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Palaeoenvironmental Framing of the *O Areal* Roman Saltworks and Related Anthropogenic Activities in North-western Iberia

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ABSTRACT
The NW Iberian city of Vigo contains buried structures of a Roman *salinae* that follow the ancient coastline. To investigate its environmental legacy, we studied two pedo-sedimentary profiles at the *O Areal* saltworks to reconstruct human activities during and after the *salinae* use, as well as framing them within the last two millennia of climate variability. The bottom layer consists of organic-rich sands, with marine palynomorphs, confined within the saltworks' structures that operated during the Early Roman Empire, when the demand in fish-salted products increased and the salting industry fluorished on the Atlantic coast of Iberia. During the Late Roman Empire, salt production at the *O Areal* may have ended, coeval with the development of a marsh with hydro-hygrophyte vegetation and the salting industry demise. The Roman environment also experienced intense agropastoralism that triggered water eutrophication. After Roman times, a dune phase sealed the archaeologicl structures. The overall trend points to a shift from a marine to a terrestrial setting coeval to known periods of climate variability. Therefore, humans and climate impacted the coast during the last two millennia, including the very intense Roman-period saltworks, agriculture and livestock. Roman times climate would have also influenced the saltworks' establishment and abandonment.

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Introduction

The preservation of food has been a problem for all past societies. In this sense, the importance of salt to humans is of interest to understanding our relationship with food preservation. This includes all stages of salt production including extraction, storage, transport, and trading of salt (e.g. Harding, 2013). All of these started during the Neolithic (Clark, 1952; Nenquin, 1961), when the introduction of agriculture and animal husbandry triggered permanent settlements and a dietary change from a protein-rich to a carbohydrate-rich diet that needed a salt supplement, and when the sedentary way of life of animals also needed extra portions of salt introduced in animal diets (Adshead, 1992; Harding, 2013). Therefore, the emergence of multiple applications of salt beyond direct consumption – meat and fish preservation, medicinal, leather tanning, flux in metallurgy, etc. –, made salt a highly prized commodity for past societies.

Iberian salt exploitation dates to the Neolithic (Weller, 2002). Despite the importance of salt, and documentary evidence of salt production, supply, and trade since Antiquity (Carusi, 2008 and references therein), actual well-preserved archaeological remains of salt production are quite scarce (Castro Carrera et al., 2019 and references therein). There are several ways to obtain salt, however, the main method was through solar evaporation marine water saltworks located on coastal areas according to Graeco-Roman written sources (Carusi, 2008 and references therein; Currás, 2017 and references therein). These coastal saltworks seem to have been operating for millennia on the Iberian Peninsula owing to Iberia's large coastline (Puche Riart, 2019).

The importance of salt increased in parallel to the rise in fishing, their derivatives, and the associated trading networks, becoming a staple product ('the white gold') during Roman times (Chevallier, 1991).

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Some examples of Roman salting factories are those of *Gades* (Cádiz) and Huelva (Alonso Villalobos, Gracia Prieto, and Ménanteau, 2003; Campos Carrasco, Pérez Macías, and Vidal Teruel, 1999; Lagóstena Barrios, 2001). Both were based in the Mediterranean Region of Iberia, where nowadays suitable climate conditions for salt production by evaporation exist, i.e. high summer temperatures with low rainfall. However, fish salting factories flourished during Roman times in the Atlantic coastal zone of Iberia as well, both in Spain (Galicia and Asturias) and Portugal (Fernández Fernández, Valle Abad, and Rodríguez Nóvoa, 2022; Suárez Piñeiro, 2003).

Unfortunately, well-preserved archaeological remains of Roman saltworks are scarce (Lowe, 2018), as mostly perishable materials (i.e. wood) were used for the construction of ponds, channels, and sluice systems, so they are considered as an example of ephemeral archaeology (Castro Carrera et al., 2019). A paradigmatic exception of this, as it presents unprecedented well-preserved structures – including perishable materials – is that of the *O Areal* Roman saltworks (Castro Carrera et al., 2019; Currás, 2017; Lowe, 2018; Martín-Seijo, 2019; Martín-Seijo and Teira-Brión, 2010) found on the Atlantic coast of Iberia (Figures 1 and 2). This unprecedented finding, together with the importance of salting factories in the area, reveals that this coastal area of Iberia also had a notable importance of solar evaporation saltworks and salting industries during Roman times (Currás, 2017; Fernández Fernández et al., 2021; Fernández Ochoa and Martínez Maganto, 1994; Martins, 2019) and provides an example of the relationship of Romans with the marine ecosystem (Lowe, 2018).

Fish salting was related to salt production and fishing in the Atlantic coastal zone of Iberia, where at least 11 *salinae* are described between the Duero River and Pontevedra (Martins, 2019). The presence of an important commercial harbour together with the many fishing and salting industries on the NW Iberian coast points to the importance of this area to Imperial trade routes (Fernández Fernández et al., 2022). Salting industries flourished during the 2nd and 3rd centuries until they slowly declined, with some halting production by the 3rd century AD while a few others continued up to the 4th or beginning of the 5th centuries AD (Fernández Fernández et al., 2022; Pérez Losada, Fernández Fernández, and Vieito Covela, 2007). Solar evaporation saltworks were discontinued during the second half of the 3rd century AD (Castro Carrera et al., 2019).

The exploitation of the marine *salinae* needed the construction of ponds, channels, etc., to allow the influx of water from the sea for to evaporate and crystallise. To do so, sea-salt evaporation ponds were distributed along the ancient coastline (Castro Carrera et al., 2019). Solar evaporation saltworks need specific environmental conditions for the proper water evaporation and salt crystallisation. A climate with large insolation days and low precipitation is optimal, a characteristic of the Mediterranean. The present climate of NW Iberia is Atlantic, and current environmental conditions are not the best suited for the exploitation of marine *salinae*. However, climate conditions in NW Iberia during Roman times were different in terms of temperature and precipitation (Martínez Cortizas et al., 1999; Mighall et al., 2006), and the Roman Warm Period (RWP) is considered to have been importance for the salting process in the area. The warmer climate of the Roman period plus the prevailing drier conditions of the Early Empire (Martínez Cortizas et al., 1999; Mighall et al., 2006), would have enabled the solar evaporation ponds to be effective on the Atlantic coast of Iberia (Tallón-Armada et al., 2018). Consequently, the palaeoenvironmental framing of Roman saltworks in Atlantic Iberia could offer insights into the development of this activity that is linked to solar evaporation. In this sense, human activities could be contextualised within the climate variability of the Late Holocene.

