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T. Rodríguez-Ramos, P. Lorenzo & L. González
Marine Allelopathy: Principles and Perspectives

F. Fatela, J. Moren & C. Antunes
Salinity Influence on Foraminiferal Tidal Marsh Assemblages of NW Portugal: an Anthropogenic Constraint?
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INDEX

      Bottom Sediment Signature Associated with the Oporto, Aveiro and Nazaré Submarine Canyons
      (NW Off Portugal)

19-31  F. Rosa, F. Fatela & T. Drago
      Late Holocene Benthic Foraminiferal Records in the Continental Shelf off Douro River
      (NW Portugal): Evidences for Productivity and Sedimentary Relationships

      A short-term comparative study on Diplodon rhuacoicus young adults shell growth under enriched
      São Francisco River water

39-49  T. Rodriguez-Ramos, P. Lorenzo & L. González
      Marine Allelopathy: Principles and Perspectives

51-63  F. Fatela, J. Moren & C. Antunes
      Salinity Influence on Foraminiferal Tidal Marsh Assemblages of NW Portugal: an Anthropogenic
      Constraint?
BOTTOM SEDIMENT SIGNATURE ASSOCIATED WITH THE OPORTO, AVEIRO AND NAZARÉ SUBMARINE CANYONS (NW OFF PORTUGAL)

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Keywords: Bottom sediments; sedimentary dynamics; NW Iberia; Oporto, Aveiro and Nazaré submarine canyons.

ABSTRACT

Active submarine canyons are major sedimentary conduits between the coastal zone and the deep oceanic domain affecting the oceanic productivity, circulation pattern and with a strong influence in the adjacent sedimentary cover. This study aims to evaluate the relation between the Oporto, Aveiro and Nazaré Submarine Canyons (NW off Portugal) and the distribution of the surrounding bottom sedimentary cover in order to evaluate their influence. Thus a summary textural description of the superficial sedimentary cover of the northern Portuguese continental shelf was performed, based on the N – S direction trend distribution of the percentage values of the main textural classes (gravel, sand, silt and clay). Results allowed to establish some relations between depth and the general textural characteristics of the superficial sedimentary cover, mostly in the sectors where the three submarine canyons are located, suggesting that canyon’s morphology, incision degree and the distance of the canyon’s heads to the coastline have an important role in the distribution of bottom particles and in the sedimentary dynamic processes close to the submarine valley, which is reflected in the textural characteristics of the bottom sediments.

INTRODUCTION

Submarine canyons carved in the continental margin act as sedimentary conduits, in which sediment transport processes from the continental shelf to the abyssal plain are intensified. They are considered to be responsible for the major part of mass transfers between the coastal zone and the deep oceanic domain. Their efficacy is strongly dependent on the local and regional energetical conditions (e.g. upwelling, internal waves, turbidity currents, etc), the distance between the canyon’s heads and the coastline, their morphology and the shelf area affected by their presence (Magalhães, 2001). Several studies point to the fact that canyons whose heads...
are located near the coastline can have a significant influence on the coastal processes such as nearshore hydrodynamics and littoral sedimentary drift (e.g. Nazaré Submarine Canyon, Duarte & Taborda, 2000; Duarte et al., 2003)

Although many authors have studied these impressive geomorphology structures, their origin, evolution and sedimentary dynamics, are still poorly understood. Some studies indicate that their presence strongly affects the oceanic circulation pattern and
productivity, and therefore their influence extends well beyond their morphologic imprint affecting the distribution of the bottom sedimentary deposits in the adjacent shelf.

To explain the origin of the submarine canyons four main hypothesis are generally accepted: (1) submarine canyons were carved from the terminal sector of rivers in a low stand sea level, and consequently, the active sediment transfer is maintained by a constant erosion and transport capacity; (2) they may have been carved entirely due to submarine erosion processes, related with the occurrence of turbiditic currents and/or the capture of the sedimentary material flowing along the coast by littoral drift (sensu lato); (3) their location is associated to structural lineaments and their evolution is, therefore, strongly related to the re-activation of these structures; and (4) they are the result of a combination of both structural and erosional processes.

In order to contribute to a better knowledge about these structures, DEEPCO scientific project aims to study the geomorphological, geophysical, sedimentological and micropalaeontological characteristics of the Oporto, Aveiro and Nazaré Submarine Canyons. This paper will summarize the first results obtained from the analysis work of the northern shelf’s bottom sedimentary cover, supported by parallel N-S distribution pattern of the main textural classes (gravel, sand, silt and clay).

ENVIRONMENTAL SETTING OF THE STUDY AREA. THE OPORTO, AVEIRO AND NAZARÉ SUBMARINE CANYONS

Despite its regular and smooth morphology, the topography of the northern Portuguese continental shelf is strongly marked by three important incisions: the Oporto, Aveiro and Nazaré submarine canyons (Figure 1). Several authors have associated these canyon’s origin and position to late-Variscan faults reactivated during the North Atlantic’s opening (Auxietre & Dunand, 1978; Mougenot, 1989; Rodrigues, 2001)

The Nazaré Canyon was already described as one of the largest and deepest submarine valleys of the world, and its head’s present day sedimentary dynamics is fairly known (Duarte et al., 2000; Duarte, 2002; Duarte & Taborda, 2003; Oliveira et al., in press; de Stigter et al., in press). The Oporto and Aveiro canyons are shelf break incisions and their present day morphosedimentary dynamics is less documented.

SECTOR N – OPORTO CANYON

The northern sector (N) (Figure 1) has a mean width of 30km, with the shelf break located at about 130m depth (Rodrigues, 2001). This sector presents a rough bottom morphology, with two quite prominent morphological lineaments (NNW-SSE) related with two hard rocky outcrop zones (Palaeozoic and Mesozoic competent rocks) (Vanney & Mougenot, 1981). The continental slope has typical erosional features, with very high gradients (higher than 3.5%). In general, the bottom sedimentary cover is very coarse reflecting the exposure to the high energetic North Atlantic swell and the high continental sediment input. The deposition of fine particles only occurs below 70m depth, off the Douro estuary and in the continental slope.

The Oporto Submarine Canyon is a “Nouvelle-Angleteerre” canyon type, located at about 25km W off Póvoa de Varzim, deeper than 110m depth (Rodrigues, 2001). This canyon has more than 100km length towards the Iberian Abyssal Plain (Vanney & Mougenot, 1981) and its morphology is related with the occurrence of mass movements, with no apparent relation to the present-day watercourses (Rodrigues, 2001). At about 20-30km W off the Douro estuary, at the Oporto Canyon’s head, stands the Douro Muddy Deposit, mainly built of silty-clay particles driven from the Douro river in periods of high river discharge, transported

1 DEEPCO (Deep Sedimentary Conduits of the West-Iberian Margin) is funded by FCT (POCTI/CTA/46367/2002) and is presently in course at the Marine Geology department of the Instituto Hidrográfico (IH)
mainly suspension during storm events, when the downwelling regime combines with poleward currents resulting in a fine particles transport towards NW (Drago et al., 1999; Vitorino et al., 2002). According to Drago et al. (1999) this is a sedimentary active zone, tectonically depressed and partially protected by hard rocky outcrops of different scales (e.g. Beiral de Viana formations) being, therefore, highly efficient as a fine sediment trap.

**SECTOR C – AVEIRO CANYON**

The central sector (C) (Figure 1) is more flat and wide, registering smooth gradients (about 0.3%). The same type of hard rocky outcrops found in sector N are present in this one as well, but at a smaller size, and in what concerns the sedimentary layer, the same high energy textural characteristics are found in this sector. The shelf break is located at about 50km off the coastline, deeper than 160m, and was classified by Mougenot (1989) as a non-erosive shelf break. The continental slope has a smooth profile (mean gradients of 1%). The Aveiro Submarine Canyon is an inconspicuous wide morphology (“amphitheater” form) that begins at about 30km W off the coast, deeper than 110m depth (Figure 1). This canyon has a wide transversal profile with a half-circle upper sector of about 10km diameter. It shows no apparent relation to present-day watercourses and meets the Oporto Canyon at the Valle-Inclan Depression, before reaching the Iberian Abyssal Plain (Rodrigues, 2001).

**SECTOR S – NAZARÉ CANYON**

The southern sector (S) (Figure 1) is identical to sector C, with the same type of non-erosive shelf break, despite the fact that it registers traces of strong mass movements’ occurrences through fault steeps in the continental slope, deeper than 160m (Vanney & Mougenot, 1981). However, the adjacent morphology is more rugged, particularly at the middle shelf, were several hard rocky outcrops are present (gradients about 2-3%; e.g. Pinhal e Morraceiros). The continental shelf is covered, in general, by coarse sediments but two muddy deposits were cartographed by Duarte (2002) and Pombo (2004) in the middle shelf, north and south the Nazaré
Submarine Canyon. Since there are no important rivers flowing to this sector, the origin of this fine sedimentation is still poorly understood. Yet, several studies are presently being performed in order to evaluate this question (e.g. HERMES and DEEPCO scientific projects).

The Nazaré Submarine Canyon (Figure 1) is the largest canyon of Europe, with 170km long, between 50m depth (500m off the coast) and the Iberian Abyssal Plain (Vanney & Mougenot, 1981). This is a “Gouf” canyon type with a typical tied “V” transversal cut, E – W orientated, low longitudinal slope (10 - 20%) and head deeply carved on the coastline (Shepard & Drill, 1966; Vanney & Mougenot, 1981; 1990). Numerous hydrodynamic and sedimentary processes occur in the canyon’s head, responsible for its erosion and evolution and, consequently, its deep indentation in the coastal rim (Duarte et al., 2000; Duarte, 2002; Duarte & Taborda, 2003).

MATERIAL AND METHODS

The general longilitoral textural pattern (N – S) of the shelf’ sedimentary cover was evaluated based on the main dimensional classes percentage values (gravel, sand, silt and clay) obtained from 721 superficial and non-consolidate sediment samples (SEPLAT Program) collected using a Smith-McIntyre grab, during several surveys performed by the Instituto Hidrográfico (IH). The sample selection was defined according to the following bathymetric criteria: 60±5m, 100±5m, 150±5m, 200±20m, 300±20m, 400±20m and ≥480m depths (Figure 2).

Grain size analysis was performed using the sieving method for fractions ≥63µm, and the settling method for fractions <63µm. Textural classes were defined according to the Φ scale (Friedman & Sanders, 1978).

RESULTS

(1) The Oporto Canyon zone (sector N) presents a high grain-size variability; shallower than 100m, the dominant fractions are sand and gravel. However, in the adjacent areas, silt curve achieves percentage values of about 75% near the Douro Muddy Deposit, near the canyon’s head. At 150m and 200m the coarse fraction is still dominant (mainly sand) tending to be registered in a more regular, monotonous pattern towards south (Figure 3). At 300m, 400m and 500m the silty-clay fraction tends to increase at the Oporto Canyon vicinity, becoming the dominant fraction (Figure 4).

The Aveiro Canyon zone (sector C) is, in general, coarse and homogeneous, dominated by sand (at all depths) and gravel (at 60m and 150m depth) (Figure 3). At 300m and 400m, the silty-clay fraction increases on this sector. Deeper than 480m, clay fraction achieves locally relevance, with percentage values of about 45% (Figure 4).

The Nazaré Canyon zone (sector S) is the richest in silty-clay sediments, particularly deeper than 150m. At 60m depth, this sector presents a quite diversified textural pattern in which sand and gravel are the dominant fractions, but registering local sectors favorable to the sedimentation of silty-clay particles namely along the canyon’s side walls. At 100m depth the silt and clay curves register important percentage values at the canyon’s northern and southern margins, in the sector were two muddy deposits are present (both described by Duarte, 2002) (Figures 3 and 4).

(2) The general granulometrical variation pattern obtained indicates that sand is the dominant textural class in nearly all depths, and in all N-S extension, tending to be replaced by silty-clay fraction as depth increases (deeper than 400m). Sector S, were Nazaré Canyon is located, is the only sector in which silty-clay fraction is as important as sand (or more), systematically at all depths below 60m (exclude) particularly along the canyon’s side walls.

(3) Gravel registers important percentage values at 60m depth, namely at the canyons’ adjacent zones. At
Oporto and Aveiro canyons gravel achieves important percentage values (about 60-70%), whereas at Nazaré Canyon, gravel percentage values are always lower than 30%. Although this fraction decreases towards W with increasing depth in all extension N-S, the gravel curve always registers a local increase on the sectors where the submarine canyons are located or close to them.

