m deep), has a complex topography characterized by extensive intertidal zones and four main channels: S. Jacinto, Ílhavo, Mira and Espinheiro.

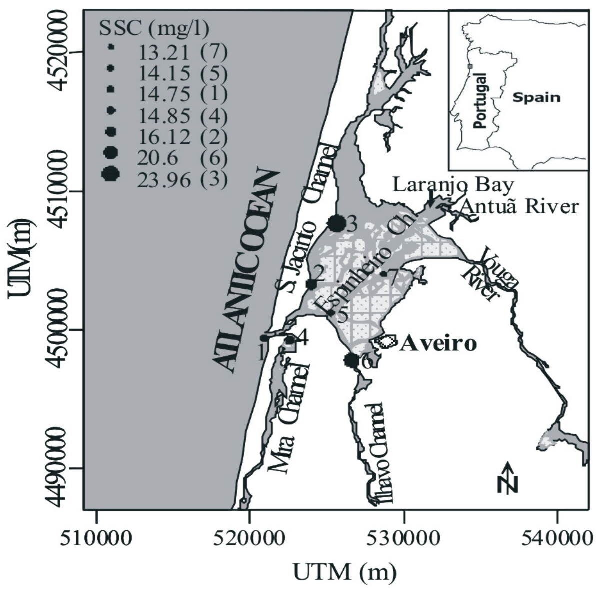

Figure 1. Ria the Aveiro with sampling stations and plots of SSC mean concentration (in the legend, between parentheses are indicated the station number).

The Ria de Aveiro lagoon is geologically very young and its origin is related to the southward transport of sediments by alongshore currents.

From centuries X to XVIII this transport of sediments along the Portuguese west coast originated a long spit that isolated the estuary of Vouga river from the coastal ocean (MARTINS, 1947; GIRÃO, 1951; ABECASSIS, 1955).

In the Ria de Aveiro channels, the surface sediments are a combination of medium to fine sands with a variable content of finer particles (silt and clay), which increases with the distance from the lagoon mouth. The inner zone of intertidal flats integrates, from top to the bottom, sand, mixed and lutitic flats that are mainly composed, respectively, by medium to fine sand, clay silty and clay sandy sediments (ROCHA *et al*., 2000).

Two rivers Vouga and Antuã, with average flows around 50 and 5 $m^3 s^{-1}$, respectively (MOREIRA *et al*., 1993, DIAS *et al*. 1999), constitute the major sources of fresh water. The total mean discharge into the lagoon during a tidal cycle is about 1.8 Mm^3 (MOREIRA *et al*., 1993), while the tidal prism is 136.7 Mm^3 for maximum spring tide, with a tidal range of 3.2 m, and 34.9 Mm^3 for minimum neap tide, with a tidal range of 0.6 m (DIAS *et al*. 2000). Ria de Aveiro hydrodynamics is therefore, essentially dominated by tidal forcing.

The tides at the mouth are predominantly semidiurnal (DIAS *et al*., 1999; DIAS, 2001), and the tidal range vary between 0.6 m at neap tides and 3.2 m at spring tides, with an average value of about 2 m (DIAS *et al*., 2000). The tides are present in the entire lagoon (DIAS *et al*., 2000). Tidal currents are strongly dependent on the local geometry, increasing in narrow and deepest channels (beginning of S.Jacinto and Espinheiro channels), where can be higher than 1 ms^{-1}. Maximum current velocities are found three hours after high and low tide, being the ebb tide currents slightly higher than the flood ones (DIAS *et al*. 1998). In general, the direction of the tidal currents is parallel to the longitudinal axis of the channels.