The aim of this study is to reconstruct the anthropogenic activities and environmental changes during and after Roman times and frame them within the known climate variability of the last two millennia in NW Iberia. To do so, we have performed a multi-proxy study on two pedo-sedimentary profiles sampled at the archaeological site P3-6 located at the *Rosalía de Castro* street within the paradigmatic *O Areal* saltworks complex.

Materials and Methods

Environmental and Archaeological Settings

The Ría de Vigo is the Galician southernmost embayment (*ría*: marine inundated river valley, i.e. Galician fjords) on the Atlantic coastline of NW Iberia (Figure 1). The area belongs to the Eurosiberian Region, with an Atlantic temperate and humid climate. The natural vegetation in the surroundings consists of deciduous trees – *Quercus robur* L., *Betula alba* L., and *Corylus avellana* L. This vegetation is extremely impacted by human activities, as the Vigo area is densely populated. Thus, the deciduous forest has been replaced with agricultural fields as well as *Pinus* spp. and *Eucalyptus* afforestation. Shrubs are abundant and dominated by *Erica* spp., *Calluna vulgaris* (L.) Hull, *Ulex europaeus* L. and *Cytisus* spp. The riparian tree belt is composed of *Alnus lusitanica* Vít, Douda & Mandák (previously believed to be *Alnus glutinosa* (L.) Gaertn, Vít, Douda, Krak, Havrdová, & Mandák, 2017), *Fraxinus excelsior* L., *F. angustifolia* Vahl., *Corylus avellana* L. and *Salix* spp.

Located in the city of Vigo (Pontevedra province, Galicia, Spain; Figure 1), the main urban area in the *ría*, the *O Areal salinae* complex was discovered in

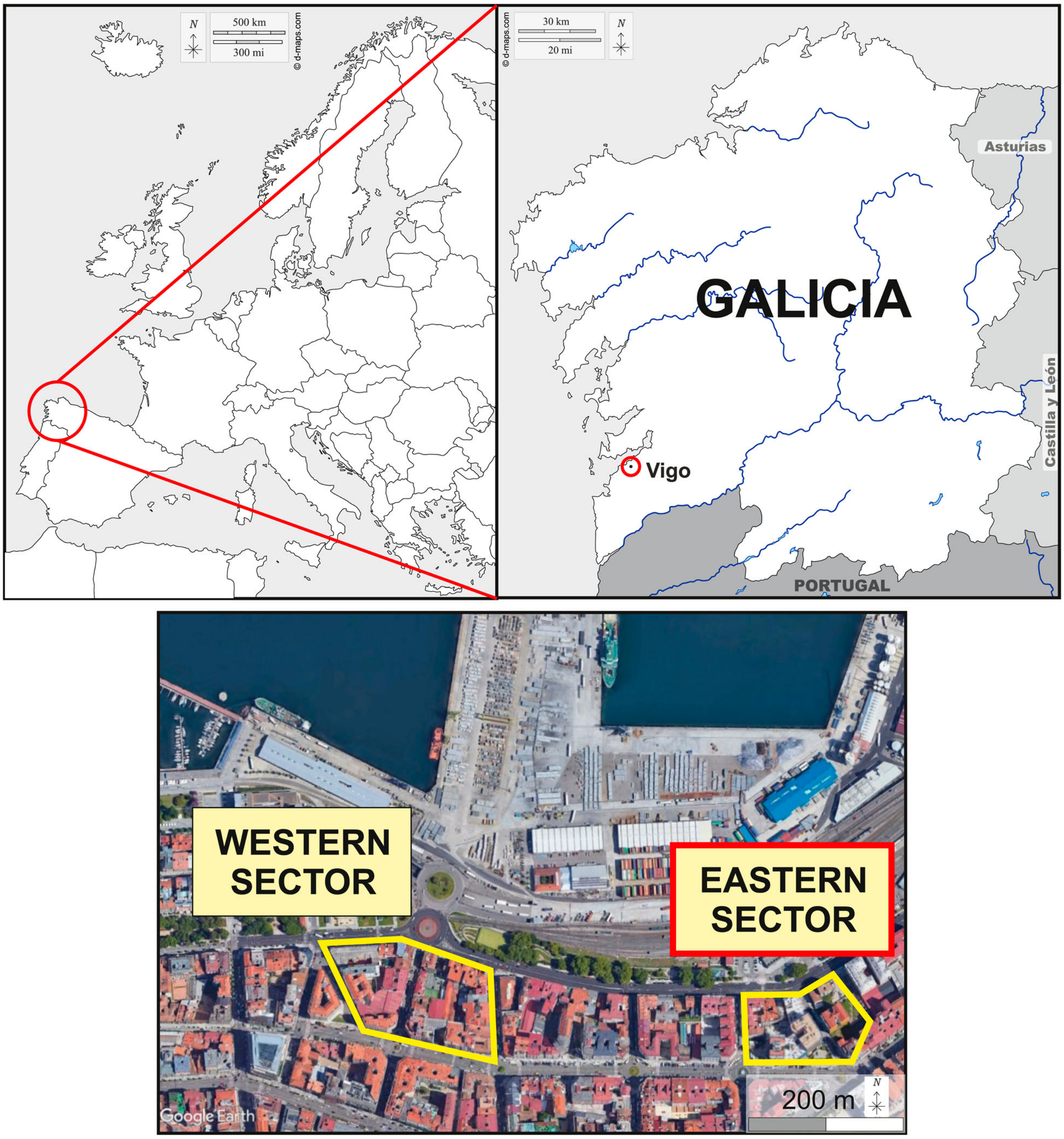

Figure 1. Location of the city of Vigo (Galicia) in Southwestern Europe (upper panel), and location of the western and easter sectors of the excavated saltworks – *O Areal salinae* – in the city of Vigo. The P3-6 archaeological site is in the eastern sector of the *salinae* complex.

the 1990s. Archaeological investigations revealed the existence of saltworks that extended over 1 km. More recently, urban archaeological work has revealed the importance of the saltwork complex with numerous, well-preserved archaeological remains including the presence of evaporation ponds and channels of a Roman *salinae* (Iglesias Darriba, 2009, 2010). Within the *salinae* complex, in the eastern sector, between the *Rosalía de Castro* and *O Areal* streets, the archaeological site P3-6 is located (Figures 1 and 2). It was discovered owing to construction works and excavated in 2007. The P3-6 site is a former solar evaporation saltworks (Figure 2) that were most likely linked to the local fishing and salting industries as well as the port facilities (Castro Carrera, 2007, 2008; Castro Carrera et al., 2019; Currás, 2017).

Nowadays, the archaeological site is separated from the coastline due to infilling from the end of the 19th century AD coeval to the urban expansion of the city and the construction of a commercial port (Castro Carrera, 2007), which resulted in the loss of fluvio-marine areas. The last few decades have led to further industrialisation and an increased as a result of port activities and the automobile industry that has led to land-use change and eutrophication. The archaeological remains from the first excavated saltworks were transformed into a museum *Centro Arqueolóxico SALINAE* that opened in 2010.