(4) Silt and clay fractions have the same general N-S variation pattern, but silt tends to be registered in higher percentage values. Towards 100m depth, the positive record of silty-clay fraction is mainly related to the several muddy deposits of the middle shelf, namely the Douro Muddy Deposit and the muddy deposits located at the northern margin (and northern adjacent area) and the southern margin of the Nazaré Canyon. At 150m and 200m depth, silty-clay fraction is mainly associated to the Nazaré Canyon sector, particularly in its side walls and head. Deeper than 300m the fine fraction increases in all extension N-S, particularly at the Oporto and Nazaré canyons sectors.
DISCUSSION

Shelf sediments

The superficial sedimentary cover is in general coarse (sand), indicating high energy levels near the bottom (Magalhães, 2001), becoming richer in the silty-clay fraction towards W, as depth increases, suggesting some bathymetric control in the sedimentation process (Abrantes, 2005).

The decrease of silt and clay observed at the southern boundary is probably related to the shelf’s minor width in this sector, as well as the higher structural complexity and the presence of many hard rocky outcrops (Mougenot, 1989).

The local positive anomaly of gravel (>60%) registered at 100m depth, north of Nazaré Canyon, is probably reflecting the gravel enrichments detected by Pombo (2004) near the rocky relieve of Pinhal. The local high percentage values of gravel registered on the southern margin of the Nazaré Canyon are probably related to the coarse biogenic deposits described by the same author, which are restricted to a rocky outcrop zone.

The dominance of sand and gravel fractions at 60m and 100m depth is in agreement with the location of the sandy-graveled deposits mapped by Dias (1987), Magalhães (2001), Abrantes (2005) and Pombo (2004). According to these authors, the coarse sediment deposits, N-S oriented approximately parallel to the present day coastline, are related with palaeo-littorals (Dias, 1987; Magalhães, 2001; Abrantes, 2005; Pombo, 2004). Indeed, the 60m depth curves seem to be recording the stage IIb of Ruddiman & MacIntyre (1981) during which the mean sea level must have been stable between 100m and 110m depth (13,000 yrs ago, at the end of the 1st Stage of Deglaciation), long enough to allow the building of new littoral morphologies at these depths (Rodrigues, 2001; Pombo, 2004). Sandy-graveled sedimentary deposits of Pinhal are possible traces of these morphologies (Pombo, 2004).

Gravel variation curve at 150m depth seems to be related to the influence of the Oporto and Aveiro submarine canyons, whose heads were 16,000 yrs ago close to the coastline. Using the Nazaré Submarine Canyon as a present day term of comparison, whose activity seems to be the cause of its deep indentation in the present day coastal rim (Duarte et al., 2000; Duarte & Taborda, 2003), this N-S record of the gravel fraction suggests that may have happen some identical erosive dynamics (digging/carving) in the Oporto and Aveiro canyons heads, back in the palaeo-coastal rim (stage I of Ruddiman & MacIntyre, 1981). These processes probably stopped when the mean sea level started to rise.

Sedimentary dynamics of Oporto, Aveiro and Nazaré submarine canyons

Results suggest that Nazaré Canyon is different from Oporto and Aveiro canyons for its richness in silty-clay sediments, in high and persistent percentage values at all depths (the lower values were registered at 60m depth).

Silty-clay sedimentary record in the Nazaré Canyon is probably dependent of its morphology (high incision degree) and geographical location (cutting the entire
shelf and deeply carved in the coastal rim) and appears to be determined through: (a) the capture of the silty-clay material that is being carried in suspension from north and south (Oliveira et al., in press); (b) the entrance of coarse sediments by littoral drift (Duarte & Taborda, 2003) through the canyon’s head which are probably causing the re-suspension of fine material in the canyon’s side walls and its settling on the canyon’s borders.

The minor width of the shelf at the Nazaré Canyon zone and the shift of direction of the coastline on this sector (Peniche, Figure 1) probably allowed the canyon’s erosive ability to be less disturbed during the mean sea level rise, and consequently, remaining active until today as several studies have recently described (Duarte, 2002; Duarte et al., 2000; Duarte & Taborda, 2003; Oliveira et al., in press). Therefore the active character of the Nazaré Canyon seems to be strongly dependent of the sediment input from the littoral drift (Duarte & Taborda, 2003), and may be the key factor to explain its high indentation and tied “V” transversal cut. In addition, the Nazaré Canyons narrow morphology may be determining a certain dynamics of capture/settling of fine sediments that are being transported in suspension on the shelf. The muddy deposits of the Nazaré Canyon’s margins described by Duarte (2002) may be partially reflecting this sedimentary dynamic.

On the contrary, the Oporto and Aveiro canyons smoother morphologies (particularly the Aveiro Canyon) suggest that their evolution by erosion stopped when the mean sea level started to rise (stage I of Ruddiman & McIntyre, 1981). The lack of fine sediment deposits associated with these canyons suggests that fine sediments are being remobilized and re-suspended from the shelf break and continental slope, through the action of slope currents and internal waves. However, the higher percentage values of silty-clay fraction registered in the northern sector (N) may be partially tracing an Oporto Canyon’s palaeo-activity, even though several studies indicate that the muddy deposit of the canyon’s head is presently active (fluvial fine sediment supply) and protected from the shelf high hydrodynamics by rocky outcrop traps (e.g. Drago et al., 1999).

**FINAL CONSIDERATIONS**

The present work allowed a preliminary analysis of the N-S and W-E general variation pattern of the main granulometrical classes of the superficial sedimentary cover of the northern Portuguese Continental Shelf. Results consolidate the shelf’s sedimentological mapping of Dias (1987), Magalhães (2001), Pombo (2004) and Abrantes (2005), as well as point out relations between depth variation and textural features of the sedimentary cover, namely in what concerns the differences between the margin sectors where the Porto, Aveiro and Nazaré submarine canyons are located. However, some questions arise: (1) How can the silty-clay fraction be related to a submarine canyon’s activity? (2) Is a submarine canyon’s incision degree the main factor that determines its energetic ability to remobilize/transport the silty-clay particles? (3) What is the relation between the distance towards the coastline of the canyons’ heads and the erosion/non-deposition capability of the Porto, Aveiro and Nazaré submarine canyons?
Apparently it is the proximity to the coastline and the consequent magnitude of the sediment input that determines a submarine canyons activity. Its resultant vigorous relief (high incision degree and deep indentation on the coastline) ends up being a morphological anomaly that will work as an active trap of fine superficial sediments transported along the shelf (Figure 5).

These first results are presently being developed through (1) textural, compositional and micropalaeontological analysis of superficial non consolidate sediment samples collected on the submarine canyons (superficial and multi-corner sediment samples from the canyon’s head and side walls) and (2) geomorphological analysis of the canyons based on seismic and multi-been data that will be obtain during DEEPCO scientific cruise.

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LATE HOLOCENE BENTHIC FORAMINIFERAL RECORDS IN THE CONTINENTAL SHELF OFF DOURO RIVER (NW PORTUGAL): EVIDENCES FOR PRODUCTIVITY AND SEDIMENTARY RELATIONSHIPS

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Keywords: Benthic foraminifera, continental shelf, Douro Muddy Patch, upwelling, climate events, Late Holocene, Western Iberian Margin.

ABSTRACT

Two gravity cores, POS287-13-2G and FF1GM92, were retrieved from the Douro Muddy Patch (DMP). A micropaleontological analysis was performed on both cores based on the benthic foraminifera record, in order to determine main foraminifera assemblages at different core levels and trace the paleoenvironmental evolution of this area of the shelf during the last 1400 years. Grain-size analyses and organic matter content of the sediments were used as additional data. Benthic foraminifera assemblages are dominated by opportunistic species in organic enriched but oxygen depleted environments, Stainforthia fusiformis (Wiliamson) and Bolivina dilatata Reuss. In the basal section of cores, sand has a significant presence and accessory foraminifera are dominated by species linked to coarser sediments and inner shelf environments. Transition to the uppermost section of cores reflects an important change in the benthic communities, with upwelling related species replacing the former accessory assemblages. At the same time, sediments become finer (mainly silt), marking the beginning of the DMP settlement in the mid-shelf. In fact the intensification of upwelling currents in the Western Iberian Margin around 1000 yr cal. BP seems to contribute to the location of the DMP, relocating the bottom suspended sediments from distal areas of the platform up to the mid-shelf.

INTRODUCTION

Continental platforms integrate the relationship between ocean and climate in a context where conditions imposed by the continental environment spread its influence towards the sea. Namely supplying the most part of sediments that record the complex evolution of oceanic, continental and climatic processes through time.

High sedimentary rates that can be found in the muddy deposits installed over the relict sediments of
shelves make it possible to build a detailed evolution of Late Holocene climate and oceanographic events.

This study intents to perform a paleoenvironmental reconstruction of the NW Portuguese Margin off Douro River during the last 1400 yr, based on the small timescale fluctuations of the benthic foraminiferal record. For this purpose, cores POS287-13-2G and FF1GM92, sampling the depositional sequence of the Douro Muddy Patch (DMP), were analyzed (Figure 1). The DMP depositional body is located in the mid-shelf off Douro River, NW Portuguese Margin (Figure 1). Its main sedimentary source is the fluvial discharges of the Douro River (Araújo et al., 1994; Drago et al., 1998), but the upward currents coming from the Oporto Canyon may also contribute with some fine material for the formation and maintenance of the deposit (Magalhães, 2001).

The micropaleontological analyses performed on both cores revealed that benthic foraminiferal assemblages established on the platform off Douro River along the last 1400 years follow the signal imposed by the climatic changes that have characterized the Late Holocene period.

**DEPOSITIONAL AND OCEANOGRAPHIC SETTING**

The Douro Muddy Patch is located in the middle shelf between 100 m and 150 m water depth, spreading circa 40 km south from the head of the Oporto Canyon. The deposit is composed by fine sediments, ranging from silt at the central body to silty sand at the fringe (classification of sediments according to Shepard, 1954).

The oceanographic setting of the shelf up to 100-200 m water depth is characterized by the mixing layer, strongly influenced by seasonal changes and fluvial discharges. The sediment supply from Douro mainly occurs in winter, when SW winds generate downwelling close to the shore and there is offshore transport of bottom fine sediments to depths less affected by erosive wave action on the inner and mid-shelf (Vitorino et al., 2002). During spring and summer, the prevalence of northerly winds induces the occurrence of coastal upwelling, which generates onshore transport of the suspended and previously remobilized fine sediments to shallower depths where the prevailing wave conditions prevent their deposition (Vitorino et al., 2002).

**METHODS AND MATERIALS**

Information concerning the retrieval of gravity cores POS287-13-2G and FF1GM92 from the continental shelf, including its depth and total length, are presented in table 1.

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Textural analysis was performed by using a Malvern 3600 laser diffraction particle sizer. Sediments were classified according to Flemming (2000). In core FF1GM92 the material is mainly silt throughout the whole sequence. The depositional sequence of core POS287-13-2G also consists of very fine sediments, except the base, where sand has a significant presence.

Organic matter (OM) was calculated by loss on ignition (Craft et al., 1991) and carbonates content by using a Bernard calcimeter (Hulseman, 1966).

Sand mineralogy was determined by means of stereomicroscope observation (50x of magnification) following the methodology described by Dias (1987) and Magalhães (1993, 2001). A minimum of 300 grains was counted. Quartz, micas, aggregates and other terrigenous are related with fluvial input, while bioclasts (foraminifers and echinoderms) represent the marine signature.

Radiocarbon age of the bottom samples are 1350 to 1270 yr cal. BP for POS287-13-2G and 1406-1174 yr cal. BP for FF1GM92, both performed by 14C AMS at Beta Analytic Inc. (USA).

Sampling of 1cm sediment slices for foraminiferal analysis was made every 10 cm. All samples were washed through a 63 µm sieve and the remaining sediment was analyzed at the binocular microscope. A minimum of 300 benthic foraminifera were counted and identified. Classification up to genera followed the systematic reviewed by Loeblich & Tappan (1988).

The diversity of species in each sample was obtained by the Shannon-Wiener Index (Hs): $H_s=-\sum p_i \ln(p_i)$, where $p_i$ represents the relative abundance of the species $i$ in the sample. Higher values of Hs translate a higher diversity of foraminifera species. Density (or standing crop) is evaluated as the number of benthic foraminifera by cubic centimeter of sediment ($n^\circ foram/cm^3$).