METHODS

The investigation about the variability of suspended sediments concentration (SSC) was conducted in seven sites (Figure 1) located in the four main channels (1 mouth of lagoon; 2 and 3 S. Jacinto Channel; 4 Mira Channel; 5 and 7 Espinheiro Channel and 6 Ílhavo Channel). Sampling was performed during 2 neap tidal cycles (11.09.2001 and 20.02.2002) and 2 spring tide cycles (20.09.2001 and 13.02.2002), at approximately 2-hour intervals, including high tide and low tide measurements. The surveys cover a range of tidal heights at the lagoon mouth from 1.2 m to 2.9 m in summer and 1.1 m to 2.2 m in winter. Water samples were collected from the surface, middle-depth (when depth is higher than 3 m) and 1 m above the bottom at each site using a Van Dorn® bottle.

To determine the concentration of suspended matter, between 1 and 3 L aliquots were filtered with the classic vacuum system using 0.45 µm Millipore® (47 mm diameter) pre-weighted filters. The filters were dried at 40 ºC for 24 h and reweighed.

A two-dimensional vertically integrated numerical model (2DH) was applied to compute time series of water flow through a transverse section of the entrance channel including station 1, during the tidal cycles. Instantaneous cross-sectional fluxes of suspended sediments were estimated as the product of field data and the computed water flow. Also included were the values corresponding to the time of slack water (determined from the numerical results), allowing the estimation of the time of null flux. Using a third-degree polynomial approximation was performed an interpolation of the instantaneous cross-sectional fluxes, in order to obtain time series of the instantaneous fluxes during each tidal cycle. Fluxes of water and suspended sediments between the lagoon and the coastal ocean were finally estimated integrating the ebb and flood tide series. This model, calibrated by DIAS *et al*. (1998), has been used to study Ria de Aveiro hydrodynamics (DIAS *et al*., 2000; DIAS, 2001) and to estimate fluxes of bacterioplankton populations and associated heterotrophic activities between Ria de Aveiro and the adjacent coastal area (CUNHA *et al*., 2003).

RESULTS AND DISCUSSION

Concentrations

During the study period, the concentration of suspended sediments showed a complex spatial and temporal pattern, depending on the tidal phase and amplitude and on the season (Figure 2). Averaged SSC obtained in each sampling station showed that lower and similar values (14.15-14.85 mgL^{-1}) were found in the stations close to the lagoon mouth, increasing through the S.Jacinto channel (Figure 1).

The differences in SSC between the various locations seem to be largely determined by the magnitude of the currents and by the physical properties of the bottom sediment particles. The highest mean value (24 mgL^{-1}) was found at station 3 that combines a zone relatively deeper with a bed locally rich in fine-grained sediments. Besides, water and suspended matter from northern side of S.Jacinto Channel and from Laranjo Bay converge in this area. The lowest SSC mean value (13.2 mgL^{-1}) was observed in station 7, which is also a deeper zone, but with a sandy bed. The proximity of this station to the Vouga river mouth pointed out the weak contribution of this river to the suspended sediments quantity, comparatively to the apparent supply from bottom and shore estuary erosion, during the study period (ABRANTES *et al*., 2003).

A qualitative analysis of Figure 2 shows that minimum and maximum values of SSC occurred in different phases of the tidal cycle. In general, the higher values were observed during the ebb (Tables 1-2) and could be explained mainly by the asymmetry in the current velocity over the tidal cycle.

Since current velocities have not been recorded during the surveys, data from SILVA (1994), QUEIROGA (1995) and DIAS (2001) have been considered to interpret the present results.

According to DIAS (2001), the first half of S. Jacinto, Espinheiro and Ílhavo channels reveal ebb dominance, but at the beginning of Mira channel there is no tidal asymmetry. However, currents measured by QUEIROGA (1995) in a location close to station 4 (Mira channel) indicated that flood currents were stronger than ebb currents. This could explain the maximum SSC observed in station 4 during the flood phase of the winter and neap summer tides.

Considering that fluctuations on SSC are a function of current velocity and analyzing current measurements made by the authors previously referred in locations close to the present sampling stations, it is possible to observe that this relation was not always found (Figure 2). In fact, if some concentration peaks were observed when the currents speed was theoretically higher (HT+/-2 and LT+/-2), some were found in low and high tides.

