Landscape Change and Vegetation history in the city of Lisbon during Roman Times and the Early Medieval Period

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Abstract:	<p>Pollen and NPP analysis performed on the sedimentary deposits accumulated in the inter-tidal banks of the Tagus Estuary allow for the reconstruction of vegetation history and landscape changes that occurred in Lisbon from the 1st to the 6th century cal AD. The high chronological resolution of this investigation makes it possible to identify changes in human activities that took place during the Roman period and reveals the extent of land use in the 2nd century cal AD. However, the most considerable landscape transformation of this 600-year period dates back to the late 5th century cal AD, when significant deforestation and increasing human activity, particularly pasturing, spread throughout the territory. This feature bears witness to the outcome of a deep socio-economic transformation following the disintegration of the Roman</p>

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	administration and sheds light on a poorly known period in this part of Iberia.

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Introduction

Over the last two decades, Lisbon’s estuarine margin has been subject to intense urban rehabilitation. This activity has led to the carrying out of archaeological projects that have revealed a series of ancient structures, below the current ground level, essentially associated with maritime-related activities. Some examples of these are the Roman anchorage area (Parreira and Macedo, 2013), a 16th-17th century tidal grid (Sarrazola et al., 2013), port structures dating from before the 1755 earthquake (Neves, 2014), 18th century vessels (Bettencourt et al., 2015) and the extensive ship building area of Ribeira das Naus (Figure 1). These structures were covered by several metres of landfills and remains of historical buildings and rested above muddy sediments deposited in a subtidal to tide-dominated, low-energy estuarine environment (Costa et al., 2017, Costa et al., in press). Taking into account these conditions, some of these lower sedimentary deposits were considered as potential or suitable environmental archives. In this paper, we present the results of the palynological analysis of a 7.5-m-long sedimentary core collected at Ribeira das Naus (Figure 1) with the aim of reconstructing the vegetation history which accompanied the development and evolution of the city of Lisbon, comprising the period from Roman times to the Early Medieval Age. This task has been carried out using analysis and interpretation of the fossil pollen and non-pollen palynomorphs (NPP) trapped in the muddy sediment of the subtidal to intertidal estuarine area (Figure 1).

The reconstruction of the evolution of vegetation is an ideal approach for understanding landscape changes in the past. It can provide a useful means for addressing questions such as the type of human impact which occurred, what the diverse rhythms of land use were within a territory and can provide information regarding the origins of a certain type of cultural landscape. One of the best expressions of this approach is achieved when a diachronic perspective is considered. It is when long-time archives are examined that trends become apparent and the complexity of socio-environmental interactions can be disentangled and understood (Redman et al., 2004; Mercuri, 2014).

The study of vegetation history in southwestern and central Portugal has been addressed in the case of several coastal lakes and lagoons located to the south of the Tagus estuary (Mateus, 1985, 1992; Queiroz, 1999a; Mateus and Queiroz, 2000; Queiroz and Mateus, 1994, 2011; Santos and Goñi, 2003) and some archaeobotanical deposits found in archaeological excavations carried out in the district of Lisbon (van Leeuwaarden et al., 1999; Queiroz, 1999b, Bugalhão and Queiroz, 2006). The area located in the inner Tagus estuary has been addressed by van der Schriek et al. (2008) and Vis et al. (2010). Furthermore, S. Gomes (2011a, 2011b) has studied the Nazaré region to the north of Lisbon and the region of Figueira de Foz-Mira, located in central Portugal, has been extensively researched by R. Danielsen (2008, 2010, 2011). These investigations have traced the evolution of vegetation back to the Holocene with diverse degrees of resolution and chronological control. However, a reconstruction of changes in vegetation in the Lisbon area, thereby providing an insight into past socio-environmental interactions, has not yet been an object of research. Particular conditions arise when performing pollen analysis on a long-time sequence within an urban context such as Lisbon. In such scenarios, the remains of the vegetation in the sedimentary records is influenced (Mercuri et al., 2010; Sadori et al., 2010, Ruso Ermoli et al., 2014) by human agency in its most varied forms. As a result, in sites such as this, so influenced by human activity, it is difficult to identify climatic trends as a primary cause of vegetation shift and environmental change. Nevertheless, even if climatic evolution is masked by human activity, it is expected that the palynological remains trapped in the sediment may supply extremely valuable information which can enable us to gain a better understanding of past landscape changes in Lisbon.