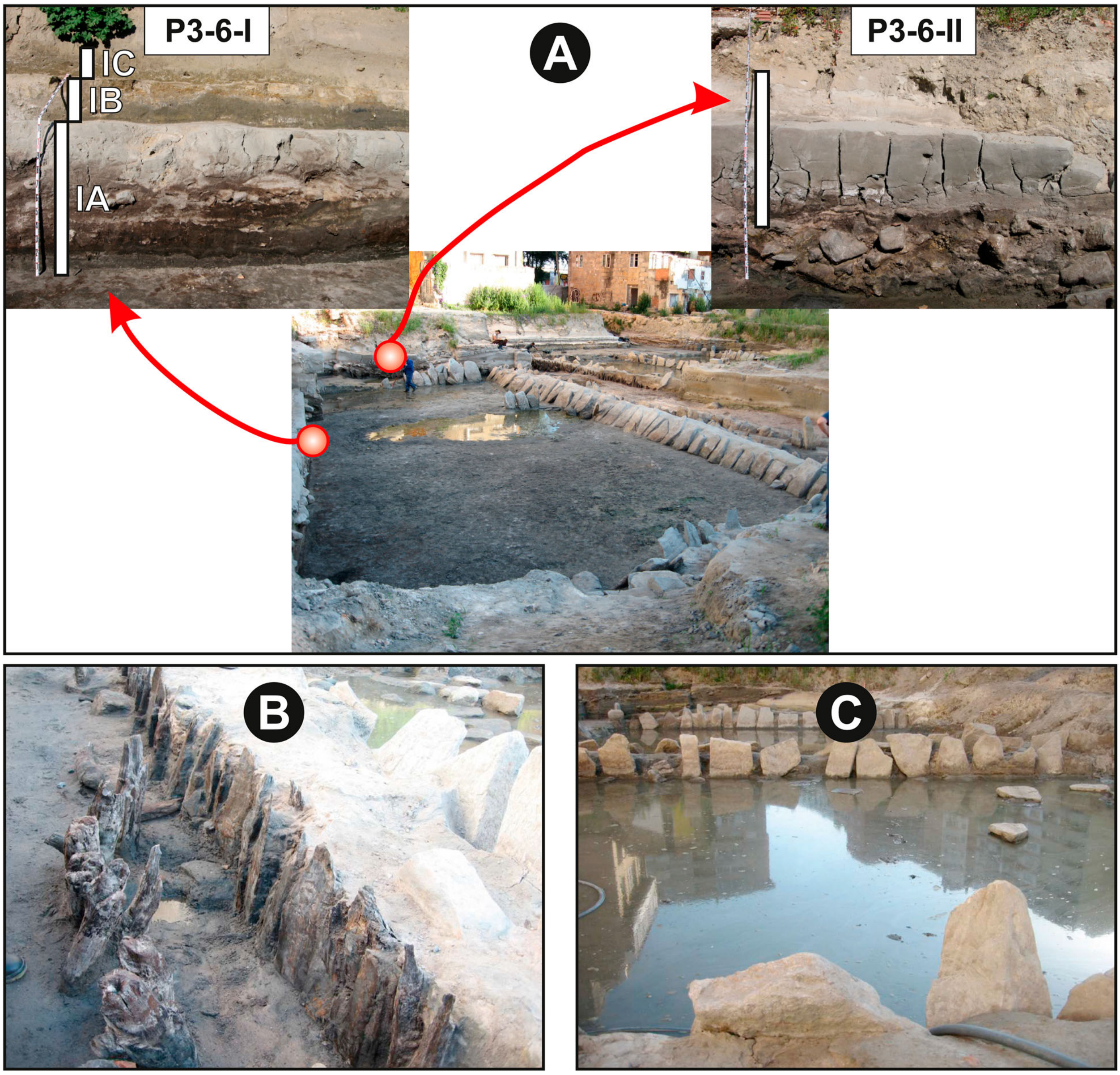

Figure 2. Pictures taken at the P3-6 archaeological site. (A) A view of the *salinae* excavated located in the eastern sector of the *O Areal* saltworks complex indicating the location of the pedo-sedimentary profiles covering the use and abandonment of the Roman saltworks and representing the complexity of the environment: (left) a sequence of sedimentary infilling of a solar evaporation pond (P3-6-I), and (right) a sequence of sedimentary infilling of a seawater inflow channel (P3-6-II) of the *salinae* (more information in Figure SI1, Table SI1 and Table SI2). (B) A detail of the evaporation pond border with stones and well-preserved wood. (C) A view of the evaporation ponds with water showing that current phreatic level is close to the excavated surface. Photos by M. Costa-Casais.

Sampling of the Profiles and Radiocarbon Dating

The P3-6 site presented a complex fossilised sedimentary environment where anthropogenic structures were mixed with structures linked to natural sedimentary processes. Owing to the complexity of the site, sampling was planned to consider the variability in the sedimentary facies (Costa-Casáis, Rodríguez Fernández, & Martínez Cortizas, 2007). A visual analysis of several sectors of the archaeological site P3-6 helped to define different sedimentary environments and select those profiles integrating them. Two pedo-sedimentary profiles were selected (Figure 2, Figure SI1) covering the use and abandonment of the Roman saltworks. They represent the complexity of the environment: profile P3-6-I comprised a sequence of sedimentary infilling of a solar evaporation pond, while profile P3-6-II records the infilling of a seawater inflow channel of the *salinae*. Profile sampling was continuous, taking 5-cm-thick or 2.5-cm-thick samples, depending on the increased presence of silt in profile P3-6-II. As a result, 47 samples were obtained for P3-6-I, a 186 cm-depth profile (Table SI1), and 26 samples for P3-6-II, a 75 cm-depth profile (Table SI2).

All P3-6-II samples were analysed by palynological, geochemical and stratigraphical analyses. In the case

Table 1. Results of radiocarbon dates from the two profiles.