A possible explanation for this phase shift between the velocity and the sediments concentration, may be the advection of sediments resuspended in remote areas (time advection is mainly dependent on flow velocity and on the distance between the resuspension local and the sampling station). The time taken for the particles to disperse throughout the water column after they have been eroded (scour lag) may also account for this shift.

Another explanation could be that resuspension was not related with current velocity but with wind-induced turbulence, which presumably was out of phase with tidal currents. The relative importance of each process is difficult to evaluate due to the complexity of the processes and to the lack of observations and of hydrological measurements concurrent with the water sampling campaigns.

During periods of low current velocity and low turbulence, the vertical settling of sediments imposes a downward movement with possible bottom deposition and decreasing in SSC. The vertical distribution of SSC showed a more or less pronounced gradient with maximum values found near-bottom (Figure 2 and Tables 1-2), suggesting that not only resuspension of bottom particles but also settling processes are occuring.

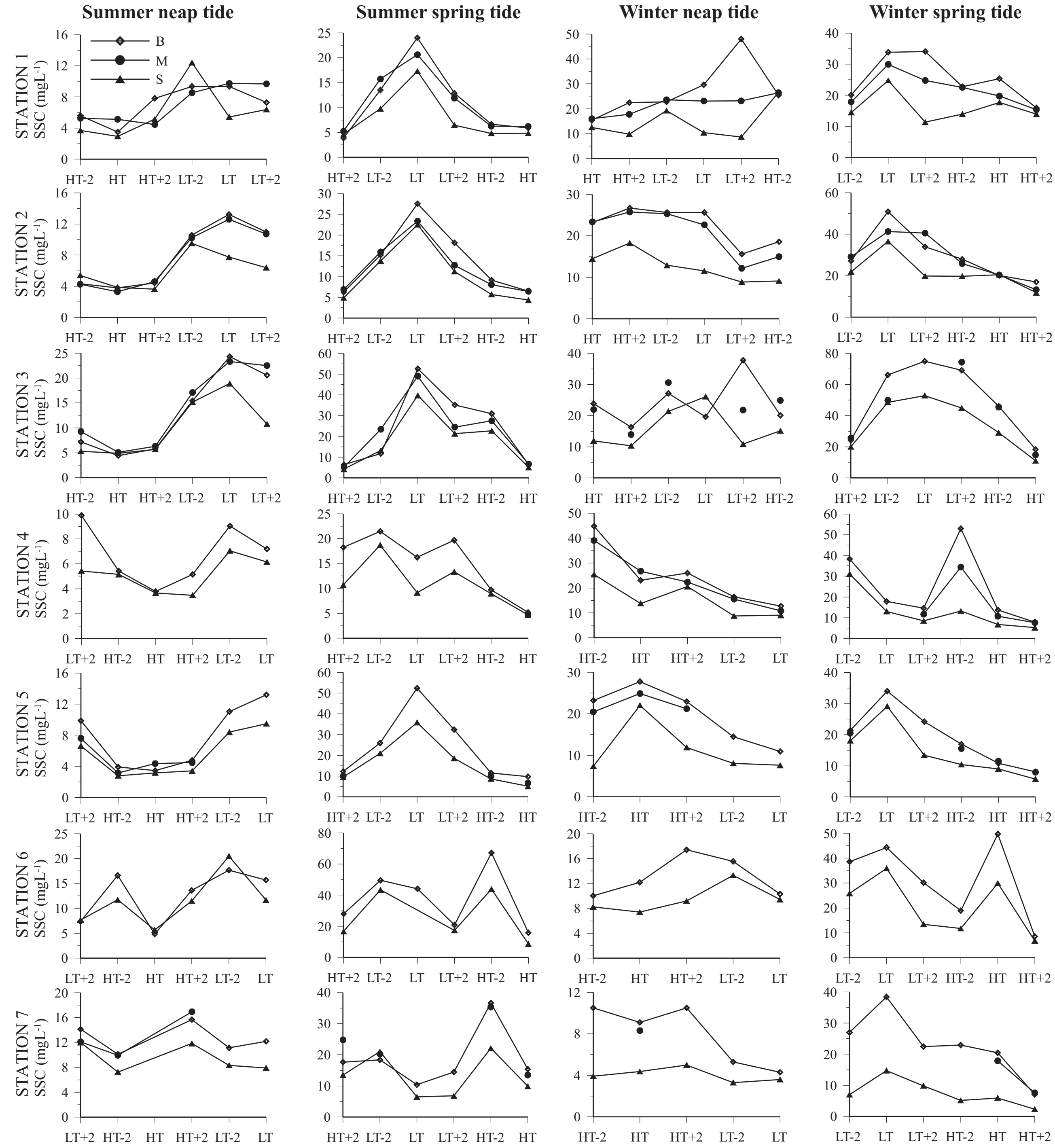

Figure 2. Time evolution of SSC during tidal cycles sampling moments: HT (high tide), HT+2 (two hours after high tide), LT-2 (two hours before low tide), LT (low tide), LT+2 (two hours after low tide) and HT-2 (two hours before high tide) near the bottom (B), in the middle depth (M) and near the surface (S).

Generally, during spring tides concentrations in the water column were higher than during neap tides (Tables 1-2). The root mean square of current velocity values estimated by DIAS *et al*. (2003) for spring tide was about two times the values found for neap tides conditions. According to these authors maximum spring tidal velocities in areas close to the study stations vary between about 0.5 ms^{-1} at the beginning of Mira channel (southward of station 4) and 2 ms^{-1} at the lagoon mouth (DIAS, 2001). Currents of these magnitudes are large enough to erode and transport a high quantity of sediments in suspension.