Site Description

Geology

The studied area is located on the northern margin of the Tagus estuary at the mouth of Esteiro da Baixa (EB) stream (Figure 1): It lies in a valley resulting from the confluence of two other rivulets, Arroios and Valverde, where the present-day city centre of Lisbon is located. Both the Arroios and Valverde streams are embedded in Miocene sediments consisting essentially of sands, silts, clays and limestones, which are rich in fossils deposited in fluvial-estuarine-marine environments, and, particularly in the case of the Valverde stream, in Neo-Cretaceous basalts and pyroclasts from the Volcanic Complex of Lisbon-Mafra (CVL) (Pais et al., 2006).

The sediment core was collected in an intertidal area claimed from the estuary during the 1950s by the deposition of an anthropic landfill in order to build the Ribeira das Naus Avenue (Figure 1).

Climate

According to the Köppen classification, the city of Lisbon is characterised at present by a hot summer Mediterranean climate (Kottek et al., 2006). According to the Portuguese Institute of the Sea and the Atmosphere (www.ipma.pt), during the period between 1981 and 2010, mean temperatures ranged from 23.5 °C in July to 11.6 °C in January and total precipitation had a value of 774 mm per year.

Botany

Although it is not possible to classify the natural vegetation in this particular sector of the Tagus Estuary due to the long-term human influence on the area, certain assumptions can be made by taking into account geographical and environmental correspondence with other sites located near the coast in central and southwestern Portugal (Queiroz, 1999a). The environmental context which characterises the area currently occupied by Lisbon would have allowed for the development of sclerophyllous forests of *Quercus coccifera*, *Q. faginea*, *Q. suber*, *Arbutus unedo*, *Viburnum tinus* and *Rhamnus alaternus*. Pine woods of *Pinus halepensis*, *P. pinaster* and *P. pinea* would have grown in littoral and sandy environments. The presence of shrub communities composed of *Calluna vulgaris*, *Erica umbellata*, *E. australis*, *Cistus monspeliensis*, *Halimium halimifolium*, several species of *Ulex* and *Lavandula*, among many others, would have been found in the context of forest clearances and degraded soils. *Alnus*, *Salix*, *Rubus* and *Vitis* would have been the main taxa to be found in riparian environments.

Archaeological and Historical Background

Human presence can be traced back to the Palaeolithic period in the Tagus Estuary and in the area corresponding to the present-day municipality of Lisbon (Cardoso, 2011). Evidence of human occupation during the Neolithic and Bronze Age in Lisbon have also been widely reported (Muralha and Costa, 2006; Valera, 2006; Banha da Silva, 2013). Human presence is known to have been continuous since, at least, the 1st millennium BC. Evidence of Iron Age dwelling structures is well known in the Castelo Hill area and in the western EB valley (Sousa, 2014) (Figure 1). Material evidence supporting contact with foreign societies and strong connections with fluvial and maritime activities underline the role of human settlement, with the city being used as an important commercial seaport 2000 years ago (Fabião, 2020). The Roman city of *Felicitas Iulia Olisipo*, the name that later evolved into *Lisboa*, extended downwards from the Castelo Hill to the EB and the Tagus estuary. It was

during this period of urban development that the first evidence of manipulation of the riverfront became more evident and permanent (Costa et al., 2018), with the city expanding until the 4th century AD (Bugalhão, 2017). The occupation of Lisbon is archaeologically attested during Late Antiquity and the Early Middle Ages. Nevertheless, the abandonment of several buildings has also been reported during this period (Mota and Martins, 2018). This feature has usually been associated with the demographic contraction of the city and the socio-economic transformations of the Late Empire.

Materials and Methods

In 2014, a sediment core of ca. 750 cm in length was retrieved at Ribeira das Naus (38,706781, -9,138285, WGS84) at a height of -101.5 cm mean sea level (MSL) using *van der Horst* and *Livingstone* core samplers (Figure 1). The sediment was kept at 4°C until subsampling each 2 cm for the analysis of diverse paleoenvironmental proxies, such as texture, composition (% organic matter and % calcium carbonate), organic chemistry (% organic carbon, % total nitrogen, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) and morphoscopy (Costa et al., submitted). Six samples were ^{14}C dated for the extrapolation of an age model using CLAM 2.2 software (Blaauw, 2010). Sedimentation rates of ca. 0.9 cm yr⁻¹ (between -850 cm and -570 cm MSL; ca. 30 cal AD to 350 cal AD) and 1.9-2 cm yr⁻¹ (-570 cm to -100 cm MSL; ca. 350 cal AD to 590 cal AD) were extrapolated (Costa et al., submitted). The age-depth model indicates that the bottom of the sequence dates back to the 1st century cal AD and the uppermost samples were deposited around the 6th century cal AD (at ca. -101.5 cm MSL). The lack of sediment deposits above this height is likely due to both natural and anthropic factors such as the absence of accommodation space, a decrease in sediment availability and anthropic sediment removal due to the construction and maintenance of the post-medieval Doca da Caldeirinha.