Profile	Sample code	Laboratory code	Depth interval (cm)	Depth average (cm)	Radiocarbon dates (BP)	Two-sigma calibrated ages (cal. yr BP) *	Two-sigma calibrated ages (BC/AD) *	Probability
P3-6-IA	P3-6-IA-5	Beta-248421	95-97.5	96.25	1530 ± 40[#]	1345–1520	**AD 430–605**	**0.986**
						1315–1323	AD 627–635	0.014
	P3-6-IA-9	Beta-248422	105–109	107	1550 ± 40	1355–1524	**AD 426–595**	**1**
	P3-6-IA-22	Beta-248423	158.5-161	159.75	1720 ± 40[#]	1650–1703	AD 247–300	0.304
						1536–1646	**AD 304–414**	**0.696**
	P3-6-IA-24	Beta-248424	163.5-166	164.75	1670 ± 40	1664–1696	AD 254–286	0.126
						1508–1625	**AD 325–442**	**0.732**
						1471–1502	AD 448–479	0.054
						1414–1456	AD 494–536	0.089
	P3-6-IA-27	Beta-248425	171-173.5	172.25	1810 ± 40	1688–1824	**AD 126–262**	**0.632**
						1604–1674	AD 276–346	0.368
	P3-6-IA-32	Beta-248426	183.5-186	184.75	2020 ± 40[#]	2085–2098	149–136 BC	0.014
						1866–2060	**111 BC-AD 84**	**0.952**
						1833–1855	AD 95–117	0.035
P3-6-II	P3-6-II-13	Beta-248427	30-32.5	31.25	1270 ± 40	1175–1289	**AD 661–775**	**0.782**
						1117–1164	AD 786–833	0.165
						1074–1101	AD 849–876	0.053
	P3-6-II-15	Beta-250985	35-37.5	36.25	1290 ± 40[#]	1175–1296	**AD 654–775**	**0.912**
						1123–1162	AD 788–827	0.086
						1087–1089	AD 861–863	0.002
	P3-6-II-18	Beta-248428	42.5-45	43.75	940 ± 40	771–925	**AD 1025–1179**	**0.962**
						743–760	AD 1190–1207	0.038
	P3-6-II-22	Beta-248228	52.5-55	53.75	940 ± 40[#]	771–925	**AD 1025–1179**	**0.962**
						743–760	AD 1190–1207	0.038
	P3-6-II-26	Beta-250986	70–75	72.5	1040 ± 40[#]	1019–1057	AD 893–931	0.124
						902–1009	**AD 941–1048**	**0.792**
						853–868	AD 1082–1097	0.023
						823–850	AD 1100–1127	0.047
						800–811	AD 1139–1150	0.013

Note: Calibrated ranges are shown. * Calibrations performed with the IntCal calibration curve (Reimer et al., 2020) using the software CALIB 8.20 (Stuiver et al., 2021). [#] Dates published at Tallón-Armada et al. (2015).

of P3-6-I, the sampling in the field was done in three sections P3-6-IA (186-75 cm), P3-6-IB (75-35 cm), and P3-6-IC (35-0 cm) (Figure SI1). For this profile, all samples were studied using geochemical and stratigraphical analyses, while palynological analysis was performed on 20 samples from P3-6-IA. The sections not palynologically studied in P3-6-I, including some of the P3-6-IA samples, correspond to the sand-dominated (i.e. dune) layers (Table SI1).

Selected samples were sent to Beta Analytic Inc. (Miami, USA) for AMS radiocarbon determination on the acid-alkaline-acid extraction of bulk organic matter. A total of six samples were dated in P3-6-I, within section A (sections B and C are sand-dominated), and five in P3-6-II. Radiocarbon results (Table 1) were calibrated with the IntCal curve (Reimer et al., 2020) using the software CALIB 8.20 (Stuiver, Reimer, and Reimer, 2021).

Stratigraphy and Geochemistry

Colour and sedimentary characteristics of the samples were described in preliminary reports by Costa-Casais et al. (2007, 2008) and later by Tallón-Armada (2012) (Table SI1, Table SI2). Taking into account how coastal solar evaporation saltworks work, it was hypothesised that the saltworks were most likely located on a marsh. The selected pedo-sedimentary properties that were analysed on the profile samples to reflect that (based upon a large organic matter content as well as indicators of marine waters). Hence, we performed a series of analyses to obtain records of C, N, S, P, Br, loss-on-ignition (LOI), pH, and charcoal. LOI is used as a proxy for total organic matter (OM) content, while C, N, and S are indicative of the OM composition and the C:N ratio is indicative of the degree of decomposition. Phosphorous is an element that tends to be enriched in anthropogenic layers (e.g. Provan, 2010), while Br is incorporated into organo-halogenated compounds on soils and sediments, providing information on humified organic matter and, for the Holocene, on the age of the OM (e.g. Martínez Cortizas et al., 2016). In addition, S, P and Br are linked to biogeochemical processes in marsh settings (Otero and Macías, 2001; Schlesinger, 2000).

Prior to the stratigraphical and geochemical analyses, sub-samples were air-dried and sieved to separate coarse (>2 mm) and fine (<2 mm) fractions. Macrocharcoal particles were obtained from the coarse fraction; while pH measurement and elemental composition determination were performed on the fine fraction. pH was measured in water (pH_w) and KCl (pH_{KCl}) suspensions (1:2.5) with a pH meter, following Guitián and Carballas (1976) and Urrutia, García-Rodeja, and Macías (1989). Elemental composition was conducted on finely milled (<50 μm) samples. Total C, N, and S contents were determined by complete combustion in a LECO Elemental Analyzer, model CNS-2000. P and Br contents were determined using an energy-dispersive miniprobe X-ray fluorescence multielement analyser. Both analysers are hosted at RIAIDT in the Universidade de Santiago de Compostela. LOI was obtained by combustion of the sub-samples at 550°C for 16 h and expressed as a percentage of weight loss of the initial dry weight at 105 °C (Heiri, Lotter, and Lemacke, 2001). The records of charcoal, pH, C, N, S, and P of P3-6-I were previously described by Tallón-Armada et al. (2013).

Palynology

A total of 46 samples were palynologically analysed, 20 from P3-6-IA (Table SI1) and 26 from P3-6-II (Table SI2). Palynological extraction was completed at the Archaeobiology laboratory of the CCHS-CSIC using hydrochloric acid to remove carbonates, sodium hydroxide to dissolve organic matter, and hydrofluoric acid to remove silicates, including a heavy liquid density separation. Residues were mounted on slides in glycerol, and identification and counting completed at ×400 on a light microscope, and at ×1000 using immersion oil for more delicate identifications, supported by the Archaeobiology pollen reference collection at the CCHS-CSIC as well as keys and atlases (Fægri and Iversen, 1989; Moore, Webb, and Collinson, 1991; Reille, 1992, 1995, 1998). In addition, Ubera, Galán, and Guerrero (1988) was followed for the identification of pollen types within the genus *Plantago*, whereas Renault-Miskovsky, Girard, and Trouin (1976) for the genera within the Oleaceae family. Poaceae pollen grains assigned to Cerealia t. were those with a grain size larger than 45 µm and with an annulus diameter of at least 8–10 µm (López-Sáez and López-Merino, 2005). Non-pollen palynomorphs (NPP) were identified following van Geel (2002) and Shumilovskikh, O'Keefe, and Marret (2021).