RESULTS

Core FF1GM92

In core FF1GM92 foraminifera assemblages are dominated by the species Stainforthia fusiformis (Williamson) and Bolivina dilatata Reuss, with relative abundance values around 15% and 25% respectively. The sedimentary sequence is composed mainly

<table>
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<th>Calibration</th>
<th>Conventional radiocarbon age (yr BP)</th>
<th>2σ calibrated result (yr Cal. BP)</th>
<th>Calendar years (yr Cal. AD)</th>
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by silt, present always above 80% and frequently rounding 90% of the total sediment (Figure 2). The terrigenous component of sediments is dominated by mica particles, always with more than 60% of the total component, associated with quartz and “other terrigenous”, the latter frequently containing charcoal particles (Drago, 1995), as it can be seen in figure 2.

From core base until circa 210 cm Cassidulina spp. appears associated with fine sediments and are the most important accessory species. Diversity of species is high, with Hs value around 3.4 – 3.6. Sand material is slightly more significant in these basal levels, reaching 25% of total sediment. The terrigenous fraction has a significant presence of “other terrigenous” particles (around 20%), in detriment of mica, which exhibits its lowest values, circa 60% (Drago, 1995). Carbonate content of samples presents the highest values at core base, circa 7% (Drago, 1995).

S. fusiformis shows the highest abundance values (around 15%) between 190 cm and 90 cm, and the same is evident for B. dilatata (20%-25%). Accessory species Epistominella exigua (Brady), practically absent in the lowermost section of the core, increases significantly up to 5%. Nonionella turgida (Williamson) also increases around 120 cm and reaches its most significant abundance (10%) at level 90cm. In this section of the core diversity of benthic foraminifera species reaches the lowest values (Hs: 3.0 – 3.3). As for the sediment, mica particles dominate the terrigenous fraction with more than 90% of the total component and quartz increases to its highest values (almost 20%) between 220 cm and 160 cm (Drago, 1995). “Other terrigenous” particles become less important, with values ranging from 5% to 15% (Drago, 1995).

From circa 90 cm to the top a decrease is evident for B. dilatata, S. fusiformis and N. turgida. Also, density values slightly decrease. On the contrary, diversity of species increases, with Hs values reaching again 3.4 to 3.6. These data reflect a different dynamics of the benthic foraminifera population as a response to new environmental conditions. Mica continues to dominate the terrigenous component, always above 90% (Drago, 1995).
Core POS287-13-2G

In core POS287-13-2G *S. fusiformis* and *B. dilatata* are always the most abundant species amongst benthic foraminifera, with medium abundance values around 20% to 30%. They show a dominant behaviour throughout the core, just as in core FF1GM92. The depositional sequence is characterized by the presence of two main different sedimentary units. The lower unit, with a sandy nature (sand has circa 45-65%) includes the core base up to 330 cm. From 330 cm to the core top silt dominates the deposits with more than 80% of total sediments, and sometimes reaching more than 90% (Figure 3).

From the base up to 320 cm accessory species are typical foraminifera from inner shelf environments, which can be related to coarser sediments (Murray, 1991; Diz, 2004; Mendes et al., 2004; Blázquez, 2005): *Planorbulina mediterranensis* D’Orbigny and *Bulimina elongata* D’Orbigny occur in quantities always below 10% (Figure 4), *Rectuvigerina phlegeri* Le Calvez has also a significant presence in this assemblage, around 5% to 10% (Figure 4). Assemblages of this section of the core present the higher Hs diversity values, reaching the score of 4.

Sediments are composed by a rather homogeneous mixture of silt and sand, both altering between 40% and 60%. They are associated with higher carbonate and lower organic matter contents (Figure 5).

Between 320 cm and 200 cm *Brizalina spathulata* (Wiliamson) and *N. turgida* are co-dominant with *S. fusiformis* and *B. dilatata*. The species related with coarser sediments almost disappear as sandy sediment becomes insignificant and the fine fraction makes up more than 90% of the deposits. *Cassidulina laevigata* D’Orbigny and *E. exigua*, practically absent in the base of the core, gain importance as accessory species, although their abundance is always below 5%. The organic compound reaches here its highest values, around 10%. On the contrary, the lowest values for diversity of species are found in this section of the core, with Hs index always below 3.

Up to the top there is a decrease of the organic matter content down to half, returning to approximately the same values it exhibited at the core base, around 5%. It is accompanied by some variations in the relative abundance of main foraminifera species. Around 200 cm, abundance for *B. spathulata*, *C. laevigata*, *N. turgida* and *E. exigua* suffers a significant drop, which suggests a possible turn in food supply.
Relative abundance of the most important species in cores FF1GM92 and POS287-13-2G, as well as diversity of species index Hs, are synthesized and represented in figure 6.

DISCUSSION

Foraminifera assemblages of both cores reveal very high diversity of species, typical of continental shelves environment (Colom, 1974). Therefore dominant species are clearly more abundant than the rest, although never reaching 50% of total assemblages.

The dominance of *S. fusiformis* and *B. dilatata* in the benthic assemblages of both cores probably reveals continuous and abundant organic matter supply, providing an organically enriched but oxygen depleted environment (Schmiedl *et al.*, 1997; Gooday & Alve, 2001). Other Bolivina and Brizalina species, also opportunistic under such conditions, are the co-dominant taxa.

Variations in benthic foraminifera communities, grain-size distribution and organic matter content, allowed to set three main zones in the sedimentary record of both cores (Figures 7 and 8) that can be related with the climatic events of Late Holocene.

In Zone 3, the depositional record from the basal section of core POS287-13-2G has higher percentages of sand (50-35%). Core FF1GM92 also has some sand material close to the bottom but in much less quantity (15-25%). This coarser material probably corresponds to a depositional stage previous to the fine sediments.
that build up the DMP in the mid-shelf. To the top of Zone 3, sedimentation in POS287-13-2G becomes similar to that of FF1GM92, mostly composed by silts which set the beginning of the installation of the DMP (Weber et al., 2005).

In the benthic foraminifera record, species that can be associated with coarser sediments and inner shelf environments, like *P. mediterranensis*, *B. elongata* and *R. phlegeri* (Murray, 1991; Diz, 2004; Mendes et al., 2004; Blázquez, 2005), are present only in the lower 30 cm of POS287-13-2G, characterizing this mid-shelf environment before the settlement of the DMP. *C. laevigata*, a species related to fine sediments (Murray, 1991; Schmiedl et al., 1997; Mendes et al., 2004), is significant in the assemblages of both cores basal section. Nevertheless its abundance increases only when sand material starts to decrease (core POS287-13-2G). This means that *C. laevigata* importance as an accessory species in the mid-shelf assemblages can be directly associated with the accumulation of the DMP sediments. Very low abundance values are notable in both cores for upwelling related *B. spathulata* (Mathieu, 1988). The same occurs for *N. turgida* and *E. exigua*, also with preference for fresh organic matter (Schmiedl et al., 1997; Diz & Francés, 2005). Diversity (Hs) of benthic foraminiferal assemblages exhibits the highest values in this zone (Figure 7). These data suggest that in the earliest stages of the DMP installation, the sediments deposition took place in an environment where upwelling processes were not a significant oceanographic phenomena, contrary to what is verified today for this region. Also, a possible increase of freshwater input, identified around 1230-1200 yr cal. BP (Moreno & Fatela, 2005), that is probably related with climate decline during the glacier advances of the Dark Ages (450-950 AD) as suggested by Lamb (1997), could make platform areas within the range of fluvial discharges receive coarser, quartz dominated sediments. If so, food supply would be dominated by organic matter of continental origin.

In Zone 2 the silt and clay fractions reach its highest values (more than 90%), in what represents the full establishment of the depositional and oceanographic conditions that led to the formation of the DMP. *B. spathulata* becomes co-dominant with *S. fusiformis*, and both *E. exigua* and *N. turgida* gain importance as accessory species. The further development of these opportunistic species points out to a shift in the quality of the organic matter reaching mid-shelf benthic environments. Diversity (Hs) values exhibit a significant decrease on the foraminiferal assemblages of both cores.
The decrease of assemblage’s diversity due to the proportional increase of species with opportunistic behaviour has been associated by some authors (Caralp, 1989; Schmiedl et al., 1997) with important organic influxes, especially when seasonal upwelling occurs. In such cases, benthic foraminifera populations assume a dynamics where the most opportunistic species take advantage of abundant fresh food supply, thus dominating the assemblages. A period of increased oceanic productivity in the Iberian Margin between 1060 and 670 yr cal BP has been identified by Soares (2004; see also Soares & Dias, 2006 and González-Álvarez & Francés, 2005) and seems to fit with this section of the cores. Using the reservoir effect in radiocarbon as an environmental proxy, Soares (2004) points out to the establishment/intensification of seasonal upwelling along the Iberian Western Margin, around 1000 yr cal. BP. He also defends that since then and until present day, this phenomena has suffered oscillations with a tendency to be more intense during warmer climate periods. If so, this section of the depositional record will correspond to the Medieval Warm Period (950-1250 AD). The occurrence of upwelling processes in the Western Margin therefore seems to be contemporaneous with the installation of the Douro Muddy Patch. Upwelling currents seem in fact to contribute for deposition of DMP sediments in this area of the mid-shelf, considering that its ascending currents can be seen in one hand as a barrier to the spreading of suspended sediments and, on the other hand, as an agent that relocates part of these sediments from distal areas back to the middle-shelf.

In Zone 1, the uppermost section of the cores, a notable variation in some upwelling related species can be found. Decrease is evident for *B. dilatata*,

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<th>B. torques</th>
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<td>26</td>
<td>5</td>
<td>22</td>
<td>3</td>
<td>359</td>
</tr>
<tr>
<td>270</td>
<td>18</td>
<td>67</td>
<td>24</td>
<td>15</td>
<td>4</td>
<td>6</td>
<td>18</td>
<td>7</td>
<td>27</td>
<td>6</td>
<td>25</td>
<td>5</td>
<td>371</td>
</tr>
</tbody>
</table>

*NB* – number of total benthic foraminifera identified in each sample
**S. fusiformis** and **N. turgida** in core FF1GM92, and for **B. spathulata** in core POS287-13-2G. This data associated with higher values of benthic foraminiferal assemblages diversity (Hs) in both cores (Figures 6 and 7), and with the decrease of organic matter content in POS287-13-2G (Figure 5), suggests a possible turn in food supply. The climatic and oceanographic changes of the Little Ice Age (1300-1850 AD) are probably behind this change, in particular a lower intensity of the upwelling phenomena during this period, as suggested by Soares (2004).

**CONCLUSIONS**

Late Holocene benthic foraminiferal assemblages of the two cores retrieved from Douro Muddy Patch (Western Iberian Margin) were used for the paleoenvironmental reconstruction of the Portuguese continental shelf off Douro River.

Three main zones were settled in the sedimentary record according to variations in foraminifera species, grain-size distribution, organic matter and carbonate content. These variations are related with environmental oscillations, particularly in the oceanographic and climate conditions, occurred in this region for the last circa 1400 years.

Benthic foraminifera assemblages of both cores are dominated by opportunistic species in organic enriched but oxygen depleted environments. A significant increase in upwelling related species is used to define the transition from core Zone 3 to Zone 2. The appearance/intensification of coastal upwelling around 1000 yr cal. BP (transition of the Dark Ages to the Medieval Warm Period) is simultaneous with an increase of fine sediment’s deposition in the mid-shelf and the Douro Muddy Complex settlement, suggesting that upwelling currents contribute for
the DMP sediment supply. In this context, coastal upwelling ascending currents can be seen both as a barrier to the spreading of suspended sediments for deeper areas and as an agent that relocates part of these sediments from distal areas back to the middle-shelf. This will represent an additional sediment source supply to the main SW winter storms process and reinforce the DMP role as a continental shelf sediment trap.

Transition to Zone 1 is marked by a decrease in some of the upwelling related species and in the organic matter content, as a probable adjustment to new oceanographic and climatic conditions. The occurrence of a less intense seasonal upwelling in the Western Margin during the Little Ice Age should be behind these environmental adjustments.