Samples for pollen and NPP analysis were collected each 20-30 cm. A total amount of 30 samples were prepared following standard palynological preparation procedures, including treatment with HCl, sieving at 150 μm , HF, KOH, acetolysis and mounting in Glycerine (Fægri and Iversen, 1989). *Lycopodium* tablets were added to a known weight of sediment in order to estimate pollen concentration values (Stockmarr, 1971). Pollen and NPP were identified at x630 magnification in accordance with published morphological keys (Reille, 1992-1998; Van Geel, 2006; Danielsen and Mendes, 2014). Cerealia was identified according to Andersen (1979). A minimum of 300 terrestrial pollen grains per sample were counted, excluding Cyperaceae, Asteroideae and Cichorioideae. Pollen and NPP percentages were calculated as percentages of this pollen sum (Blackford and Innes, 2006).

Stratigraphic pollen diagrams were prepared with the help of C2 software (Juggins, 2011), plotting pollen and NPP percentages and concentrations against heights (in cm MSL). Constrained Incremental Sum of Squares (Grimm, 1897) was used to establish biozones or pollen zones. A rarefaction curve according to the 300 grains pollen sum was calculated using Past software (Hammer et al., 2001) in order to obtain an index of palynological richness interpreted as an approximate measure of floristic diversity (Birks and Line, 1992).

Pollen results

Three pollen zones have been distinguished in accordance with cluster analysis. When required, sub-zones have been further identified within these pollen zones. Figure 2 features selected pollen and NPP percentages. Figure 3 presents the most significant pollen concentration values.

Zone RN1 (-840 to -607 cm MSL): Two sub-zones have been distinguished within this pollen zone: RN1b (-840 to -737 cm MSL) and RN1a (-736 to -607 cm MSL). These have mainly been defined on the basis of the percentages of *Erica* and Poaceae, which are the two main contributors to the whole pollen assemblage. In RN1b Poaceae and *Erica* show values of between 20-30% each, although *Erica* pollen decreases sharply below 13% in the upper samples of this sub-zone and never reaches values higher than 20% in RN1a. Both Asteroideae and Cichorioideae present 10% representation throughout RN1b, but an increase to 15% is reported in RN1a. Human-related taxa such as *Rumex*, *Centaurea jaceae* type and *Centaurea cyanus* type, Cerealia, *Papaver rhoeas* type and *Plantago lanceolata* type (above 5%) are continuously present, yet *Rumex* and *Centaurea* become more recurrent in subzone RN1a. *Vitis* pollen, already witnessed in RN1b, increases in RN1a. Other herbs and heliophilous taxa such as Lamiaceae, Rosaceae and Fabaceae (which may include shrub species), Apiaceae, *Spergula*, Chenopodiaceae, *Corrigiola* and *Ranunculus* are also observed. Brassicaceae pollen, which attains values of around 5%, is always present in the RN1 pollen zone. Evergreen *Quercus* pollen dominates among tree taxa, with values usually below 10%. Deciduous *Quercus* occurs with values lower than 4% and *Quercus suber* is slightly present in RN1b, increasing in sub-zone RN1a. *Pinus* pollen is recorded at below 5% representation. Riparian taxa such as *Alnus*, *Salix* and *Fraxinus* can also be observed. However, *Alnus* pollen presents a decaying trend coeval with that of *Erica*. Pollen of *Castanea* (2%) and *Olea* (5%) are also recorded, as are shrub taxa such as *Cistus ladanifer* type and *Genista-Cytisus* type. Various coprophilous fungal spores, particularly *Sporormiella*, occur in all samples. Other fungal, fern and algae spores are also present.

Zone RN2 (-600 to -570 cm MSL): This pollen zone is formed by two samples that are characterised by a marked variability of *Erica* and Poaceae percentages. A sharp drop in Poaceae is recorded at -600 cm MSL, where it reaches a representation of 12%, while *Erica* increases up to 31%. This percentage shift is provoked by the disruption of Poaceae pollen visible at concentration values. In the upper sample, located at -570 cm MSL, Poaceae increases markedly and records 40% representation, a feature that is coincident with a sharp decline in *Erica* pollen. Other than that, no significant changes are noticed in the rest of the pollen taxa, with the exception of an increase in *Olea*, which reaches 9%. Both Cichorioideae and Asteroideae decrease in these two samples and higher values of *Echium* are witnessed. Anthropogenic and cultivated species are still recorded, as are coprophilous fungal spores.