The total land pollen (TLP) sum consisted of a minimum of 200 pollen grains (trees, shrubs, and non-hydro-hygrophyte herb pollen types) per sample (minimum = 213; average = 265; median = 266). This sum is excluding hydro-hygrophyte pollen types (i.e. Cyperaceae, *Myriophyllum alterniflorum* t., Potamogetonaceae, *Typha angustifolia* t., and *Typha latifolia* t.), fern, fungal and algal spores, as well as other NPP. Palynological percentages were calculated using the TLP sum.

Numerical Methods

Palynological zones were identified by optimal splitting by information content (Birks and Gordon, 1985) on the records of both profiles independently and only on those types with percentages larger than 0.5% TLP. Percentages were recalculated and square root transformed prior to analysis. Diagrams were plotted and zonation analysis was performed with Psimpoll 4.27 (Bennett, 2009).

We also performed principal components analysis (PCA) to describe the major features of the palynological records. The analyses were completed on the transposed data matrix (PCA_{tr}); that is, with samples in columns (variables) and taxa in rows (cases). Correlation matrix and varimax rotation solutions were applied to the dataset (after the Z-score transformation of the percentages) to constrain the co-variation in the components. PCA was done using the IBM SPSS statistics 25 software.

PCA_{tr} summarises the main palynological assemblages of co-existing taxa and their importance in each sample based on co-variation patterns. This approach has been successfully used on other palynological records (Silva-Sánchez, 2010; López-Merino et al., 2012, 2016; Horák-Terra et al., 2015; Mighall et al., 2023). Using transposed data matrices, taxa showing large factor scores (i.e. larger abundances) in each principal component, are those that explain most of the variation of the palynological dataset in samples with large factor loadings. This allows the identification of assemblages with statistically significant contributions to the total variance, and to express quantitatively the proportion of variance explained by each principal component for each sample.

Results

Stratigraphy and Geochemistry

The stratigraphical features of the profiles (Table SI1, Table SI2) identified five layers in P3-6-I, and four in P3-6-II (Figure SI1). These layers are described together with the pH, LOI, C, N, S and P records (Figure 3). The carbon to nitrogen ratio (C:N) was calculated as a proxy for the degree of organic matter (OM) decomposition.

P3-6-I

Layer-I-1 (186-171 cm) is greyish black and consists of banded organic-rich silt and sand. OM content is high, as shown by the records of charcoal, LOI, C, N, S and P. Charcoal and S are more abundant in the bottommost samples, while LOI, C, N and P in the topmost samples. C:N varies from 12.6 to 15.1, indicating a moderate degree of decomposition of the OM. Bromine follows a similar pattern than the OM with large values. pH is very acidic (2.1-2.4).

Layer-I-2 (171-156 cm) is grey and consists of organic-rich fine silty sediment. OM content is high, with maximum values in LOI, C, N, P and S that decrease from bottom to top. The presence of charcoal is low. C:N varies from 14.4 to 20.1, indicating a low degree of OM decomposition. Bromine values decrease. pH changes from very acidic to acidic (2.2-5.4).

Layer-I-3 (156-105 cm) consists of sand and presents a change from darker to lighter colours from bottom to top. The bottommost part consists of deep brown sand with abundant charcoal that transitions to beige laminated find sand-rich sediment. The transition between the two colours is characterised by gravel and pebbles at 131–126 cm. OM content is extremely low, as evidenced by the records of LOI, C, N, S and P. Charcoal is present. C:N varies from 18.2 to 13.2, indicating a low to moderate degree of OM decomposition. Bromine values are very low. pH changes from neutral to slightly alkaline (6.9–8).

Layer-I-4 (105-95 cm) is grey and consists of silt with the presence of very fine sand. OM increases, as evidenced by the LOI, C and N records. C:N values are very stable varying from 11.7 to 11.9, indicating a higher degree of OM decomposition. Bromine values are slightly higher than in the previous layer. pH is neutral (7-7.2) and charcoal fragments disappear.

Layer-I-5 (95-0 cm) is of varying grey hue and consists of sand with varying amounts of silt. OM content is extremely low, as evidenced by the records of LOI, C, N, and P. S peaks at 70–55 cm, when the silty sediment is more organic and an incipient degree of paedogenesis seems to have occurred. C:N varies from 13.3 to 5.6, indicating a moderate to high degree of OM decomposition. Bromine values are very low. pH changes from neutral to acidic to alkaline (range from 4.4 to 8.4). Charcoal is present.

P3-6-II

Layer-II-1 (75-55 cm) is greyish black and consists of banded sand and organic silt with rounded pebbles and gravel in the basal sediments. OM content is low, as evidenced by the LOI, C, N and P records. S has higher values in the bottommost sample. Charcoal values are low. C:N varies from 14.9 to 16.2, indicating a low degree of OM decomposition. Bromine values are very low. pH is very acidic (2.8–3).

Layer-II-2 (55-50 cm) is greyish black and consists of organic silt with the sand. OM increases, as shown by the LOI, C, N, P and S records. Charcoal values are low. C:N varies from 13 to 12.4, indicating a moderate degree of OM decomposition. Bromine values increase slightly. pH is acidic (3.7–5).

Layer-II-3 (50-22.5 cm) is grey and consists of organic silt. OM content is higher in the basal 10 cm (Layer-II-3a) and values decrease from 40 cm to the top of the layer (Layer-II-3b), as evidenced by the LOI, C, N and S records. Phosphorous values present a seesaw pattern. Charcoal concentrations are low. C:N values range from 12.9-10.4, indicating a moderate to a high degree of OM decomposition. Bromine follows the same trend than OM indicators. pH changes from acidic to neutral (5.4–7).

Layer-II-4 (22.5-0 cm) is of greyish colour and consists of sand and silt. OM content decreases, as shown by the records of LOI, C and N, while S increases. Charcoal content is negligible. C:N values range from 10.6 to 9.3, indicating a high degree of OM decomposition. Bromine values are low and pH changes from neutral to acidic (6.6–4).

Palynological Results and Zonation

Palynomorph preservation and diversity were good, with 60 terrestrial pollen types recorded among the TLP sum and 36 types within the hydro-hygrophytes and NPP (Figure SI2, Figure SI3). Three and four palynological assemblage zones were detected in P3-6-IA (Figure 4, Figure SI2) and P3-6-II respectively (Figure 5, Figure SI3).