ACKNOWLEDGEMENTS

This work was a contribution of the FCT project – Envichanges (PLE/12/00). The authors acknowledge Dr. Anabela Oliveira for discussions and comments.
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PLATE I

Main species of benthic foraminifera in cores FF1GM92 and POS287-13-2G

1. *Statonforthis fusiformis*  
2. *Bolivina dilatata*  
3. *Brizalina spatulata*  
4. *Bulimina elongata*  
5. *Epistominella exigua* dorsal view  
6. *Epistominella exigua* ventral view  
7. *Nonionella turgida* ventral view  
8. *Planorbulina mediterranea* ventral view  
9. *Rectigrinella phlegeri*  
10. *Cassidulina latrigata*


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A SHORT-TERM COMPARATIVE STUDY ON
*Diplodon rhuacoicus* YOUNG ADULTS SHELL GROWTH
UNDER ENRICHED SÃO FRANCISCO RIVER WATER

A.B.L. AMARAL(1); T. V.S. ALVES T. V.S.(1); M. LOPES-LIMA,(2) & J. MACHADO(2,3,4)

**ABSTRACT**

The culture of freshwater mussels (Superfamily Unionacea) has attracted the attention of several research studies in the past decade in order to achieve and dominate the complete life cycle of these animals. Furthermore it seems obvious that it’s necessary to control the growth and quality parameters of the specimens under culture. Concerning this, the present work consisted in a comparative study on the shell growth of *Diplodon rhuacoicus* (Lea, 1834) with four different treatments: two of these treatments were made in tanks with São Francisco River water enriched with two inorganic calcium sources (calcium carbonate and calcium and magnesium bicarbonate); the other two were done with the animals placed in grated stainless steel cages submerged in the São Francisco river at different depths (three and six meters below surface). This research study happened in a short-term (one and a half month), from late spring to early summer seasons. According to our results it was not possible to see any significant differences on the shell growth of *Diplodon rhuacoicus* under these four different treatments and the control situation, at least in such a short period.

**INTRODUCTION**

*Diplodon rhuacoicus* (Fam. Hyriidae) is a small size freshwater mussel (3-5 cm width) with a beautiful and shiny shell nacre; it prefers sandy bottoms and can be found, in Brazil, from one to up to eight meters depth along the São Francisco River (Mansur et al., 1987).

The global decline of non-marine mollusks is causing increasing concern (Lydeard *et al*., 2004). In particular, freshwater bivalve mollusks have shown severe declines during the last decade with many species now facing extinction. The major factor...
in the demise of the world’s freshwater mussels, including the *D. rhuacoicus*, has been the large-scale impoundment of rivers over the past 75 years (Bencke, 1990; Bogan, 1993; Yeager, 1993) causing habitat degradation, alteration and fragmentation with implications on the absence or decline of host fish populations and a series of additional interferences with the chemistry, biology, hydrology and geomorphology of streams. Another is the large scale infestation in rivers and lakes of exotic species considered to be the major cause on recent severe declines in the unionoidea populations in North and South America (Gillis and Mackie 1994; Schloesser and Nalepa 1994; Nalepa 1994).

Other *Diplodon* spp. has been used in association with semi-intensive finfish and shrimp aquacultures to filter the infrastructures water affluents and effluents particulate organic matter. This type of polyculture has proved itself to be very efficient, giving an important contribution to the water quality control and to the rationalization of the means of production used, at nearly zero cost. It has also contributed to: the increase of protein rich start materials, the creation of productive employment and subsequently of additional income. This integration attends to the real concept of sustainable development and should be encouraged. The importance in the uses that can be given to these animals can be further enhanced by emphasize that their shells give excellent start materials for the mother-pearl industries and are also rich in organic and mineral materials with superb nutritional and even medicinal value. Actually, a series of treatments of various kinds, with freshwater and marine bivalve shells, are being used by oriental naturopathy to help in the treatment of specific symptoms of several diseases and its use is generalized in most of southeast Asian countries like China, Japan, Korea, Taiwan, and Thailand (Rocha, 2001; Alves, 2004).

It is vital to increase our knowledge about the culture and the reinsertion of this species in the wild in order to develop the best strategy for the

**MATERIALS AND METHODS**

**Animal’s preparation**

Freshwater mussels, *Diplodon rhuacoicus*, were collected from São Francisco basin in Nova Glória, Bahia, Brazil; having the collection site the following geographical coordinates: 09° 15’ 47.5” S and 038° 16” 51.3” W.

The bivalves were manually collected using scuba diving gear. The sediment samples were also collected by scuba diving and scraping of the bottoms substrate. The sediment samples were sieved in a 5 millimeters grid.

The animals were selected giving preference to the younger individuals and the final size obtained ranged between 0,920 and 1,410 centimeters. The transport was made in thermic boxes with animal layers intercalated with damp cloth.

To avoid contamination by pathogenic organisms and undesirable epibiont larvae release, the mussel’s shells were fairly cleaned with a brush followed by depuration in order to remove all the particulate matter from the animal’s gills.

The specimens were kept in 19 litter tanks with aerated water and river sediment in the bottom for a period of 5 days. The water parameters in this procedure was as follows: pH between 7,3-7,6; the photoperiod was 12 hours light/ 12 hours darkness to mimic the natural situation and room temperature. Feeding was administered daily with cultured polyclaige solutions.
Studies on the shell growth with enriched São Francisco River water (EW)

These studies were characterized by the use of two inorganic sources of calcium to enrich the São Francisco River water. The following compounds were used: calcium and magnesium bicarbonate (CaMg(CO$_3$)$_2$) and calcium carbonate CaCO$_3$.

For the final concentration of calcium determination, we had to take into account the natural amount already present in the river's water. Once determined, the natural concentration was increased to the desired final concentration with calculated amounts of both compounds (Table 1).

We organized the experiments in two groups. To each group, an individual test tank was assigned with its own air-lift biofilter, constant aeration, and a specific inorganic source of calcium. 10 young adult animals were kept in each tank. The pH and temperature monitoring as well as feeding was done on a daily basis. A daily monitoring of the mortality was also performed.

Each 15 days a detailed morphometric study was made on the animals, where data referring to the height, width, and thickness for each individual was logged. This experiment had the duration 45 days.

Biometric study

The growth rate (GR) was calculated using a formula used by Marrom (1946) and Rezende (1998):

$$GR = \frac{(Log L_f - Log L_i)}{t} \times 100$$

Where: $L_f =$ Final Length  
$L_i =$ Initial Length  
$t =$ Time in days

Statistical analysis

The statistic evaluation of the comparative study done between the four treatments, was done by one-way analysis of variance (ANOVA) with a level of significance of 5%. A t-test was also done for each pair NW 3/6 meters and EW (CaCO$_3$)/(CaMg(CO$_3$)$_2$).

RESULTS

The mean values of the physicochemical parameters (pH and water temperature) for each treatment are indicated in Table 2.
The biometrical study was made with data collected every 15 days during the whole period of the experiments.

From table 3 and graphic 1 is possible to observe that the experiments of EW with CaMg(CO$_3$)$_2$ (1,15±0,12) and NW at 3 meters depth (1,08±1,11) apparently expressed a better efficiency in promoting shell growth on *D. rhuacoicus*. In contrast, the experiments of EW (CaCO$_3$) (0,62±0,63) and NW at 6 meters depth (1,59±0,39) presented the lowest shell growth ratio. However the statistical treatment from the growth ratio data done with one-way ANOVA didn’t detect significant differences between the four treatments (P>0,05) neither the individual t-tests done between the pairs EW CaMg(CO$_3$)$_2$/ EW (CaCO$_3$) and NW 3 meters/NW 6 meters.

A casualty rate up to 30% was expected for each treatment due to the young age of the in fact this number was in general higher reaching a maximum of 60% casualties in the experiment with EW (CaMg(CO$_3$)$_2$)

**DISCUSSION**

According Machado *et al.* (1988), shell growth on freshwater bivalves is promoted by acidification caused by oxygen declining in the environmental water or by the metabolic rate internal increasing in the mantle fluids of these animals.

This respiratory/metabolic acidosis tendency causes dissolution on the calcium carbonate reserves stored under the form of calcareous microspherules inside the mantle with the increase of Ca$^{2+}$ and CO$_3^{2-}$ ion contents in the haemolymph. These Ca$^{2+}$ and CO$_3^{2-}$ gradients, facilitated by high epithelium permeability to calcium ions, will thrive them by diffusion towards the shell, mainly in the summer. On the other hand, the Ca$^{2+}$ and CO$_3^{2-}$ ion content tendency to decrease in the winter, which with low respective permeability, doesn’t promote the passage of these ions to the shell compartment, on the contrary, forcing them to stay in the mantle where they are incorporated in the calcareous microspherules.

**Table 2. Physico-chemical parameters.**

<table>
<thead>
<tr>
<th>Experimental Groups</th>
<th>Mean Temperature / C°</th>
<th>Mean pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>NW (3 meters depth)</td>
<td>26,5 ± 0,43</td>
<td>7,8 ± 0,1</td>
</tr>
<tr>
<td>NW (6 meters depth)</td>
<td>26,5 ± 0,41</td>
<td>7,8 ± 0,11</td>
</tr>
<tr>
<td>EW (CaCO$_3$)</td>
<td>26,4 ± 0,67</td>
<td>7,8 ± 0,13</td>
</tr>
<tr>
<td>EW (CaMg(CO$_3$)$_2$)</td>
<td>26,4 ± 0,74</td>
<td>7,8 ± 0,12</td>
</tr>
</tbody>
</table>

**Table 3. Statistical analysis of the growth rate (%)**

<table>
<thead>
<tr>
<th>Experimental Groups</th>
<th>Mean</th>
<th>Stand. Dev.</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>EW (CaMg(CO$_3$)$_2$)</td>
<td>1,15</td>
<td>±0,12</td>
<td>1,22</td>
<td>0,97</td>
</tr>
<tr>
<td>EW (CaCO$_3$)</td>
<td>0,62</td>
<td>±0,63</td>
<td>1,71</td>
<td>0,06</td>
</tr>
<tr>
<td>NW (3 meters depth)</td>
<td>1,08</td>
<td>±1,11</td>
<td>3,23</td>
<td>0,10</td>
</tr>
<tr>
<td>NW (6 meters depth)</td>
<td>0,59</td>
<td>±0,39</td>
<td>1,18</td>
<td>0,07</td>
</tr>
</tbody>
</table>
It was expected that the experiments with EW (CaCO₃) revealed expressive results when comparing those with NW, but even with Ca²⁺ and CO₃²⁻ ions supersaturation the treatments didn’t increase significantly the calcification of the shell and subsequently the growth rate when comparing with the other experimental situations at least in such a short term. We may speculate that due to the high physiological pH revealed during all the experiments, the greater concentration of Ca²⁺ and CO₃²⁻ ions in the EW (CaCO₃) treatment, the calcification mechanism was directed to the microspherules of the mantle.

According Lorenz and Bender (1977) in *Mytilus edulis* there’s a direct correlation between the magnesium concentration and shell growth. This link was revealed when this marine bivalve was submitted to water with high levels of magnesium which is atypically incorporated in the shell. These discoveries combined with the results obtained by Dodd (1965) that found a seasonal variability of this metal (Mg²⁺) in *M. edulis* shells, showing that an increase or a decrease of magnesium in the shell could be correlated with the highest (summer) and lowest (winter) calcification rates respectively. In contrast, an opposite effect was revealed in the European unionid *Anodonta cygnea* by Wilbur and Bernhardt (1984) showing that when exposed to low concentrations of (Mg²⁺) ion, the shell growth is promoted and vice-versa. Based on these contradictory statements it is also possible to speculate that our results concerning the magnesium assay, suggests that the influence of this ion on the growth of *D. rhuacoicus* doesn’t have any expressive meaning, confirming its unspecific and unclear role on the shell calcification.

So, as a final conclusion, short-term periods of exposure of young bivalves of *D. rhuacoicus* to enriched water with both calcium ion sources as well as at different depth in the river didn’t allow us to discern significant results but gave us some indication that can be used in a longer term studies in order to clarify the knowledge about the growth of these animals.

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MARINE ALLELOPATHY: PRINCIPLES AND PERSPECTIVES

T. RODRÍGUEZ-RAMOS, P. LORENZO & L. GONZÁLEZ

Keywords: Allelopathy, algae, allelochemicals, marine environment

ABSTRACT

Current knowledge of allelopathic interactions in marine environments guides us to think that allelopathy may provide an advantage to toxin-producing phytoplankton, since allelopathic compounds liberated by them act as strong mediators in phytoplankton dynamics, affecting species succession. We have considered allelopathic relations as one more of the different types of biotic or abiotic stresses that algae undergo in marine systems, a process by passive interference very different from the processes of competition by space and resources. The lack of information on interactions with hydrodynamic, chemical and biological factors and the chemical nature and synthetic pathways of many marine allelochemicals, as well as the methodological difficulties to study chemical interactions among phytoplankton in natural marine ecosystems are the most important reasons for which this ecophysiological factor is included in very few ecological models. We summarize and propose the possible allelopathic interactions that could take place between donor and target species in marine ecosystems. Recent studies suggest that toxins produced by the phytoplankton species responsible for the HABs are not likely to be the allelochemical compounds, or they do not have the major allelopathic capacity, at least. Organic compounds liberated into the natural environment can play a wide range of roles in addition to the allelopathic one.