Stations 1, 4 and 5 reveal higher SSC values in winter neap tides. These anomalous patterns were probably related with wave activity and littoral advection (see below for a discussion of the seasonal fluctuations).

Seasonal variability, with winter higher SSC in almost all stations (Tables 1-2), was probably more related with wind climate, biological activity and coastal wave regime than with rivers discharges, which were below the mean flow during the surveys.

In the winter sampling period, especially during the neap tide situation, winds blow essentially from north with intensities higher than 3 ms^{-1}. It is possible that wind-induced turbulence eroded the bottom mud deposits in the large shallow areas, as well as the finer sediments in the intertidal zones. In this case, resuspend particles are subsequently advected through the estuary. Resuspension by wind velocities as low as 3 ms^{-1} has also been reported for silt deposits in the mesotidal Dollard estuary by DE JONGE and VAN BEUSEKOM (1995).

The seasonal variations of SSC can also be influenced by biological processes, which may vary on a seasonal scale. If

Table 1. *Flood and ebb averaged suspended sediment concentration 1 m from the bottom for the summer and winter surveys. Minimum and maximum values observed in each situation are indicated between right parentheses.*

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7
Summer spring tide (mgL^{-1})							
Flood	8 [5.9-12.9]	11 [6.5-18.1]	24 [6.4-35.1]	12 [5.2-19.7]	18 [9.8-32.4]	35 [15.9-67.2]	22 [14.5-36.6]
Ebb	14 [3.9-24]	16 [6.2-27.5]	24 [6.4-52.6]	19 [16.2-21.4]	30 [12.3-52.4]	39 [28-49.5]	15 [10.4-18.4]
Summer neap tide (mgL^{-1})							
Flood	5 [3.5-7.3]	6 [3.8-11]	11 [4.4-20.6]	5 [3.8-6.6]	6 [3.5-9.9]	10 [4.9-16.6]	12 [10.1-14.1]
Ebb	9 [7.8-9.4]	9 [4.4-13.2]	15 [5.8-24.3]	7 [5.2-9]	10 [4.8-13.2]	16 [13.6-17.7]	13 [11.1-15.7]
Winter spring tide (mgL^{-1})							
Flood	27 [22.8-34.1]	27 [20.1-33.9]	44 [18.3-69.1]	27 [13.7-52.9]	17 [10.9-24.2]	33 [18.9-49.7]	22 [20.4-23]
Ebb	23 [16-33.8]	32 [17-50.8]	55 [24.2-75]	21 [7.9-38.3]	21 [8.1-34]	30 [8.6-44.3]	24 [7.1-38.4]
Winter neap tide (mgL^{-1})							
Flood	30 [15.3-48]	19 [15.6-23.2]	27 [20.1-37.8]	34 [23-44.7]	25 [23.2-27.8]	11 [10-12.2]	10 [9.1-10.5]
Ebb	25 [22.5-29.6]	26 [25.6-26.7]	21 [16.3-27.2]	18 [12.7-26]	16 [10.9-23]	14 [10.3-17.4]	7 [4.3-10.5]