Zone RN3 (-540 to -110 cm MSL): Three sub-zones have been identified within this pollen zone: RN3a (-540 to -398 cm MSL), RN3b (-368 to -272 cm MSL) and RN3c (-236 to -110 cm MSL). Percentages of the main pollen taxa do not show significant variability in sub-zone RN3a, except for a slightly higher presence of *Olea*. A marked decrease in Brassicaceae (from 5% to 1%) is also visible between -470 and -398 cm MSL. Continuous values of Poaceae (25%) are reported up to -334 cm MSL, within the RN3b sub-zone, where values rise by up to 40%. This feature is coincident with a slightly higher occurrence of human-related taxa such as *Vitis* (2%), *Rumex*, *Centaurea jacea* type and other heliophilous herbs such as Scrophulariaceae, *Spergula* and Fabaceae, although the latter could also include some shrub species. At the same time, a marked decrease in *Erica* pollen, which reaches 4% in this sub-zone, and *Cistus ladaniferus* type is reported. A decrease in tree pollen is also visible in sub-zone RN3b with reference to *Quercus* and *Pinus* percentages. In parallel with this trend, a peak of coprophilous fungal spores, mainly of *Sporormiella* but also *Chaetomium*, is noticed. In the upper sub-zone RN3c an increase in pollen of *Cistus ladanifer* type (now around 4%), *Juniperus* and *Genista-Cytisus* type is reported. A slightly lower occurrence of ruderal taxa is now seen, although Cerealia and *Vitis* pollen are still recorded with values similar to those of pollen zone RN2 and RN1. *Plantago lanceolata* pollen type presents a peak (11%) at -144 cm MSL, while *Sporormiella* spores show higher values. A more continuous and higher abundance of *Isoetes* is noticed in the upper samples.

Discussion

The age model dates the lowermost sample of the pollen sequence (-740 cm MSL) to between 19 cal BC and 89 cal AD and indicates that the uppermost sample (-120 cm MSL) was formed between 546 and 625 cal AD. Considering that there is no report of a hiatus or any other disruption in the sedimentation process (Costa et al., submitted), we can conclude that the pollen analysis of the Ribeira das Naus sequence provides continuous evidence of vegetation change over a period of approximately six centuries. The analysis of the 29 samples provides pollen data for roughly each 19 years, which constitutes a very high chronological resolution for the analysis of vegetation history during this chronological period.

According to the local paleogeographic data available for the site (Costa et al., in press), the present-day area of Ribeira das Naus in Lisbon, and thus the coring site, was located within the waterbed of the Tagus estuary 2000 years ago. The coring site was then situated west of the mouth of the Valverde and Arroios streams, geographical features that divided two landforms east and west (see figure 1) where Lisbon's Baixa quarter is now located. Consequently, the bottom samples of the sedimentary sequence were formed in a subtidal environment located at a distance of approximately 200 m from the position of the Tagus estuary shoreline at that time and below a 6-m-deep water-column (Costa et al., submitted). The presence of such fluvial conditions in this context may imply a hindrance regarding the degree of representation of the local vegetation, taking into account that the Tagus river could be a source for extra-regional pollen supply. Despite the inability to completely rule out the occurrence of some pollen of extra-regional provenance into this record, its relevance in the assemblage is considered to be of minor importance due to the fact that: i) the coring site was formerly located at the mouth of a small tributary stream, a feature that blocked the major influence of water discharge from the Tagus; ii) the mineralogical composition of the sediments recovered in the fluvio-estuarine beaches below the Iron Age and Roman Period occupation sites (NARC, Roman Cryptoporticus and Banco de Portugal; Figure 1) on the margins of the EB stream indicates a strong influence of the local fluvial system on the input of sediments to the area (Costa et al., 2018); and iii) the composition of the coarse fraction at Ribeira das Naus (Costa et al., submitted) shows the input of diverse anthropic materials, which most probably derive from the increase in human activity which took place in the Roman city of *Felicitas Julia Olisipo*. In accordance with this evidence, sedimentary input into the estuary mainly resulted from the erosive dynamics of continental deposits due to both natural and anthropogenic forcing, which triggered shoreline aggradation. This suggests that pollen input other than that transported by the wind was foremost controlled by continental erosive supply, which reinforces the theory of the local character of the pollen record at this stage. The lack of a significant amount of eroded pollen reported in the samples indicates a low input of older re-worked pollen and ultimately reinforces the correspondence between the pollen assemblage and contemporary vegetation.