P3-6-IA

In **Zone-IA-1** (186-168.5 cm) trees are dominated by deciduous *Quercus* and *Castanea*, with *Alnus* and *Corylus* also showing continuous values. Shrubs are not well represented, *Erica* t. being the most abundant taxa together with the climber *Hedera*. Herbs are the best represented among the total land pollen, with Poaceae, Fabaceae undiff., Cichorioideae, *Aster* t., Amaranthaceae/Chenopodiaceae, *Plantago coronopus* t., *Urtica dioica* t. and Cardueae dominant. Cerealia t. is present. This zone is characterised by a large abundance of Dinoflagellate cysts (Dinocysts). Trilete and Monolete fern spores and Cyperaceae are also present, with *Typha latifolia* t. values increasing by the top of the zone. Algal remains such as *Botryococcus*, *Spirogyra* spores together with heterocysts of the cyanobacteria *Rivularia* (HdV-170) also appear, as well as spores of dung fungi such as *Sordaria* t. (HdV-55A) and *Sporormiella* t. (HdV-113).

Zone-IA-2 (168.5-152 cm) shows the decline in deciduous *Quercus*, *Corylus*, *Alnus*, and *Castanea*. Some trees that were not previously present appear, such as *Betula* and *Salix*. Low shrub values are recorded, including *Frangula alnus*. Herbs dominate, with *Cannabis/Humulus* t. and Brassicaceae first recorded. Cerealia t. is also present. This zone shows a sizeable decrease in Dinocysts, and an increase in the Cyperaceae, Monolete and Trilete fern spores, as well as the presence of Potamogetonaceae, *Typha angustifolia* t. and *Typha latifolia* t.

Zone-IA-3 (108.5-85 cm) shows the lowest tree percentages of the diagram, with the decrease in the values of deciduous *Quercus* and *Castanea*. *Alnus* occurs in larger values. Shrubs are represented by low amounts of *Erica* t. and *Daphne gnidium* t. Herbs still dominate with Poaceae, Cichorioideae, *Aster* t. and Fabaceae undiff. notable. The NPP records show the dominance of ferns, both Trilete and Monolete. Hydro-hygrophytes such as Cyperaceae and

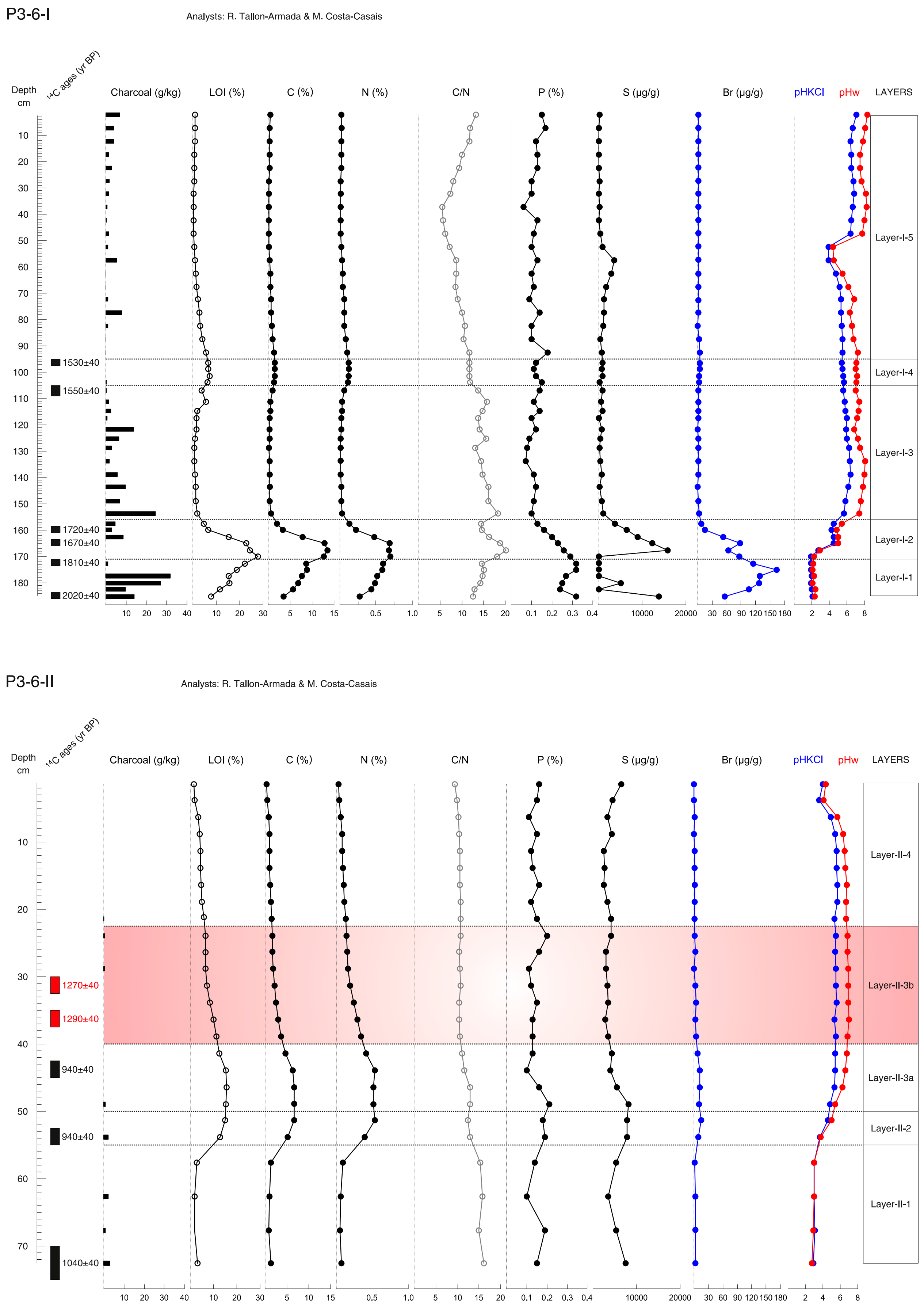

Figure 3. Macrocharcoal, stratigraphical and geochemical data of the profiles P3-6-I (upper panel) and P3-6-II (lower panel) plotted against depth. Radiocarbon dates, and stratigraphical layers for the two profiles are also included on the left and right respectively. Radiocarbon dates that present reversal results in P3-6-II are shown in red, as well as the layer that must have been reworked (Layer-II-3b). Pictures of the two profiles are in Figure SI1.