Table 2. *Flood and ebb averaged suspended sediment concentration near surface for the summer and winter surveys. Minimum and maximum values observed in each situation are indicated between right parentheses.*

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7
Summer spring tide (mgL^{-1})							
Flood	5 [4.8-6.5]	7 [4.4-11.2]	17 [6.7-22.7]	9 [4.7-13.3]	11 [5.1-18.6]	23 [8.6-43.9]	13 [6.8-22.1]
Ebb	11 [4.6-17.3]	14 [4.9-22.5]	19 [4.2-39.8]	13 [9.1-18.7]	22 [9.5-35.8]	35 [16.8-44.1]	14 [6.5-21]
Summer neap tide (mgL^{-1})							
Flood	4 [2.9-6.4]	5 [3.8-6.4]	7 [4.9-10.8]	5 [3.7-5.4]	4 [2.8-6.6]	8 [5.7-11.7]	10 [7.3-12]
Ebb	8 [5.2-12.4]	7 [3.6-9.5]	13 [5.7-18.9]	6 [3.5-7.1]	7 [3.4-9.5]	15 [11.5-20.5]	9 [7.9-11.8]
Winter spring tide (mgL^{-1})							
Flood	14 [11.4-17.7]	20 [19.7-20.5]	28 [11-44.9]	10 [6.7-13.2]	11 [9-13.4]	18 [11.8-29.9]	7 [5.2-9.8]
Ebb	18 [14-24.8]	23 [11.8-36.5]	41 [20-52.9]	16 [5.2-31.1]	18 [5.8-29.1]	23 [6.8-35.9]	8 [2.4-14.7]
Winter neap tide (mgL^{-1})							
Flood	16 [8.7-26.6]	15 [9.1-23.3]	13 [10.9-15.1]	20 [13.8-25.4]	15 [7.4-22]	8 [7.4-8.2]	4 [3.9-4.4]
Ebb	13 [9.8-19.3]	14 [11.5-18.2]	19 [10.3-26.1]	13 [8.8-20.5]	9 [7.6-11.9]	11 [9.2-13.3]	4 [3.3-5]

flocculation owing to organic processes is important, then seasons must have an influence on the floc formation (FETTWIS *et al*., 1998). The examination under binocular microscope of the suspended sediments retained in the filters showed that biogenic material (predominantly plant fragments, copepods and diatoms) and aggregates are more abundant in the bottom samples during the summer than in the winter.

It could be hypothesized that the formation of flocs, with settling velocities larger than the primary particles, may explain partially the seasonal variations observed in Ria de Aveiro lagoon.

Fine-grained sediments are more easily kept in suspension in the winter situation than in the summer, because flocculation is less important in the first case. However, as filtering processes may enhance the aggregation as well as cause break up of the flocs, this interpretation should be carefully considered.