INTRODUCTION

Marine plant organisms play critical functional roles in marine ecosystems since they transform the solar energy and carbon dioxide in organic matter. This organic matter serves like food and habitat to omnivores, detritivores and herbivores in aquatic ecosystems as well. In addition, marine plants are important in the taking, storage, release and deposition of nutrients.

There are several important differences between terrestrial plants and phytoplankton environments. Firstly, phytoplankton are unicellular and drift in the water, where physical factors such as viscosity, shear...
forces and low Reynolds numbers are determinant; diffusion and laminar advection are the main ways of transferring molecules (Legrand et al. 2003) between donor and target species in the sea, something indispensable for the occurrence of allelopathy. As far as the chemical factors are concerned, the dilution of the allelopathic compounds in the water is responsible for their very low concentration (Legrand et al. 2003).

Natural released products are essential and beneficial to the plant which produces them, and probably contribute actively in communication processes by serving as attractants, deterrents, toxicants to other organisms and/or as protectants to abiotic and biotic stresses (Karamanoli 2002; Reigosa and González 2006). In fact, allelopathic compounds liberated by toxin-producing phytoplankton act as strong mediators in phytoplankton dynamics (Smayda 1997) affecting species succession (Keating 1977). However, the allelochemical effect seems to be determined by concrete group characteristics of both target and donor species (Fistarol et al. 2004), as well as by the different strains of each species used in laboratory experiments.

Different disorders in the environment, like an increase in the organic compounds concentration, can alter the structure and the function of vegetal communities (Wells et al. 2005). Seaweeds have shown sensitivity to a large rank of compounds released to the marine environment and the effects are more perceptible than in animal species (Baden 1989).

ALLELOPATHY

The concept of allelopathy is generally accepted among scientists as an ecophysiological process but, since the mechanism is extraordinarily difficult to demonstrate in the field, its importance in aquatic systems is still debated. One of the most conflictive points is to differentiate between allelopathy and competition (Larsen and Bryant 1998) and some authors assert that allelopathy is part of resource competition (light, nutrients, carbon dioxide) because it is impossible to separate these two mechanisms in natural systems (Igarashi et al. 1999). By other way, (Uchida 2001) classified allelopathic contact among species into a global process called interference with the objective to discern between resource competition and allelopathic effects and to recognize, at the same time, whether in the nature these processes can both coexist. In this text we considered the allelopathic relations as one more of the different types of biotic or abiotic stresses that undergo algae in marine systems (Tillmann 2004) and, therefore, within the classic definition of competition, allelopathy would be a process of competition by passive interference very different from the processes of competition by space and resources.

Production of allelopathic substances interfere with growth and development of accompanying species and, in the case that the growth of competitors is inhibited, it gives competitive advantages to the species which produces the allelopathic substances (Lewis 1986). In addition, these allelopathic substances are believed to be secondary metabolites with harmful capacity (Granéli and Hansen 2006).

Allelopathy has been demonstrated for bacteria (Long and Azam 2001) cyanobacteria (Suikkanen et al. 2005), dinoflagellates (Tillmann and John 2002; Kubanek et al. 2005), and diatoms in coastal environments (Subba Rao et al. 1995).

In some cases the allelopathic process can interfere in the plant capacity to use the available resources, as it is the case of allelopathic compounds inhibiting the correct development of mycorrizas, allowing the receptor species a better absorption of nutrients, or those in which allelochemicals modify the ratio of the soil microbial populations varying, indirectly, the balance of nutrients or, when by means of complex relations with the organic matter, they are able to modify the amount of nutrients available in the soil solution. Nothing is known about this in marine ecosystems.
The joint analysis of all the factors that could be affecting the allelopathic process could be shown a synergic, additive or even antagonist effect, becoming the allelopathic relation in a more complex one than it would be expected for a single laboratory analysis.

In aquatic systems there is a broader diversity of species and chemical compounds than in terrestrial ecosystems (McClintock and Baker 2001), although nothing is known about quantitative interactions with hydrodynamic, chemical and biological factors at different time and space scales. Another disadvantage in allelopathy modeling in marine ecosystems is often the missing chemical identification of the produced compounds and their biosynthetic pathways (Ianora et al. 2006). Three major classes including phenolics, alkaloids and terpenoids were reported as potent allelopathic compounds. The plant chemicals associated with allelopathic activity are called allelochemicals. The frequency and diversity of toxins released by microalgae suggest that allelochemicals production might play a role in competition among algal species.

Methodological difficulties to study chemical interactions among phytoplankton in marine ecosystems are the most important reason for which this ecophysiological factor has been underestimated in plant marine competition. In this sense, we know little about the role of allelopathy in the marine environment (Solé et al. 2005) but phytoplankton allelopathy in the sea promotes a stable coexistence of that competitive phytoplankton that would otherwise exhibit competitive exclusion of weak species (Sarkar et al. 2006). Evidence is accumulated that secondary metabolites in phytoplankton also regulate and control algal biology, species succession, competition, and communication (Legrand et al. 2003). Allelopathy is an adaptation by which some phytoplankton species could achieve a competitive advantage over other species (Legrand et al. 2003) and it should be considered as a physiological adaptation such as surface area and volume ratio variation, production of secondary metabolites, different nutrient requirements, pigment composition, etc.

Despite the importance that we can suppose to the allelopathic process in marine environment, as a result of the difficulties mentioned above, very few ecological models include allelochemistry (Mukhopadhyay et al. 1998), but it is evident that such an important process should be included in future models that consider species interactions (Wolfe 2000).

Biological active compounds, produced by cyanobacteria and algae, are especially important either because could be toxics to marine organisms with ecological or economical interest or such compounds could possibly be helpful in combating toxic algal blooms through the development of environmentally friendly algaecides. However, it would be necessary a detailed previous study, because it is unlike that allelochemicals released by one algae influence another algae without affecting any other ecosystem components (Legrand et al. 2003). On the other hand, knowledge about such compounds has a beneficial effect in the sense of a better understanding of interactions between competing organisms of the same habitat (Volk 2005).

Allelopathy may be a successful strategy for phytoplankton species that occur in dense blooms (Kubanek et al. 2005). Allelopathic process could be maximizing the concentration of accessible allelopathic compounds to competitors and minimizing the opportunity for the evolution of resistance in competitors because of the infrequent occurrence of these blooms (Lewis 1986).

Although knowledge is often missing due to the lack of information on the chemical nature and synthetic pathways of many marine allelochemicals, (Gross 2003) pointed that allelopathy occurs in all aquatic environments and different mechanisms operate depending on where allelopathy takes place. The author also mentioned that allelopathic interactions are common among submersed macrophytes, benthic algae and cyanobacteria, which are able to produce and release allelopathic active compounds. Some researchers consider that
allelopathic interactions are closely associated with competition for resources (Granéli and Hansen 2006), but nowadays authors begin to think that other mechanisms like defense could be related with allelopathy (Ianora et al. 2006). There are examples of allelochemical interaction with other environment factors, for instance, nutrient limitation, pH variations, temperature, and growth phase (Granéli and Flynn 2006; Ianora et al. 2006).

In the light of this, we summarize and propose the possible allelopathic interactions that could take place between donor and target species in marine ecosystems (fig. 1). Proximity between donor and target species is the first condition for the allelopathic processes to occur. In addition, many abiotic and biotic factors have been found to influence toxicity and to affect the production and fate of allelopathic substances from algae (Granéli and Hansen 2006). In fact, low light, high pH and nutrient deficiency can enhance allelochemicals release from donor species (Granéli and Hansen 2006). Moreover, biotic factors such as high density, growth condition, growth stage and, in summary, the global ecophysiological state of the algae could also modify allelopathic activity of donor species (Granéli and Hansen 2006). The reduced movement capacity of most of target phytoplankton species avoids an effective response to chemical signals(Wolfe 2000), enhancing this allelopathic effect.

Donor species can affect target species by several ways. In most cases, they release allelochemicals into the medium and thereby come into contact with cell membranes of target species (Granéli and Hansen 2006). However, there are other less common processes such as: cell contact (Uchida 2001), through exudates (Tillmann 2004) or defence substances acting as allelochemicals (Pohnert et al. 2007). Bacterial and light degradation or binding to the target membranes (Granéli and Hansen 2006) are known to affect the allelochemicals accumulation when they are released. On the other hand, receiver species sensitivity to allelopathic substances could depend on cell concentration, size-, species-, and group-specific of target algae (Granéli and Hansen 2006), ecophysiological stage could also affect them. Allelopathic compounds can produce different responses on target species. In most cases, allelochemicals kill receivers, causing a hard decrease in their biomass, but if allelopathic substances are at low doses, defense responses such as sexuality or encystment could be observed (Ianora et al. 2006). Target organisms could suffer sub-lethal damages which allow them to continue living, because they maintain a positive growth rate, although smaller than that of the control or donor species absence (Fistarol et al. 2004). The last possibility is that a positive effect occurs, with an increase of the growth rate of the target species, as in the case of Alexandrium tamarense (Fistarol et al. 2004). In addition, reading (Pohnert et al. 2007), it is possible to be suggested that defense or communication chemical compounds could be released from target species during dangerous situations. The modes of action include damaging cell membranes, inhibiting protein activity, or modifying a physiological function (Legrand et al. 2003), although in most cases this mode of action is still unknown.

Because toxins are secondary metabolites, they are often produced as a response to stress, in a similar way to lipids and polysaccharides (Larsen and Bryant 1998; Igarashi et al. 1999). On the other hand, the physiological condition and the inherent characteristics of the target species strongly determine their degree of resistance or detoxification to allelochemicals (Suikkanen et al. 2004). This suggests that competition in limited environments may be dramatically affected by allelochemical production.

An important type of bloom-forming phytoplankton are the denominated Harmful Algal Blooms (HABs), popularly known as Red Tides, which cause massive fish kills, contaminated
seafood and altered ecosystems in ways that humans perceive as harmful (Gross 2003; Gross et al. 2003), proliferating both in marine and freshwater environments under not very clear conditions. The explosive growths sometimes appear during changes in weather conditions but important causes as variations in upwellings, temperature, transparency, turbulence or salinity of the water, the concentration of dissolved nutrients, wind or surface illumination may be contributing (Bower et al. 1981). It is no clear why these species produce toxins, secondary metabolites with no explicit role in the internal economy of the organisms that produce them. It is even possible that algal species which are normally not toxic may be rendered toxic when exposed to atypical nutrient regimes (e.g. phosphate deficiencies) resulting from cultural eutrophication (FAO 2004).

At the beginning, it was thought that this toxins were the allelopathic compounds in themselves, inhibiting growth of competing microalgae (de Jong and Admiraal 1984; Yasumoto et al. 1987; Gentien and Arzul 1990), as in the case of the domoic acid or the okadaic acid, but nowadays there are evidences of which this is not certain (Sugg and VanDolah 1999; Lundholm et al. 2005). There are some studies in which the allelopathic effect of the donor species is shown, but in most of them the effect because of the high pH of the filtrate has not been taken in account (Arzul et al. 1999), then this results may be wrong or they must be carefully interpreted. Because of this kind of methodological errors, the allelopathic capacity of some species or strains has been recently put in doubt (e.g. Nodularia spumigena (Mogelhoj et al. 2006)). It is known that the main production of the toxin used to occur at the exponential growth phase (e.g. domoic acid produced by Pseudo-nitzschia multiseries (Lundholm et al. 2005)) and then it declines during stationary phase (pattern of toxin production generally followed by dinoflagellates (Singh et al. 1982; Boyer et al. 1987; Boczar et al. 1988; Anderson et al. 1990; Roszell et al. 1990; Taroncher-Oldenburg et al. 1997), while in allelopathic tests, culture filtrates from the exponential growth phase of the donor species have a stronger inhibitory effect on the target species compared to that at the exponential phase (e.g. Alexandrium tamarense in laboratory culture (Wang et al. 2006), although this is one of the studies in which the effect of the high pH was not taken into account. There are also some cases in which a non-toxic strain of a donor species is able to inhibit the growth of the target species (Wang et al. 2006). Finally, some studies were done in order to assess the role of okadaic acid in growth competition. On the one hand, dinoflagellate species that co-occur with Prorocentrum lima, the donor species, were grown in medium preconditioned by P. lima; on the other, two of the species most sensitive to growth inhibition in the previous experiment were selected for study of growth inhibition by purified okadaic acid. The results suggested that okadaic acid does not represent the major growth-inhibitory activity found in P. lima’s medium (Sugg and VanDolah 1999).

Sometimes, production of allelochemicals has been shown to be one of the determinants for bloom development, dynamics, and fate (Rengefors and Legrand 2001). For example, the exclusion of another phytoplankton species by the toxic haptophyte Chrysochromulina polylepis and its success as a bloom-forming species has been attributed, among other factors, to the production of allelochemicals (Schmidt and Hansen 2001).