The low occurrence of tree pollen at the bottom of the sequence indicates that forests were not particularly relevant in the vegetation of Lisbon during the 1st century cal AD. Rather, the high abundance of pollen from shrubs and herbaceous vegetation indicates that a semi-open landscape characterised the area during this period. Pollen of evergreen *Quercus* indicates patches of the evergreen *Quercus coccifera* and *Quercus rotundifolia* species co-existing with shrub communities of *Olea europaea*, *Erica scoparia*, *Calluna*, *Phillyrea* and Cistaceae. These taxa formed a sclerophyllous vegetation community that has already been documented in the central and southern Atlantic coast of Portugal during the recent Holocene (Mateus, 1992; Queiroz, 1999). The evergreen *Quercus* taxonomical category, as featured in the pollen diagram, comprises both species of this genus, but it may also include species of *Quercus faginea*, a deciduous/marcescent tree that is hardly distinguishable from the evergreen oak species on the basis of pollen morphology. Therefore, the assessment of the spread of *Q. faginea* woodland in the area remains inaccessible. Nevertheless, the high development of

sclerophyllous vegetation leads us to consider that the relevance of *Q. faginea* would not have been particularly high. The presence of deciduous *Quercus* pollen in the record, on the contrary, more likely indicates the spread of deciduous trees. Even though *Quercus robur* would not have found particularly optimal conditions for growth in this area, based on its mesic requirements, it is feasible that the pollen record bears witness to some species of deciduous oak species spreading at a regional level. Pollen of deciduous *Quercus* could also reflect communities of *Quercus pyrenaica* spreading through moister areas at higher elevations. Nevertheless, considering that potential hybridization between diverse species of oaks is a common feature (Amaral Franco, 1990; Sánchez de Dios et al., 2006) with similar effects on pollen morphology, it is possible that under deciduous *Quercus* taxonomy, hybrids of *Q. faginea*, *Q. pyrenaica* and *Q. robur* species were also present. As indicated by the occurrence of *Quercus suber* pollen, the presence of this tree is attested at that time and, according to its xeric-adapted ecology, it is likely to have spread in the same areas where sclerophyllous communities grew.

Considering that pollen productivity and the dispersal of *Pinus* is very high (Broström, et al., 2008), the low palynological representation of this taxon at Ribeira das Naus suggests that pine woods were scarce in the region. Since further determination of *Pinus* species was not palynologically possible, resolving the relevance of coastal or other pinewood species, such as those adapted to higher altitudinal environments, remains unattainable. Mesophilous species of *Alnus*, *Fraxinus* and *Salix* show the spread of these communities along the river shoreline in the lower lands. Despite the fact that the diffusion of this riverine vegetation was not great, it is noteworthy that alder species were particularly present during the 1st century cal AD.

The area of Lisbon was characterised by the development of grasslands, as is indicated by high percentages of Poaceae. The relevance of open areas in the landscape is also attested by the occurrence of heliophilous vegetation such as Apiaceae, *Echium*, *Medicago*, Caryophyllaceae and *Corrigiola*. Herbaceous communities distinctive of soils influenced by human activity, such as Asteroideae, Cichorioideae, *Plantago* and *Rumex*, were also widespread at the time. Furthermore, there is evidence of taxa growing in cultivated sites reported by pollen of *Papaver rhoeas* and *Centaurea jacea* type, which probably indicates the presence of species of *Centaurea calcitrapa* (Queiroz, 1999). This assemblage of ruderal pollen taxa is the palynological evidence of a high degree of land management taking place in Lisbon during the 1st century cal AD. The permanent record of Cerealia pollen corroborates the presence of cereals in the city and may suggest the existence of cultivated areas. *Vitis* pollen, although we cannot rule out that its occurrence in the record results from the presence of wild species, likely reflects the cultivation of vines that were possibly dedicated to wine production in a highly human-managed environment. The pollen assemblage of Ribeira das Naus essentially reflects the landscape of the Roman town of *Felicitas Julia Olisipo* in the 1st century cal AD. The palynological data indicates that, at that time, the process of urban development and city spread in the area between Castelo Hill through the area now known as the Alfama quarter and the EB near the Tagus estuary (Figure 1) took place under highly anthropic activity that had a great impact on the landscape. Multiple archaeological projects have documented the increasing process of urbanization that was ongoing at that time (Fabião, 2020; Ribeiro et al., 2017; Mota and Martins, 2018; Bugalhão, 2001, 2017), including the construction of public buildings, funerary monuments and the proliferation of industrial facilities linked to products deriving from the fishing industry. The landscape configuration inferred from the palynological record of Ribeira das Naus corresponds positively with the local activity of the area.