Highly coastal wave energetic conditions were observed during the winter cases when northerly winds blew (conditions favorable to the occurrence of upwelling). Measurements from the wave buoy located in Leixões (northern of Ria de Aveiro) indicated that significant wave heights and periods exceeded 1.5 m (2.5-3.6 m in neap tide) and 7 s, respectively. These conditions probably induced high resuspension of the coastal particles, especially in neap tides. Consequently, more sediment could be supplied to the lagoon system by the flood tidal currents.

Two stations (6 and 7) present their higher averaged SSC in summer, with maximum values occurring in spring tide conditions. These results may be justified considering the high abundance of organic matter and that the amplitude of this tide was the highest of the sampling tides.

Fluxes

The estimated water and suspended sediments fluxes between Ria de Aveiro lagoon and the ocean for each one of the tidal cycles in analysis are presented in Figure 3.

The net water balance corresponded to an exportation of 0.5 to 12.4 millions of m^3 per tidal cycle. The magnitude of water fluxes appears to be dependent on spring-neap tidal cycles. In fact, the highest ebb/flood fluxes were observed in the summer spring tide case, when the highest tidal amplitude of the sampling periods was observed. Even though the amplitude of the winter spring tide case was lower than the summer one, the net flux was higher in winter.

Fluxes of suspended sediments were negative during the summer, corresponding to a net export to the sea of 249 to 644 ton per tidal cycle. In winter, the fluxes were contrasting in sign ranging from $11x10^3$ ton, during spring tide, to 535 ton in neap tide. During the summer, the fluxes of sediments to the ocean increase with tidal range as a consequence of tidal currents velocities effects on resuspension, transport and deposition of particles. This exportation is also consistent with the ebb dominance of the lagoon. Winter scenario is quite different, especially during neap tide, because other factors (wind climate and coastal wave regime), conjugated with tidal currents, play an important role on fine-grained sediment dynamics. Despite the water balance indicated exportation to the coastal ocean a net retention of suspended sediments inside the lagoon occurred under neap tide conditions and, consequently, the lagunar system acted as a natural fine sediments trap. This was already suggested by DIAS *et al*. (1984) based on the distribution of the hydraulically equivalent mica flakes. Under winter spring tide conditions a large amount of particles were present in the water column, resulting in a stronger seaward flux of suspended sediments.

CONCLUSIONS

During the study period, the suspended sediments concentration has varied along the lagoon with tides, spring-neap cycles and seasons.

The differences in SSC between the various sampling stations were largely determined by the differences in the tidal currents magnitudes and by the characteristics of bottom sediments.

The SSC during ebb were usually higher than during flood due to the general tidal currents ebb dominance in Ria de Aveiro.

Seasonal fluctuations seem to be more related with wind events, biological activity and coastal waves regime than with