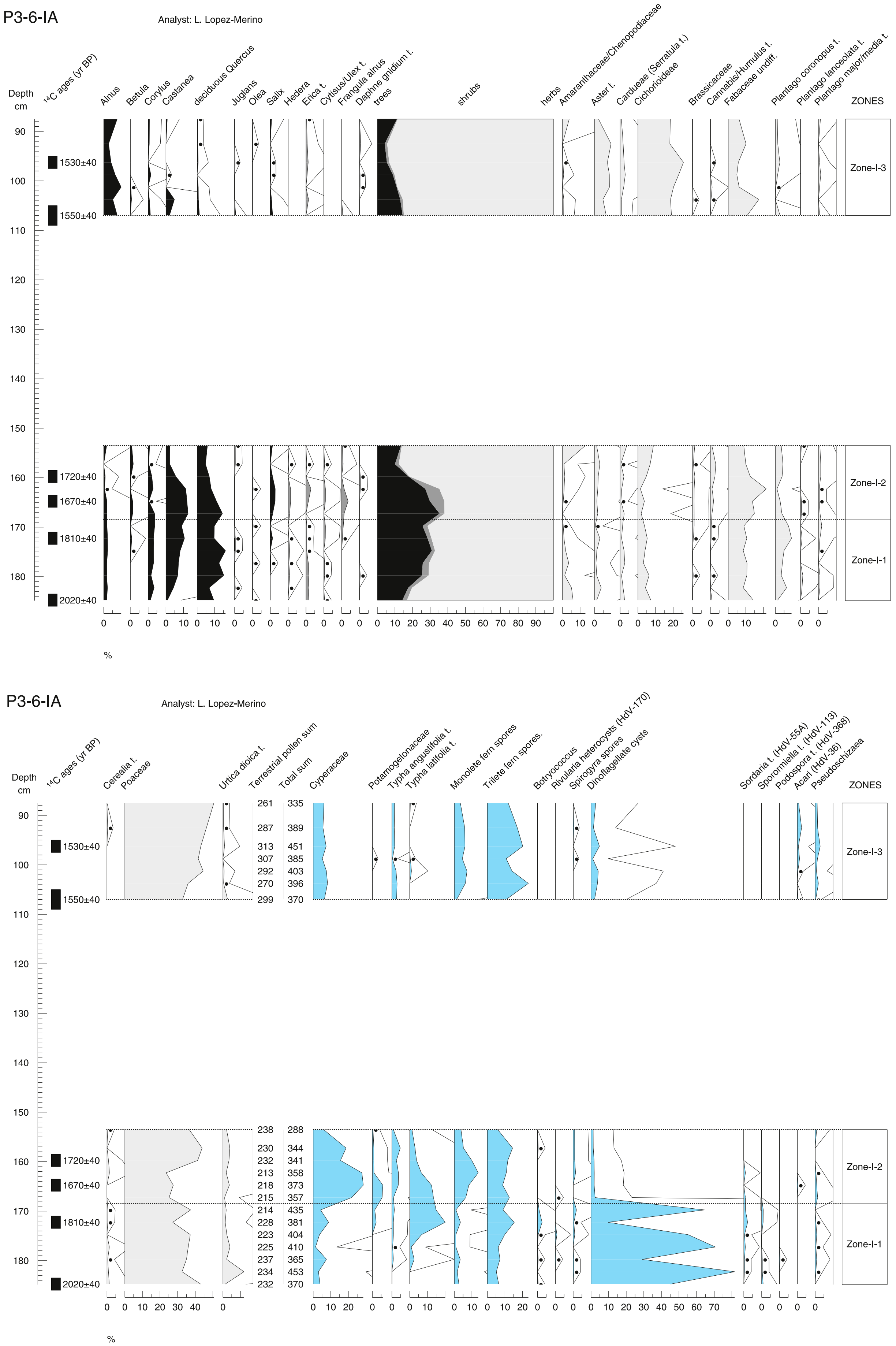

Figure 4. Synthetic palynological percentage diagram of the P3-6-IA profile plotted against depth. The filled silhouettes show the percentage curves of the taxa, while the white silhouettes show the ×10 exaggeration curves. Dots stand for percentages below 0.5%. Radiocarbon dates, and the detected palynological zones are also included. The complete palynological diagram with all identified taxa is in Figure SI2.