Around 125 cal AD a shift in pollen percentages and concentration values indicates that herb vegetation replaced *Erica* shrub communities. Vegetation changes also affected alder forest, which now retreated as did, to a lesser extent, oak woods. The spread of grasslands (Poaceae) and other heliophilous vegetation (Asteroideae, Cichorioideae, Caryophyllaceae,

Scrophulariaceae) supplies evidence of landscape opening in the area of the Roman town of *Olisipo*. Even if no other signs of more abundant farming are present at this stage, the landscape shift is coeval with the increase in pollen of vegetation growing in nitrophilous and ruderal environments, such as *Polygonum aviculare*, *Centaurea cyanus*, *Plantago lanceolata* and *Papaver rhoeas*. This is an indication of increased land management and, ultimately, suggests that the vegetation change took place as a result of human activity. It can be presumed that the pollen record of Ribeira das Naus reflects the spread of human occupation and land use throughout the area presently corresponding to the EB (Figure 1) and the increasing land use along the margin of the Tagus estuary towards the west. In this context, the retreat of the riparian alder, which is also reported at this time at other sites in the Tagus estuary (Vis et al., 2010), suggests that the areas closer to the estuarine margin were affected by human activity. The urban spread of *Olisipo* is well documented by archaeology (Banha da Silva and Valongo, 2017; Henriques and Valongo, 2017; Costa and Carvalho, 2017), which indicates that the occupation of this western part of the city experienced increasing density during the 2nd century AD. Evidence of coprophilous fungal spores suggests a higher relevance of husbandry activities, a feature that is consistent with increasing occupation in this area.

The increase of *Vitis* pollen during the 3rd century cal AD indicates the spread of this plant in the area. Wild *Vitis* species (*Vitis vinifera* subsp. *sylvestris*) can grow as part of the riparian vegetation in Mediterranean environments (Rivas-Martínez et al., 2002; Mercuri et al., 2016). However, wild *Vitis* pollen is indistinguishable from that of the domesticated species of vines (*Vitis vinifera* subsp. *vinifera*). Therefore, the spread of the anthropogenic-related *Rumex* and *Plantago lanceolata* and the process of landscape opening attested during the 2nd and 3rd centuries cal AD lead us to consider the possibility that the occurrence of *Vitis* was human-induced and that vineyards became widespread in *Olisipo* at that time. Wine had already been produced and consumed in Roman Lusitania, both locally and regionally. However, between the 2nd and 3rd centuries AD a specific type of amphora known as Lusitana 3 (Fabião, 1998) was manufactured for wine exportation in Lisbon. The pollen record of Ribeira das Naus demonstrates the spread of vine agriculture at that time and also proves the process of landscape shaping within the logic of wine consumption in the Roman world.

The pollen record shows significant changes in the main vegetation taxa (*Erica* and Poaceae) around the 4th century cal AD. These changes occur abruptly, in a period of no less than 50 years according to the age-depth model. The most noticeable change is in the case of Poaceae, which almost ceases to provide pollen into the record. This feature has an impact on the remaining percentages of pollen taxa, particularly in the case of *Erica*, which appears to have replaced herbs in a rapid succession of vegetation. Nevertheless, pollen concentration data shows that there is no increase in *Erica* pollen after the Poaceae decay and, therefore, no shrub spread occurred at that time in the area. A similar mathematical effect on pollen percentages is observed in the contiguous upper sample, yet conversely, Poaceae supplies a major amount of pollen to the record and, as a result, it appears to be suggested that a spread of herbs took place at the expense of shrubs. Although in this case *Erica* retreated slightly, we consider that the succession of the vegetation communities was much more modest than that suggested by pollen percentages alone. The causes for these changes in the palynological percentages remain unclear and difficult to interpret, as we discard the idea that they reflect variations in the composition of the vegetation of the area. On the contrary, they most probably express the emergence of local processes resulting from the modification of the sedimentary pattern. According to Costa et al. (submitted), the sequence provides sedimentological variability interpreted as evidence of high energy sedimentary deposits related with storms and higher river discharges or maritime turmoil. The archaeological record reveals the abandonment of the fishing industry on the coast of *Olisipo* around that time (Fabião, 2009). However, no clear signs of deposits of high energy events have, so far, been documented in the area close to the river shoreline near the drilling site.

During the 4th century cal AD evidence of vegetation growing in human-perturbed sites and plants of heliophilous ecology, such as Brassicaceae, suggest that land use was frequent and continuous in the area. Vine cultivation was still present and increasing evidence of cereal pollen in the late 4th century cal AD reflects significant relevance of crop cultivation at that time. Moreover, the record of coprophilous fungal spores is abundant and provides evidence of the presence of animals and possible husbandry, a feature that underlines the deep anthropogenic activity that characterised the city during the late years of the Roman Empire.