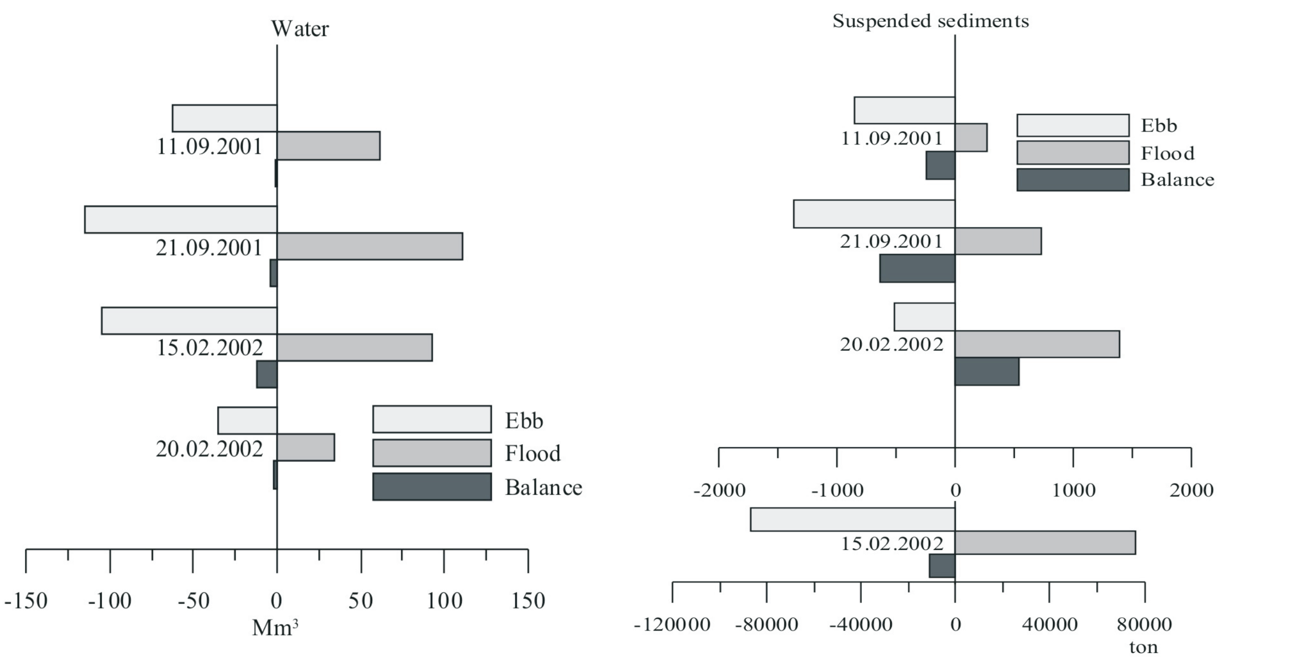

Figure 3. Fluxes of water and suspended sediments through a cross-section of the channel at station 1.

rivers discharges. At spring tides, the currents are stronger enough to resuspend and transport more sediments, therefore higher values of SSC were observed under spring tide conditions. In general, suspended sediments concentration in Ria de Aveiro during the summer was mainly related to the local boundary-layer dynamics (resuspension /sedimentation). During the winter external factors diluted tidal current effects and give rise to a more complex scenario. These features were also reflected in the estimated fluxes of suspended sediments.

Exports of suspended sediments from the lagoon system to the coastal ocean occurred in the summer, denoting the ebb dominance. In winter, especially during the neap tide case, Ria de Aveiro acted as a trap of the fine-grained sediments advected from the coastal ocean, eroded from the lagoon system and transported by the rivers.

This study pointed out the necessity to perform more measurements of suspended sediment concentration and of concurrent hydrological parameters (currents, temperature, salinity and rivers discharge) in order to better understand the sediments transport in this lagoon. Important questions about the irregular patterns observed in the suspended fine-grained dynamic of Ria de Aveiro lagoon as well as the higher values of suspended sediments concentration found in some stations during the neap tide and in summer conditions still need to be clarified.

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LITERATURE CITED

ABECASSIS, C., 1955. The history of a tidal lagoon and its improvement (The case of Aveiro, Portugal). *Proceedings of Fifth Conference on Coastal Engineering*, pp. 329-363.

ABRANTES, I.; ROCHA, F. and DIAS, J.A., 2003. Distribuição e composição dos sedimentos em suspensão na Ria de Aveiro. *Thalassas*, 19 (2b), pp. 27-28.

CUNHA, M.A.S.D.; DIAS, J.M.; ALMEIDA, M.A.; LOPES, J.F. and ALCÂNTARA, F. 2003. Fluxes of bacterioplankton between a tidal estuary and the sea: returning to the. "Outwelling Hypothesis". *Netherlands Journal of Aquatic Ecology*, 37, pp. 45-54.

DE JONG, V.N. and VAN BEUSEKOM, J.E.E., 1995. Wind and tide-induced resuspension of sediment and microphytobenthos from tidal flats in the Ems estuary. *Limnology and Oceanography*, 40, pp. 766-778.

DIAS, J.M., 2001. Contribution to the study of the Ria de Aveiro hydrodynamics. Portugal: University of Aveiro, Ph.D. thesis, 288p.