Allelopathy, as well, may represent a determinant in species succession at the end of a bloom, when the environment is nutrient-limited (Fistatol et al. 2005).

During a bloom succession, phytoplankton are thought to utilize chemical signals to enhance their defense capacities against grazers (Wolfe et al. 1997) and pathogens (Fuhrman 1999), and for outcompeting other phytoplankton for available resources.
EFFECTS OF NATURAL ORGANIC COMPOUNDS

It is difficult to know the role of natural compounds released to the environment by marine plants. Probably, most of them play more than one role in nature arise from natural selection. Interactions among toxic phytoplankton and their zooplankton grazers are complex. There are toxins from dinoflagellates used to kill or deter the grazers that do not affect competitor species as allelochemicals (Tillmann and John 2002). Beyond effects on direct grazers, toxins may accumulate in and be transferred through marine food webs, affecting consumers at higher trophic levels, including fish, seabirds, and marine mammals and then they are considered a natural contamination under a human point of view. Some of those compounds, which we think over pollutants, can not be considered allelochemical compounds because they are not released to the environment and they are taking directly from phytoplankton by predators.

There are a lot of potential pollutant compounds that are released to the environment by marine plants and we do not know (Sugg and VanDolah 1999). The neurotoxic amino acid, domoic acid (DA) is one of the most studied in last years (Hasle 2002; Lundholm et al. 2004). Domoic acid is released mainly by species of the genus *Pseudo-nitzschia* and *Nitzschia* (Fehling et al. 2004) and it has led to shellfish harvesting closures (Fehling et al. 2004). Recently have been shown that DA is used by diatoms themselves as a functional component of a high-affinity iron acquisition system (Wells et al. 2005).

Brevetoxins, large lipid-soluble polyether marine toxins from Karenia brevis, produce toxic interaction with animals (Baden 1989) but there are indications about allelopathic relations among *K. brevis* and other phytoplankton species (Kubanek et al. 2005). In the Gulf of Mexico, *K. brevis* forms almost monospecific blooms with cell concentrations of thousands to millions cells per litter and different sympatric species of phytoplankton experienced reduced growth when exposed to high concentrations of alive *K. brevis* (Kubanek et al. 2005). Those experiments seem to indicate that *K. brevis* compounds others than brevetoxins act jointly, with additive or synergistic interactions, and it contributes at least partially to the competitive dominance of the red tide dinoflagellate.

Serine/threonine protein phosphatases are regulatory enzymes critical to growth and replication in eukaryotes. Okadaik acid (OA) and dinophysistoxin-1 (DTX-1) are produced by certain species of marine dinoflagellates and are potent phosphatase inhibitors. OA can cause the hyperphosphorylation of a broad range of animal and higher plant proteins.

In culture, the dinoflagellate *Prorocentrum lima* Ehrenberg, contains both OA and dinophysistoxin-1 DTX-1 throughout its growth cycle. Maximum concentrations of toxins occurs during the stationary phase (McLachlan et al. 1994).

(Windust et al. 1996) tested a variety of microalgae against OA solutions which inhibited the growth of all the target species at micromolar concentrations except the OA producer *P. lima*, which was not affected even at much higher levels. It is known that *P. lima* survived at 0°C during a long period of time and recovered when it was brought to a higher temperature. During the cold period some cell damage is likely with concomitant losses of organic compounds to the medium that can affect the associated microalgae (McLachlan et al. 1994) providing a competitive advantage to the producer which is not affected by the toxin. This differential activity of phytochemicals suggests that they may play an allelopathic role in marine environment, but nothing is known about the strategies adopted by *P. lima* to avoid autotoxicity. In fact, little is known about the role that this phycotoxin plays in the ecology of its producer, the benthic dinoflagellate *P. lima*.

Exudates from *P. lima* inhibited the growth of three dinoflagellate species that coexist with *P. lima* by inhibiting their protein phosphatase activity. In contrast, the protein phosphatase activity of *P. lima*
was refractory to both, exudates and purified OA (Sugg and VanDolah 1999).

Despite the high dilution factor in the sea, additive effects among natural pollutants as OA and DTX-1, may enhance the effect against microalgal growth (Windust et al. 1996). Saxitoxin (STX) and its naturally occurring analogues are produced by both marine and freshwater microalgae. Its polar nature allows it to readily dissolve in water. Dinoflagellates in the ocean, particularly *Alexandrium catenella*, *Alexandrium minutum*, *Alexandrium ostenfeldii*, *Alexandrium tamarense*, *Gymnodinium catenatum* and *Pyrodinium bahamense* var. *compressum* produce saxitoxins.

The allelopathic property of toxic *Alexandrium* species was studied using bioassays. The results revealed that in the exponential growth phase in
all species of *Alexandrium* cultured, allelopathic activity was positively related to both haemolytic and toxic activities (Arzul *et al.* 1999). However, at the stationary phase, the allelopathic activity was observed to be higher in relation to haemolytic and toxic activity at the log phase. Some *Alexandrium* strains did not even contain saxitoxins, but were still allelopathic. Thus, the allelopathy displayed in *Alexandrium* spp. must be due to some yet-unknown toxins (Granéli and Hansen 2006).

As we have summarized previously, it is only rarely that the main known toxins, known from a specific harmful algal species (OA, DTX-1, SXT), are the most likely allelopathic compounds while in most cases the known toxins and the allelopathic substances are different chemical compounds, at least at concentrations found in nature (Granéli and Hansen 2006).

Especial attention deserves a recent line of research in marine environment, the role of the secondary metabolites released as information molecules, used for cell-to-cell communication, namely volatile chemical cues (Steinke *et al.* 2002). This is the case of the diatom unsaturated aldehydes, which are involved in a stress surveillance mechanisms. (Vardi *et al.* 2006) demonstrated how the accurate perception of diatom-derived reactive aldehydes can determine cell fate in diatoms. In particular, the aldehyde (2E,4E/Z)-decadienal (DD) can trigger intracellular calcium transients and the generation of nitric oxide by a calcium-dependent NO synthase-like activity, which results in cell death. They proposed the existence of a sophisticated stress surveillance system in diatoms, which has important implications for understanding the cellular mechanisms responsible for acclimation versus death during phytoplankton bloom successions. According to these authors, when stress conditions during a bloom and cell lysis rates increase, DD concentrations could exceed a certain threshold, and possibly function as a diffusible bloom-termination signal that triggers an active cell death.

Diatom-derived aldehydes may also have an allelopathic role, since they have been shown to affect growth and physiological performance of diatoms and other phytoplankton species (Casotti *et al.* 2005).

Recently a novel class of oxylipins (oxygenase-mediated oxygenated compounds) based on C16 polyunsaturated fatty acids in diatoms has been described (Cutignano *et al.* 2006; d’Ippolito *et al.* 2006), suggesting that these new compounds may also be involved in signaling or allelopathy.

The way that organic chemical compounds are accumulated in the marine environment remains poorly studied. This realm is dominated by viscous forces, and chemical information is transmitted by “simple” diffusion and advective laminar flow (Wolfe 2000). Allelochemicals, in marine environment, might be released either actively by secretion or by passive means: leaching from algae tissue or algae cells, wounds in plant tissue or decaying plant material (Erhard and Gross 2006). Another possibility of allelochemical release is the presentation of active substances on the algae surface, so that their transference would be gotten by direct cell-cell contact (Erhard and Gross 2006).

**CONCLUDING REMARKS**

Allelopathy in marine environments is a new and attractive discipline that has emerged over recent years. The chemical relation among algae and other organisms in the sea offers excellent perspectives for the development of strategies to control blooms and to obtain natural and friendly algaecides. Advances in algae ecophysiology, molecular biology and genetic engineering of plants have been indispensable for this progress. More exploratory studies are still necessary and should be supported in order to know the complex relations among organisms in marine environments, to preserve biodiversity and to increase our basic knowledge about allelopathy and natural adaptation to changing physical, chemical and biological factors in marine environment.
ACKNOWLEDGEMENTS

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SALINITY INFLUENCE ON FORAMINIFERAL TIDAL MARSH ASSEMBLAGES OF NW PORTUGAL: AN ANTHROPOGENIC CONSTRAINT?

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Keywords: Benthic foraminifera, tidal marsh, estuaries, salinity, anthropogenic constrain, NW Portugal.

ABSTRACT

The composition of benthic foraminifera biocenoses from Lima and Minho tidal marshes exhibits a significant difference in spite of the proximity and regional affinities of both estuaries. The assemblages distribution along the Lima tidal marsh are dominated by J. macrescens and T. inflata at the high marsh zone; the low marsh and tidal flat zones are dominated by Quinqueloculina sp., Bolivina spp., H. germanica, and J. macrescens close to the estuary mouth, which become replaced by M. fusca, J. macrescens, T. inflata and H. wilberti upstream in an intermediate profile and by Ammobaculites spp. and M. fusca at the inner domain. In the Minho high marsh dominance belongs to H. manilaensis, M. fusca, P. limnetis and Psammophora sp., but P. limnetis is absent in the inner profile; the low marsh and tidal flat zones are dominated by M. fusca and Psammophora sp.. These biocenoses appear closely related with the salinity input inside the estuaries. In general we can consider that marsh assemblages from Lima mouth fit to the standard biocenoses under high marine influence, as in Minho the dominance belongs to lower salinity tolerant foraminifera. Considering the morphosedimentary trend of estuaries in the last 5000 years, the singularity of Minho assemblages can be seen as the natural evolution of estuarine ecosystems while the marine signature of Lima assemblages may result from human impact upon the lower estuary.

INTRODUCTION

Interfaunal relations together with bacterial communities, organic matter content and abiotic environmental parameters, like temperature, pH, dissolved oxygen, alkalinity, elevation and salinity have an important control on living foraminiferal distribution in sediments. The assessment of the influence of the latter two makes up the essential scope of this work developed by the EnviChanges and MicroDyn projects funded by FCT (Portugal).
Tidal marshes represent a fundamental environment to understand the distribution of coastal benthic foraminifera and the knowledge of their present-day ecology is of main importance to paleoecological interpretation studies.

Altimetric position and salinity can integrate the main abiotic parameters that constrain the distribution of benthic foraminiferal assemblages on tidal marshes environment.

The increasing elevation between the tidal flat and the external limit of high marsh, close to uplands, introduces a range of submersion times, during high tide flooding. Consequently a marsh zonation appears, related with the mean sea level and tidal regime, which is reflected in the distribution of several marsh biocenoses namely those of benthic foraminifera (e.g. Scott and Medioli, 1980; Gehrels, 1994; Horton and Edwards, 2006; Scott, 2006.)

Tidal marshes salinity is supplied by marine or diluted estuarine waters each high tide, mainly at spring tides where marsh surface becomes completely submerged. Nevertheless a significant difference is frequently present between the salinity values of these flooding waters and marsh sediment interstitial waters, where foraminifera live. This difference is seen as a result of ground water seepage, dilution by precipitation and concentration by evaporation (De Rijk, 1995; Moreno et al., 2005; Fatela and Moreno, 2006). Besides elevation/time submersion that controls the living foraminiferal assemblages distribution across the tidal marsh, salinity influences the composition of these biocenoses (e.g. Murray, 1971; Moreno et al., 2006). De Rijk (1995) shows that salinity can even represent the main controlling factor of foraminiferal marsh zonation.

The Lima and Minho rivers drain the NW of Portugal where the prevailing wet Atlantic climate is responsible for an average annual precipitation of 1300 mm. However, the maximum precipitation often exceeds 2500 mm during wet season, from October to March (Bettencourt et al., 2003).

The Lima is an international river with 67 km length between the Spanish border and Viana do Castelo, where it drains into the Atlantic, around 20 km south from Minho estuary (Figure 1). Its fluvial average flux is about 62 m³/s (www.maretec.mohid.com).

Figure 1. Location of study areas. Lima tidal marsh sampling profiles: NSR_L – Nª Sª das Areias, DAR_L – Darque, BPR_L – Barco do Porto; Minho tidal marsh sampling profiles: PR – Pedras Ruivas, CP – railway bridge, PIC – Pinelas.
The Lima estuary trends ENE-WSW and presents a semidiurnal high-mesotidal regime, which effects can be felt 20 km upstream (Alves, 2003; Ramos et al., 2006). The astronomical spring tide reaches a maximum of 4 m high (IH, 2006) but amplification by storm surge must be considered (Taborda and Dias, 1991).