Despite the relevance of human activity, no significant changes in the configuration of the vegetation assemblage have been observed during the 4th century cal AD, except for the advance of *Olea*. The increase in *Olea* pollen reveals the spread of olive trees in the area at that time. The occurrence of this feature within a context of such human pressure suggests that it was most probably human-induced. Nevertheless, unlike the case of wine, at the present time there is no proof of oil recipients being manufactured locally. This lack of archaeological material suggests that oil production in Lisbon during the 4th century cal AD was probably destined for local consumption rather than exportation.

The 4th century cal AD corresponds to a period characterised by political instability linked to the diverse waves of Germanic people arriving into this part of the Iberian Peninsula (Coelho, 1994). Several changes are reported during this time in the urban network of Lisbon, including the construction of a wall (Carvalhinhos et al., 2017) and the modification of the road network (Bugalhão, 2017). In addition, abandonment of the public buildings and manufacturing facilities relating to the fishing industry on the river margin has been archaeologically documented (Bugalhão, 2001) and further archaeological evidence supports the idea of a lower degree of occupation in the western sector of the city (Grilo et al., 2013). The effects of economic recession do not seem to have greatly affected the vegetation, according to the pollen record.

From approximately 400 cal AD a recovery of oak forest is indicated by an increase in *Quercus* pollen. The development of woody vegetation was also followed by the development of *Erica* shrub. Coeval to this shift, vegetation growing in human-perturbed environments, such as Cichorioideae or *Rumex*, retreated. It is worthy of mention that Brassicaceae herbs, a heliophilous community that had, until that time, been abundant in the area, also receded during this period. This dataset is interpreted as evidence of the recovery of woody vegetation at the expense of what were previously open fields. However, pollen remains of cereal and other apophytic vegetation are still recorded in the early 5th century AD, which can be interpreted as palynological evidence of human activity in the city. Despite the continuity of land use, the advance of woody vegetation expresses a partial recovery of the forest that may have resulted from a reduction of human pressure, which most likely took place outside of the urban area. This feature suggests that there is some degree of synchronicity of landscape evolution with the new economic and political conditions that accompanied the progressive dismantling of the Roman administration in the area.

During the second half of the 5th century cal AD, forest and shrub species such as *Pinus*, *Quercus*, *Cistus ladanifer* and *Erica* retreated. This circumstance allowed for a significant expansion of grasslands, marking the onset of a new phase characterised by open landscape in the area. Herbaceous flora was particularly widespread during this phase, as is indicated by the occurrence of heliophilous taxa such as Brassicaceae, *Spergula*, *Corrigiola*, *Scrophulariaceae* and *Sanguisorba*, among others. Rosaceae, which may also include shrub species, was more abundant at that time. During this phase, a great diversity of flora could be found in the area, as suggested by the high rarefaction values now reported. Evidence of human-related vegetation synchronous with vegetation change is found at this time, as is indicated by the occurrence of cereal pollen and increasing percentages of *Vitis*, which suggests that landscape opening resulted once again from the expansion of land use in the area. However, the most noticeable feature from this period is the spread of coprophilous