DIAS, J.M.A.; PILKEY, O.H. and HEILWEIL, V. M., 1984. Detrital mica: environmental significance in North Portugal continental shelf sediments. *Comunicações dos Serviços Geológicos de Portugal*, 70 (1), pp. 93-101.

DIAS, J.M.; LOPES, J.F., and DEKEYSER, I., 1998. An exploratory study of the dynamics of Ria de Aveiro, Portugal. In: KIM, H.; LEE, S.H. and LEE, S.J. (eds), *Hydrodynamics Theory and Applications*. Seoul, Uiam Publishers, pp. 619-624.

DIAS, J.M.; LOPES, J.F., and DEKEYSER, I., 1999. Hydrological characterization of the Ria de Aveiro, Portugal in early Summer. *Oceanologica Acta*, 22, 473-495.

DIAS, J.M.; LOPES, J.F., and DEKEYSER, I., 2000. Tidal propagation in the Aveiro lagoon, Portugal. *Physics and Chemistry of the Earth* (B), 25(4), 369-374.

DIAS, J.M.; LOPES, J.F., and DEKEYSER, I., 2003. A numerical model system application to the study of the transport properties in Ria de Aveiro lagoon. *Ocean Dynamics*, 53, 220-231.

FETTWIS, M.; SAS, M. and MONBALIU, J., 1998. Seasonal, neap-spring and tidal variation of cohesive sediment concentraton in Scheldt estuary, Belgium. *Estuarine, Coastal and Shelf Science*, 47, pp. 21-36.

GIRÃO, A.A., 1951. Evolução morfológica da região do Baixo Vouga. *Boletim do Centro de Estudos Geográficos de Coimbra*, 2/3, pp. 75-85.

LOPES, J.F.; DIAS, J.M. and DEKEYSER, I., 2000. Influence of tides and river inputs on suspended sediment transport in Ria de Aveiro lagoon, Portugal. *Physics and Chemistry of the Earth* (B), 26(9), pp. 729-734.

MARTINS, A.F., 1947. A configuração do litoral português no último quartel do século XIV. *Biblos*, XXII(I), pp. 163-197.

MOREIRA, M.H.; QUEIROGA, H.; MACHADO, M.M. and CUNHA, M.R., 1993. Environmental gradients in a southern estuarine system: Ria de Aveiro, Portugal,Implications for soft bottom macrofauna colonization. *Netherlands Journal of Aquatic Ecology*, 27(2-4), pp. 465-482.

PEREIRA, M.E.C., 1996. Distribuição, reactividade e transporte de mercúrio na Ria de Aveiro. Portugal: University of Aveiro, Ph.D. thesis, 284p.

QUEIROGA, H. 1995. Processos de dispersão e recrutamento das larvas do caranguejo Carcinus maenas (L.) na Ria de Aveiro. Portugal: University of Aveiro, Ph.D. thesis, 268p.

ROCHA, F.; BERNARDES, C. A. and DELGADO, H., 2000. Caracterização textural e mineralógica dos sedimentos da laguna de Aveiro, Portugal. *3º Simpósio sobre a Margem Continental Ibérica Atlântica* (Faro, Portugal), pp. 17-18.

RIDDERINKHOF, H.; VAN DER HAM, R. and VAN DER LEE, W., 2000. Temporal variations in concentration and transport of suspended sediments in a channel-flat system in Ems-Dollard estuary. *Continental Shelf Research*, 20, pp. 1479-1493.

SILVA, J.J.F., 1994. Circulação de água na Ria de Aveiro: contribuição para o estudo da qualidade da água. Portugal: University of Aveiro, Ph.D. thesis, 158p.

VAN LEUSEEN, W., 1996. Erosion/sedimentation cycles in the Ems estuary. *In*: Kauscht, H. and Michaelis, W. (ed), *Proceedings of an Internacional Symposium on Suspended Particulate Matter in Rivers and Estuaries* (Reinbek, Germany). Advanced Limnology Special Issue 47, pp. 179-193.