The available information about the physical and chemical characteristics is scarce. The limit for the salt-water penetration inside the estuary during spring tides can be around 20 km (Ramos et al., 2006). After Alves (2003) this limit does not exceed 15 km and in winter it may not even extend to more than 5 km upstream. Similar results were obtained by mathematical modelling where the salt-water intrusion reaches 12 km upstream, under the assumption of a “well mixed” estuary (Pinho and Vieira, 2005). Nevertheless, these results may be biased considering that Lima behaves as a “partially mixed” estuary (Alves, 2003; Pinho and Vieira, 2005).

The lower part of Lima estuary is hardly modified by the installation of industrial, commercial, leisure and fishing harbour facilities. A periodic dredging along the 2.5 km of this sector insures 10 m deep on the navigation channel. Upstream the estuary is very shallow, where salt marsh and several tidal islands develop, and it becomes almost emerged during low water spring tide (Alves, 1996).

The Minho estuary defines the NW political border with Spain along 77 km (Figure 1), joining the Portuguese region of Minho and the Spanish region of Galicia, just before to reach the Atlantic. Its fluvial average flux is about 300 m$^3$/s (www.maretect.mohid.com).

The Minho estuary trends NNE-SSW and presents a semidiurnal, high-mesotidal regime: the astronomical spring tide considers also a maximum 4 m high (IH, 2006), but storm surge amplification (Taborda and Dias, 1991) was observed during field work. The dynamic tidal effects are felt up to a distance of around 42 km upstream, due to the tidal regime and to the smoothness and low gradient of the Minho’s outlet (Bettencourt et al., 2003). We found marine influence limited to the last 11 km of the estuary (Moreno et al., 2005) but after Bettencourt et al. (2003) it can be detected 35 km far from the river mouth.

The estuary is very shallow due to widespread siltation: a significant part of the bottom emerges during low water spring tide, when connection with the sea is made by two shallow channels which incise the bottom sediment down to -1 m depth (south) and -2 m depth (north) (Alves, 1996).

So the Minho estuary provides a small accommodation volume for the tidal prism and all together these characteristics prevent extensive penetration of a salt wedge into the estuary, which essentially behaves as “partially mixed”. During ebb tide, the seawater tends to be completely flushed out of the estuarine basin (Moreno et al., 2005).

In spite of their proximity and of containing marsh environments, the abiotic characteristics of both estuaries are not the same. In fact, features of coastal waters (temperature, dissolved oxygen, pH and salinity) that cover the tidal marsh are a result of a complex balance between tides, river discharge, sediment dynamics and the morphology of each estuary.

MATERIAL AND METHODS

Sixty one surface sediment samples were collected along six profiles from Lima and Minho estuaries, extending across the tidal flat and marsh environments, under Spring conditions. The set of three profiles from each estuary represent three different levels of marine influence over the marsh zones, previously evaluated trough field salinity measurements of estuarine waters, during high spring tides. The Lima profiles of N° Sª das Areias (NSR_L), Darque (DAR_L) and Barco do Porto (BPR_L) were
collected in May 2006 and the Minho profiles of Pedras Ruivas (PR), Railway Bridge (CP) and Pinelas (PIC) are from April 2002. The two later are located at the confluence between Coura and Minho rivers (Figure 1), where an adequate development of tidal marsh can be found. Nª Sª das Areias and Pedras Ruivas (PR) profiles are the closest to the sea in both estuaries whereas Barco do Porto and Pinelas are the inner estuaries profiles, under weak marine influence (Figure 1).

Samples consist of the topmost 1 cm layer of surface sediment. The current methods of alcohol sample preservation and Rose Bengal [1g/l] staining of living microfauna were used. In Lima marsh three samples of 10 cm$^3$ were collected and joined in one sample of 30 cm$^3$ at each sampling point, in order to avoid the patchiness of living foraminifera. This procedure is an improvement relatively to Minho sampling where a single sample of 10 cm$^3$ was collected at each point.

Each sample has been washed through a 63 µm sieve. Foraminifera were separated with micropipette by wet picking. When possible, at least 100 individuals were identified and counted in each sample from the living (stained) microfauna, following the Loeblich and Tappan (1988) generic classification in the most cases.

The temperature and salinity of estuarine water has been controlled every time as possible during field works, in high and low water spring tide, using a WTW conductometer. These parameters were also measured along the tidal marsh transects, during low water, in sediment interstitial water seeped and accumulated inside perforated PVC tubes inserted into the sediment, to a depth of 40 cm below surface (De Rijk, 1995). A few sampling sites did not supply any interstitial water.

The altimetric data on the sites have been obtained from a benchmark using a topographic total station. On each benchmark the absolute orthometric height was determined by a combination of precise GPS positioning and a regional gravimetric model of the geoid, with an estimated absolute precision of 8 cm (and 2 cm of relative precision in each site). Through this technique it has been guaranteed an accurate connection to the national height datum defined by the Cascais tide gouge. To get the same height reference system of tides, the heights of all benchmarks were further reduced to the local hydrographic datum (Hydrographic Zero – HZ), which lies 2 m below mean sea level in both estuaries.

RESULTS

Foraminiferal assemblages

1.- Lima tidal marsh

A total of 37 species has been identified in living assemblages of benthic foraminifera from Lima tidal marsh.

The profile of Nª Sª das Areias – NSR_L is 2000 m from the Lima mouth. Along this transect five different settings may be distinguished based upon foraminiferal assemblages distribution (Table 1):

Tidal flat assemblage is co-dominated by Bolivina pseudoplicata Heron-Allen and Earland, Bolivina ordinaria Phleger and Parker, Bolivina sp., Haynesina germanica (Ehrenberg) and Cibicides lobatulus (Walker and Jacob), all of them with calcareous test; sampling at 2.45m above HZ.

Low marsh is dominated by Jadammina macrescens (Brady) and B. pseudoplicata, followed by B. ordinaria and Quinqueloculina spp.; sampling at 2.87 m and 3.05 m above HZ.

Lower high marsh is strongly dominated by J. macrescens associated with B. pseudoplicata, Miliammina fusca (Brady) and Cibicides cf. pseudoungerianus (Cushman); sampling at 3.16 m and 3.25 m above HZ.
Upper high marsh is strongly dominated by *Trochammina inflata* (Montagu) associated with *J. macrescens*, *M. fusca*, *Quinqueloculina* spp. and *B. pseudoplicata*; sampling at 3.33 m and 3.38 m above HZ.

Highest high marsh shows a strong presence of *T. inflata* and *J. macrescens* associated with *Haplophragmoides* spp. and *M. fusca*; sampling at 3.55 m and 3.78 m above HZ.

The profile of Darque – DAR\_L is 5000m upstream. The tidal flat was barren of foraminifera, probably due to the coarse texture of the sediment. So the distributions of foraminiferal assemblages along this transect separates four different sets (Table 2):

Low marsh is dominated by *M. fusca*, *J. macrescens*, *T. inflata*, and *Haplophragmoides wilberti* Andersen, followed by *Haplophragmoides manilaensis* Anderson, *Tiphotrocha comprimata* (Cushman and Bronnimann) and *Trochamminita salsa* (Cushman and Bronnimann); sampling between 2.43 m and 3.01 m above HZ.
Lower high marsh is strongly dominated by *M. fusca*, *T. inflata* and *J. macrescens*, associated with *Haplophragmoides* sp. and *H. wilberti*; sampling at 3.09 m and 3.16 m above HZ.

Upper high marsh is strongly dominated by *M. fusca*, *J. macrescens* and *T. inflata* followed by *Trochamminita irregularis* (Cushman and Bronnimann) and *H. wilberti*; sampling at 3.39 m and 3.58 m above HZ.

Highest high marsh shows a strong presence of *T. inflata* associated with *H. wilberti*, *Haplophragmoides* sp. and *J. macrescens*; sampling at 3.77 m above HZ.

The profile of *Barco do Porto – BPR_L* is 8500 m upstream the Lima mouth. The foraminiferal assemblages do not allow the establishment of a difference between the lower high marsh and the upper high marsh. Their distribution along this transect individualize four different sets (Table 3):

<table>
<thead>
<tr>
<th>Tidal limits</th>
<th>Faunal zones</th>
<th>Foraminiferal species</th>
<th>Others</th>
<th>Calcareous/Agglutinated</th>
<th>Salinity*</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHW</td>
<td>IA</td>
<td><em>T. inflata, H. wilberti, Haplophragmoides sp, J. macrescens</em></td>
<td><em>M. fusca</em></td>
<td>0/100%</td>
<td>-</td>
</tr>
<tr>
<td>MHWS</td>
<td>IB1</td>
<td><em>M. fusca, J. macrescens</em></td>
<td><em>P. limnetis, Paratrochammina spp, S. lobata</em></td>
<td>0/100%</td>
<td>-</td>
</tr>
<tr>
<td>High marsh</td>
<td>IB2</td>
<td><em>M. fusca, T. inflata, J. macrescens, Haplophragmoides sp, H. wilberti</em></td>
<td><em>T. comprimata, H. manilaensis, S. lobata, Paratrochammina spp.</em></td>
<td>0/100%</td>
<td>-</td>
</tr>
<tr>
<td>MHW</td>
<td></td>
<td><em>M. fusca, J. macrescens, T. inflata, H. wilberti, H. manilaensis</em></td>
<td><em>A. mexicana, S. lobata, R. moniliformis, Paratrochammina spp.</em></td>
<td>0/100%</td>
<td>-</td>
</tr>
<tr>
<td>MHWN</td>
<td>Low marsh</td>
<td><em>M. fusca, J. macrescens, T. inflata, H. wilberti, H. manilaensis, T. comprimata, T. salsa</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MSL</td>
<td>Tidal marsh</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Measured in interstitial water

Tidal flat assemblage becomes strongly dominated by *Ammobaculites* spp. followed by *M. fusca* and *T. inflata*; sampling at 1.62 m and 2.35 m above HZ.

Low marsh is dominated by *Ammobaculites* spp. and *M. fusca*, followed by *J. macrescens* and *T. inflata*; sampling between 2.87 m to 3.05 m above HZ.

High marsh is strongly dominated by *J. macrescens* and *M. fusca*, associated with *H. wilberti*, *T. inflata* and *T. salsa*; sampling at 3.31 m above HZ.
Salinity Influence on Foraminiferal Tidal Marsh Assemblages of NW Portugal: an Anthropogenic Constraint?

Highest high marsh shows a strong presence of *T. inflata* followed by *J. macrescens* and *M. fusca*; sampling at 3.76 m above HZ.

2.- Minho tidal marsh

The biocenoses of benthic Foraminifera from Minho tidal marsh are mainly composed by 13 species.

The profile of Pedras Ruivas – PR is 3750 m from the Minho mouth. Along this transect five different settings may be distinguished based upon foraminiferal assemblages distribution (Table 4):

Channel and tidal flat is dominated by *M. fusca* and *Psammosphaera* sp., associated with *H. germanica* and *Elphidium* sp.; extending from infratidal to 2.25 m above HZ. However these data must be carefully considered because, when foraminifera are present, the total number is less than 100.

Low marsh is strongly dominated by *M. fusca* and *Psammosphaera* sp., associated with *Saccammina* sp.; sampling between 2.68 m and 2.88 m above HZ.

Lower high marsh is also strongly dominated by *M. fusca* associated with *Psammosphaera* sp. and *Pseudothurammina limnetis* (Scott and Medioli); sampling at 3.27 m and 3.49 m above HZ.

Upper high marsh is strongly dominated by *P. limnetis* associated with *H. manilaensis*,
Haplophragmoides sp., M. fusca and T. comprimata; sampling at 3.64 m and 3.88 m above HZ.

Highest high marsh shows a strong presence of *H. manilaensis*, associated with *Haplophragmoides* sp. and *H. wilberti*; sampling at 3.95 m above HZ.

The profile sampled close to the railway bridge of Caminha – CP is located at the confluence of Coura River, 4250 m from the Minho mouth. Along this transect five different settings may be distinguished based upon foraminiferal assemblages distribution (Table 5):

Channel and tidal flat assemblages do not deliver other species than *M. fusca* and *Psammosphaera* sp. that are co-dominant; extending from infratidal to 2.27 m above HZ.

Low marsh is strongly dominated by *M. fusca* associated with *Psammosphaera* sp.; sampling at 2.84 m above HZ.

Lower high marsh is also strongly dominated by *M. fusca* associated with *P. limnetis*, *H. wilberti* and *Psammosphaera* sp.; sampling between 3.23 m and 3.40 m above HZ.

Upper high marsh is strongly dominated by *P. limnetis* followed by *M. fusca*; sampling at 3.47 m above HZ.