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3 fungal spores such as *Sporormiella*, *Chaetomium*, *Sordaria*, *Podospora* and *Delitschia*. This
4 body of evidence indicates that the role of husbandry had become quite relevant in the area
5 towards the late 5th century cal AD. The possibility that landscape change could have been
6 influenced by an increase in animal-oriented farming, without ruling out vineyard
7 exploitation, may, therefore, be considered.
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9 Archaeological evidence suggests that a process of urban contraction was taking place in
10 Lisbon during the 5th century cal AD (Grilo et al., 2013; Bugalhão, 2017). Regardless of the
11 uninterrupted occupation inside the city walls, the continuous use of the harbour (Parreira and
12 Macedo, 2013) and the on-going utilization of the road system (Bugalhão, 2017), a process of
13 demographic decay was occurring at this time. This context of urban decline is in line with
14 the information provided by the sedimentological proxies studied in the Ribeira das Naus
15 sequence (Costa et al., submitted). During the 5th century cal AD, there is no evidence of an
16 increase in the sedimentation rate indicating higher erosion dynamics. This feature
17 corroborates that the urban area of *Olisipo* was not experiencing a period of particularly high
18 soil perturbation resulting from climatic conditions or human management.
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20 Bearing in mind the particularities of this local setting, it is pertinent to rethink the extent to
21 which the changes observed in the pollen diagram during the late 5th century AD reflect a
22 local trend. Considering that the occurrence of a lower erosive dynamic at this time is
23 interpreted in accordance with reduced human activity, it can be considered that the human
24 impact observed in the palynological record may not have occurred locally, but rather on a
25 regional level. The fact that no great increase in cereal pollen is now witnessed is consistent
26 with lesser land use taking place in the urban area. This feature alone does not exclude the
27 fact that some human management was taking place locally, as the city had not been
28 abandoned. However, such sharp vegetation change cannot easily be explained as a local
29 phenomenon under a regressive dynamic of the city. On the contrary, we consider this forest
30 clearance as part of a new form of relationship taking place between human groups and the
31 environment within the rural area, in line with the socio-economic changes occurring during
32 the 5th century cal AD. Creating a framework for understanding the vegetation change that
33 took place from 450 cal AD is not without its difficulties, as the archaeological record of this
34 century is scarce. However, it must be taken into account that this period was characterized
35 by major transformations produced by the ending of the political, social and economic
36 structures of the Roman Empire (Wickham, 2009). What the landscape change may reflect at
37 this stage is the particular shape that the rural surroundings of *Olisipo* took at the time when
38 the Roman world was coming to an end. The influence of husbandry, substantial vegetation
39 clearance with particular emphasis on heathlands and the spread of ruderal taxa, denotes that
40 a new strategy of land-management was being implemented. This was probably achievable
41 under a new context of the redefinition of socio-economic relationships. In this sense, the
42 spread of a different kind of farm unit in rural areas and a process of population dispersal are
43 factors that could have played a significant role in the shaping of this late 5th century cal AD
44 landscape. The ultimate reasons behind this marked landscape change may not be completely
45 disentangled in this paper, but the data supplied provides a valuable source of information for
46 further discussion on this topic.
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49 The open landscape and the land use that made it possible did not extend into the following
50 century, when the pollen diagram indicates that *Erica* and *Cistus* shrubs recovered and
51 colonised spaces that were previously occupied by grasslands. Human impact slightly
52 declined, as indicated by a lesser abundance of ruderal taxa such as *Plantago lanceolata*,
53 *Centaurea* and *Rumex*. Despite this fact, human activity was still present in the area, as
54 suggested by the constant presence of cereal and *Vitis* pollen, which may indicate crops and
55 vineyard agriculture. The recovery of forests may have been a consequence of less human
56 pressure on the environment resulting from the abandonment of the land use model that had
57 enabled the establishment of an open landscape between ca. 450 and 500 cal AD. As is the
58 case with the situation reported in the 5th century AD, archaeological research can hardly
59 identify this chronological period in the stratigraphic record and, subsequently, information
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regarding land use and the economic system is not plentiful. This circumstance prevents us from inferring the ultimate causes that triggered these changes. Nevertheless, human activity seems to have been in retreat, possibly as a result of the population decay identified during the 5th and 6th centuries cal AD (Grilo et al., 2013; Bugalhão, 2017).

It is worthy of mention that the pollen diagram shows *Juniperus* communities spreading at the end of the 5th and the early 6th century cal AD. This is coeval with a slightly higher recovery of pine woods, which may suggest drier conditions occurring at that time. This could be a slight indication of the climatic shift identified in other sites of Atlantic Iberia (Santos and Goñi, 2003; Desprat et al., 2003) and in the Northern Hemisphere (Bond et al, 1997), where a cold and dry period is often described.

Conclusions

The analysis of pollen data recorded at Ribeira das Naus provides detailed information regarding the vegetation changes that occurred in the area of Lisbon from the 1st century AD to the 6th century AD. In the 1st century cal AD, Lisbon was already characterised by a highly anthropogenic environment, with strong evidence of cultivation and husbandry. Forest cover was sparse, and grasslands and heath shrubs already dominated the vegetation at that time. The pollen signal enables us to follow the urban development of the city towards the west, which is particularly visible from 125 cal AD, and bears witness to the subsequent human activity associated with the expansion of the city. One of the most remarkable examples of this feature is the identification of the spread of vineyards from 200 cal AD onwards, which significantly reinforces the archaeological evidence of local viticulture in Lisbon in that period. The landscape of Lisbon was still open during the 4th century cal AD with evidence of olive trees spreading in the area and some minor evidence of land use retreat. This scenario changed abruptly between circa 450 and 500 cal AD, when a new phase of human activity is recorded. The discrepancy between minor local erosive dynamics and major vegetation changes encountered at this time impels us to consider that human activity took place at a regional level and not in the city. This activity involved heathland clearances and a marked development of husbandry, which must be understood in the context of major changes resulting from the end of the Roman period. The pollen analysis of the sequence retrieved at Ribeira das Naus provides a new perspective on the period 450-500 cal AD in this part of Iberia and supplies significant evidence of the economic context and changing relationship of production in the Early Medieval Period.

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