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**Table 4.**

Zonation of tidal marsh living foraminifera assemblages of Minho estuary – April 2002. Profile of Pedras Ruivas – PR (Same acronyms than Table 1: HHW– 3.93 m; MHWS– 3.48 m; MHW,– 3.07 m; MHWN– 2.65 m; MSL– 2.0 m above hydrographical zero).

<table>
<thead>
<tr>
<th>Tidal limits</th>
<th>Faunal zones</th>
<th>Foraminiferal species Dominant</th>
<th>Other</th>
<th>Calcareous Agglutinated</th>
<th>Salinity*</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHW</td>
<td>IA</td>
<td><em>H. manilaensis</em>, Haplophragmoides sp., <em>H. wilberti</em></td>
<td>J. macrescens, T. comprimata, <em>P. limnetis</em></td>
<td>0/100%</td>
<td>-</td>
</tr>
<tr>
<td>MHWS</td>
<td>IA2</td>
<td><em>P. limnetis</em>, H. manilaensis, Haplophragmoides sp., M. fusca, T. comprimata</td>
<td><em>H. wilberti</em>, Paratrophammina sp.</td>
<td>0/100%</td>
<td>7.7</td>
</tr>
<tr>
<td>MHW</td>
<td>High marsh</td>
<td><em>M. fusca</em>, Psammosphaera sp., <em>P. limnetis</em></td>
<td><em>H. wilberti</em>, J. macrescens, T. comprimata, T. inflata, Saccammina sp.</td>
<td>0-0.5/ 99.5-100%</td>
<td>8.4-11.9</td>
</tr>
<tr>
<td>MHWN</td>
<td>Low-marsh</td>
<td><em>M. fusca</em>, Psammosphaera sp., Saccammina sp.</td>
<td><em>H. germanica</em>, J. macrescens</td>
<td>2.3-4.3/ 97.7-95.7%</td>
<td>15.8</td>
</tr>
<tr>
<td>MSL</td>
<td>Tidal flat Channel</td>
<td><em>M. fusca</em>, Psammosphaera sp., <em>H. wilberti</em></td>
<td><em>H. germanica</em>, P. limnetis, Elphidium sp.</td>
<td>0-3.5/ 100-96.5%</td>
<td>11.9</td>
</tr>
</tbody>
</table>

*Measured in interstitial water
Table 5. Zonation of tidal marsh living foraminifera assemblages of Minho estuary - April 2002. Profile of railway bridge – CP (Same acronyms than Table 1: HHW– 3.93 m; MHWS – 3.48 m; MHW – 3.07 m; MHWN– 2.65 m; MSL– 2.0 m above hydrographical zero).

<table>
<thead>
<tr>
<th>Tidal limits</th>
<th>Faunal zones</th>
<th>Foraminiferal species Dominant</th>
<th>Other</th>
<th>Calcareous/Agglutinated</th>
<th>Salinity*</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHW</td>
<td>IA1</td>
<td><em>H. manilaensis</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IA2</td>
<td><em>P. limnetis,</em> M. fusca</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MHWS</td>
<td>High marsh</td>
<td><em>H. manilaensis</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IB</td>
<td><em>P. limnetis,</em> M. fusca</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>T. comprimata,</em> T. inflata</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MHW</td>
<td>Low marsh</td>
<td><em>M. fusca</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Psammosphera sp.</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MHWN</td>
<td></td>
<td><em>T. earlandi,</em> C. salsa, J. macrescens</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSL</td>
<td>Tidal flat Channel</td>
<td><em>M. fusca</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Psammosphera sp.</em></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Measured in interstitial water

Table 6. Zonation of tidal marsh living foraminifera assemblages of Minho estuary - April 2002. Profile of Pinelas – PIC (Same acronyms than Table 1: HHW– 3.93 m; MHWS– 3.48 m; MHW– 3.07 m; MHWN– 2.65 m; MSL– 2.0 m above hydrographical zero).

<table>
<thead>
<tr>
<th>Tidal limits</th>
<th>Faunal zones</th>
<th>Foraminiferal species Dominant</th>
<th>Other</th>
<th>Calcareous/Agglutinated</th>
<th>Salinity*</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHW</td>
<td>IA</td>
<td><em>H. manilaensis</em></td>
<td></td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>M. fusca</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Psammosphera sp.</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MHWS</td>
<td>High marsh</td>
<td><em>H. manilaensis</em></td>
<td></td>
<td></td>
<td>2.2-2.9</td>
</tr>
<tr>
<td></td>
<td>IB</td>
<td><em>Psammosphera sp.</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>M. fusca</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>H. manilaensis</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>T. comprimata</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MHW</td>
<td>Low marsh</td>
<td><em>M. fusca</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Psammosphera sp,</em> H. manilaensis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MHWN</td>
<td></td>
<td><em>P. limnetis</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSL</td>
<td>Tidal flat Channel</td>
<td>*<em>M. fusca</em></td>
<td></td>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Psammosphera sp.</em></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Measured in interstitial water

**Low number of foraminifera (9)
Highest high marsh is exclusively dominated by *H. manilaensis*; sampling at 3.87 m above HZ.

The profile of *Pinelas*—PIC is inside the confluence of Coura River, 4750 m from the Minho mouth. No more than 9 specimens were found at channel samples, assembling *M. fusca* and *Psammospheara* sp. exclusively. The transition to the low marsh is abruptly made through a small cliff that inhibits the development of the tidal flat. Reliability of marsh zonation in this profile may be questioned because the number of living foraminifera found in lower high marsh samples is around 50 specimens. However three different settings can be suggested along the *Pinelas* profile (Table 6):

Low marsh is strongly dominated by *M. fusca* associated with *Psammospheara* sp. and *H. manilaensis*; sampling at 3.02 m above HZ.

Lower high marsh is dominated by *Psammospheara* sp., *M. fusca*, and *H. manilaensis*, followed by *H. wilberti* and *T. comprimata*; sampling at 3.30 m and 3.49 m above HZ.

Upper high marsh is strongly dominated by *H. manilaensis*, associated with *Psammospheara* sp. and *M. fusca*; sampling at 3.83 m above HZ.

Salinity

Salinity measurements performed during low and high tide, indicate clear differences between both estuaries (Table 7). In spite the values obtained close to the NSR_L and PR marsh profiles show that the lower domain of both estuaries is flooded during high tide by polyhaline/euhaline waters (around 30‰), the low tide conditions become very different. Salinity values measured at the Minho low estuary reach a minimum of 0.3‰, introducing a wide range each tidal sequence, while in Lima lower estuary polyhaline waters, exceeding a salinity of 19‰, were observed. It must be stressed that marine tidal water is completely flushed out from Minho estuary during each ebb cycle, leading to a full replacement of marine water by freshwater (Fatela *et al.*, 2003; Moreno *et al.*, 2005). This pattern is reflected in the salinity of tidal marshes interstitial waters (Tables 1 to 6). The Lima marsh consistently shows higher values, with exception of highest high marsh that leans against the terrestrial margin and is more easily washed by overland flow.

**DISCUSSION**

Foraminiferal assemblages distribution along the Lima tidal marsh is mainly dominated by *J. macrescens* and *T. inflata* at the high marsh zone (Tables 1 to 3). *Quinqueloculina* spp. joins this group at the profile NSR_L, closer to the mouth, but is replaced by *M. fusca* in both intermediate and inner profiles of DAR_L and BPR_L. The low marsh assemblage of NSR_L is dominated by *J. macrescens*, followed by calcareous foraminifera *Quinqueloculina* spp. and *Bolivina* spp. DAR_L low marsh assemblage is dominated by *M. fusca*.

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**Table 7.**
Measured waters salinity in Lima and Minho estuaries, close to sampling profiles of tidal marshes, at spring tides.

<table>
<thead>
<tr>
<th></th>
<th>Fall</th>
<th>Spring</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>low water</td>
<td>high water</td>
<td>low water</td>
<td>high water</td>
</tr>
<tr>
<td>Lima</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NSR_L</td>
<td>-</td>
<td>26.1‰</td>
<td>19.4‰</td>
<td>27.4‰</td>
</tr>
<tr>
<td>DAR_L</td>
<td>15.9‰</td>
<td>11.9‰</td>
<td>8.1‰</td>
<td>7.3‰</td>
</tr>
<tr>
<td>BPR_L</td>
<td>1.1‰</td>
<td>21.1‰</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Minho</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PR</td>
<td>1.9‰</td>
<td>30.0‰</td>
<td>0.3‰</td>
<td>28.8‰</td>
</tr>
<tr>
<td>CP</td>
<td>8.6‰</td>
<td>-</td>
<td>4.4‰</td>
<td>20.0‰</td>
</tr>
<tr>
<td>PIC</td>
<td>1.2‰</td>
<td>-</td>
<td>0.1‰</td>
<td>2.8‰</td>
</tr>
</tbody>
</table>
and other common arenaceous foraminifera. At the inner profile of BPR_L the assemblage becomes mainly dominated by *Ammobaculites* spp. and *M. fusca*. The tidal flat assemblages even show a clear difference: NSR_L exhibits a set of co-dominant calcareous species, namely the exotic *C. lobatulus* and *Bolivina* spp., whereas at BPR_L *Ammobaculites* spp., *M. fusca* and *T. inflata* maintain the dominance already found at low marsh. We can consider that this is a common assemblage distribution for marsh foraminifera, including the presence of estuarine species which upper range is often in low marshes (Scott and Medioli, 1980) and became responsible for the higher number of species found in the Lima assemblages. Nevertheless *B. pseudoplicata* and *C. cf. ungerianus* extend a significant presence across the high-marsh zone and *Quinqueloculina* spp. still is a co-dominant taxa. This presence of estuarine species, namely *Quinqueloculina* spp., is seen as a normal record of high marsh zones close to the Lima mouth, where water salinity is not far from marine standards (Murray, 1991; Swallow, 2000). The *Ammobaculites* spp. dominance for the tidal flat and low marsh of the BPR_L profile can be related with the lower salinity values of interstitial water at this inner domain of tidal marsh (Ellison and Murray, 1987).

In the Minho tidal marsh (Table 4 to 6) dominance in the high marsh zone is replaced by *H. manilaensis*, *M. fusca*, *P. limnetis* and *Psammosphera* sp.; the low marsh and tidal flat zones are here dominated by *M. fusca* and *Psammosphera* sp. (Moreno et al., 2005, 2006). They correspond to agglutinated foraminifera, characteristic from marginal marine environments and are related to very low salinity values (Murray, 1991; Sen Gupta, 2002). Calcareous foraminifera, *H. germanica* and *Elphidium cf. incertum* (Williamson), can be present but in low proportions and exhibit very thin tests (Moreno et al., in press). At Pinelas transect, calcareous foraminifera are completely absent.

Foraminifera from the Lima and Minho tidal marshes show an expected distribution that follows the elevation of sampling points across each profile, reflecting the ecological conditions imposed by high tide flooding (Gehrels, 2000). However the bulk composition of tidal marsh foraminiferal assemblages is in turn strongly influenced by estuarine water salinity and consequent sediment interstitial water salinity.

The Lima estuary is located only 20 km south of Minho estuary and both rivers drain the same region of Iberian Peninsula, in similar climate conditions. However the Lima marsh foraminiferal zonation is composed by a normal salinity assemblage while in Minho a low salinity marsh assemblage is present.

The intense siltation of Portuguese estuaries, last 5000 years onwards (Freitas and Andrade, in press), has been opposed by human intervention. The Lima estuary offers a paradigmatic example of such an action, presenting numerous artificial harbor structures and requiring periodic dredging. Marine flood waters finds, in this way, an easy path through the lower domain of this estuary. In contrast the Minho estuary has a much less extensive artificial intervention, a higher average flux and its mouth is constrained by a sand barrier and several granite outcrops. An intense siltation is responsible for the emersion of large expansions of soft bottom during ebb spring tides. Consequently, it provides a small accommodation volume for the tidal prism and the large sand shoal that occupies most of the estuarine mouth constricts the sea water input. All together these characteristics prevent a regular and extensive penetration of salt wedge into the Minho estuary, favoring the dominance of lower salinity tolerant foraminifera (Moreno et al., 2005, 2006).

**CONCLUSIONS**

The composition of tidal marshes foraminiferal assemblages are closely related with the salinity input inside the estuaries, reflecting in the case of Minho River a particular dynamics and the morphology of this estuary basin, which prevents a regular and expansive flooding by salt water during each tide.
Nevertheless the singularity of Minho lower salinity tolerant foraminifera assemblages can be seen like the natural evolution of estuarine ecosystems while the marine signature of Lima assemblages may correspond to a result from the built infrastructures and dredging human impacts upon the lower estuary.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


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