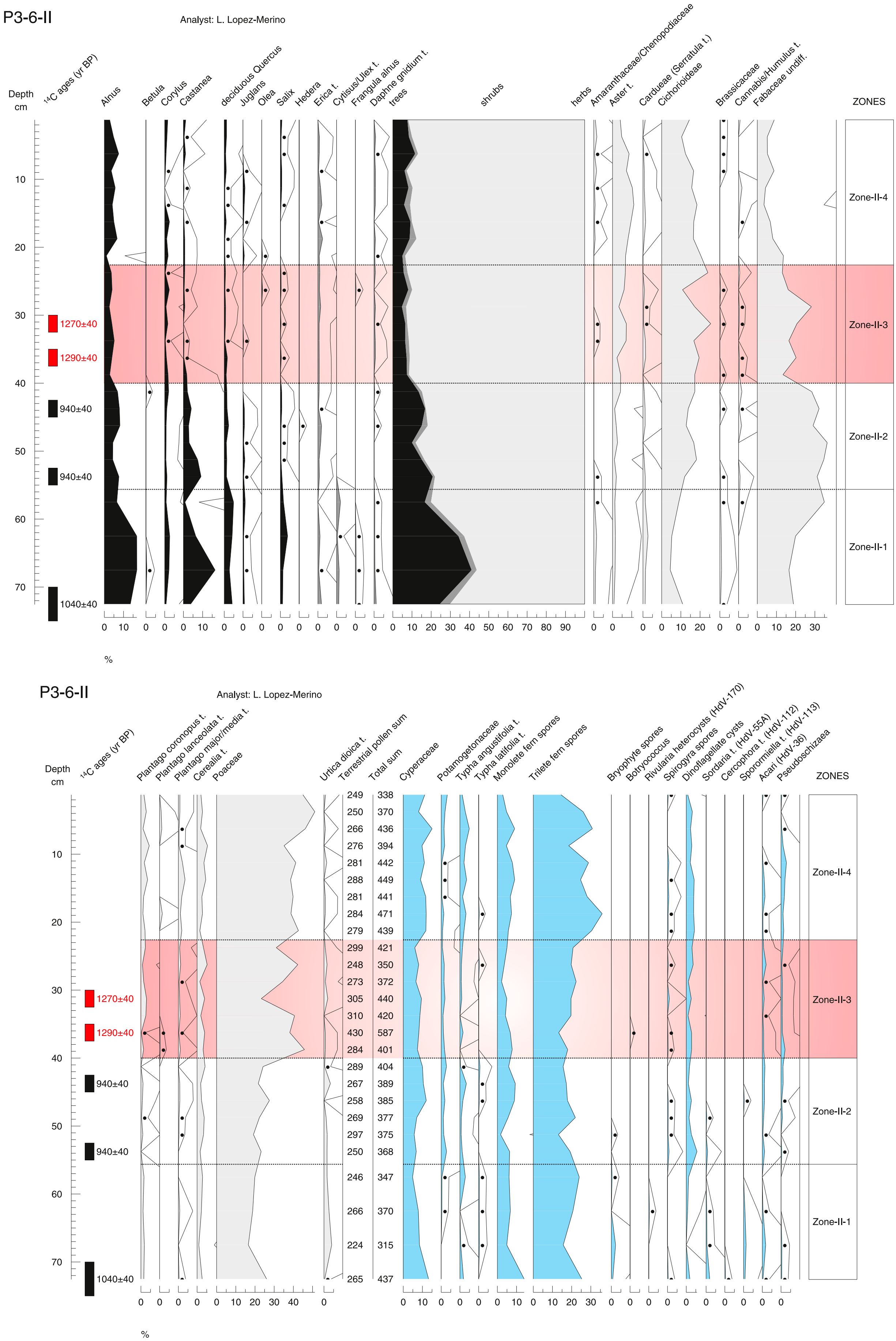

Figure 5. Synthetic palynological percentage diagram of the P3-6-II profile plotted against depth. The filled silhouettes show the percentage curves of the taxa, while the white silhouettes show the ×10 exaggeration curves. Dots stand for percentages below 0.5%. Radiocarbon dates, and the detected palynological zones are also included. Radiocarbon dates that present reversal results are shown in red, as well as the zone that must have been reworked (Zone-II-3). The complete palynological diagram with all identified taxa is in Figure SI3.

Typha angustifolia t. are also important. Dinocysts show slightly higher values than in the previous zone.

P3-6-II

In **Zone-II-1** (75-55 cm) trees are well represented with *Alnus*, *Castanea*, deciduous *Quercus*, *Salix* and *Corylus* showing the highest percentages. *Juglans* appears regularly. Shrubs are not abundant, and only *Erica* t. and *Cytisus/Ulex* t. have a semi-continuous presence. Herbs are the most abundant taxa, dominated by Poaceae, Fabaceae undiff. and Cichorioideae. Cerealia t. and *Urtica dioica* t. also appear. The records of hydro-hygrophytes and NPP show an abundance of Trilete and Monolete fern spores alongside Cyperaceae. Bryophyte spores are present as well as other NPP such as *Acari* (HdV-36) and dung fungi such as *Sordaria* (HdV-55A) and *Sporormiella* (HdV-113).

Zone-II-2 (55-40 cm) contain lower tree percentages than Zone-II-1 owing to the lower values of *Alnus*, deciduous *Quercus* and *Salix* mostly. *Juglans* is represented by continuous values. Among herbs, Fabaceae undiff. and Cichorioideae percentages increase and Poaceae maintains high values. *Urtica dioica* t. is also present and Cerealia t. increases. Records of hydro-hygrophytes and NPP vary with decreasing percentages for Trilete fern spores and increasing ones for Cyperaceae. Other vascular plants characterise the assemblage with continuous and higher presence such as Potamogetonaceae and *Typha angustifolia* t. Algal remains such as Dinocysts and spores of *Spirogyra* are also present together with other NPP such as *Acari* (HdV-36) and *Pseudoschizaea*.

Zone-II-3 (40-22.5 cm) is characterised by the lowest tree percentages of the entire profile, with only *Alnus* having a continuous presence. Poaceae, Cichorioideae and *Aster* t. increase and Fabaceae undiff. decreases in value compared to Zone-II-2. Cerealia t. has slightly larger percentages, while *Plantago coronopus* t. and *Plantago major/media* t. show continuous presence. Hydro-hygrophytes and NPP assemblages are similar than in the previous zone, although with lower values of Dinocysts.

Zone-II-4 (22.5-0 cm) shows a slight increase in *Alnus* and *Salix* percentages, although tree percentages are very low. *Juglans* appears. Herbs are abundant, with Poaceae and Cichorioideae dominating and presenting similar values than previously. In addition, *Aster* t. presents increasing while Fabaceae undiff. decreasing percentages compared to Zone-II-3. Cerealia t., *Plantago coronopus* t. and *Plantago major/media* t. also appear. Hydro-hygrophytes and NPP records do not show significant changes compared to those in the previous zone.

PCA$_{tr}$ of the Palynological Dataset

Four principal components explained 95.3% of the palynological variance. Figure 6 shows factor scores for selected taxa and the fractionation of communalities for each sample (factor scores for all taxa are in Figure SI4).

The first principal component (PC1) explained 42.9% of the total variance. Poaceae, Cichorioideae, Trilete fern spores and *Aster* t. have large factor scores, while Fabaceae undiff., *Castanea*, deciduous *Quercus* and Dinocysts show large negative scores, and *Typha latifolia* t. moderate negative ones. PC1 would be indicative of the dominance of an open landscape. The fraction of the variance explained PC1 is very significant for samples in Zone-IA-3, Zone-II-3, and Zone-II-4. It is also important for samples in the topmost part of Zone-IA-2.

The second principal component (PC2) explained 26.9% of the total variance. Fabaceae undiff., Trilete fern spores, Cichorioideae and *Alnus* show large positive factor sores, while *Castanea*, Monolete fern spores and Cerealia t. have moderate positive ones. *Typha latifolia* t. shows moderate negative scores. PC2 would be indicative of the presence of an open landscape, with a likely human impact. The importance of alder would be linked to the importance of freshwater. The fraction of the variance explained PC3 is significant for samples in Zone-II-1 and Zone-II-2. It is also important, together with PC1, for samples in the topmost part of Zone-II-3.

The third principal component (PC3) explained 15% of the total variance. Dinocysts show a large positive factor score, and Poaceae and deciduous *Quercus* moderate positive scores. Poaceae shows a moderate negative score. Dinocysts are resting forms of dinoflagellates and, most of them, are part of the marine plankton. Therefore, PC3 would be indicative of the local prevalence of marine conditions within a regionally open woodland with deciduous *Quercus*. The fraction of the variance explained PC3 is significant for samples in Zone-IA-1.

The fourth principal component (PC4) explained 10.6% of the total variance. Cyperaceae, *Typha latifolia* t., *Castanea*, deciduous *Quercus* and Poaceae are the taxa with large positive factor scores, while Monolete fern spores have a moderate one. Cichorioideae and Dinocysts show large and moderate negative scores, respectively. PC4 would be indicative of the local presence of hydro-hygrophyte vegetation within a regionally open woodland with *Castanea* and deciduous *Quercus*. The fraction of the variance explained PC4 is significant for samples in Zone-IA-2.

Chronological Aspects and Palaeoenvironmental Interpretation

In this section, we have integrated the multi-proxy results to provide a palaeoenvironmental, chronological and archaeological interpretation of the pedo-sedimentary profiles. Six radiocarbon dates were obtained

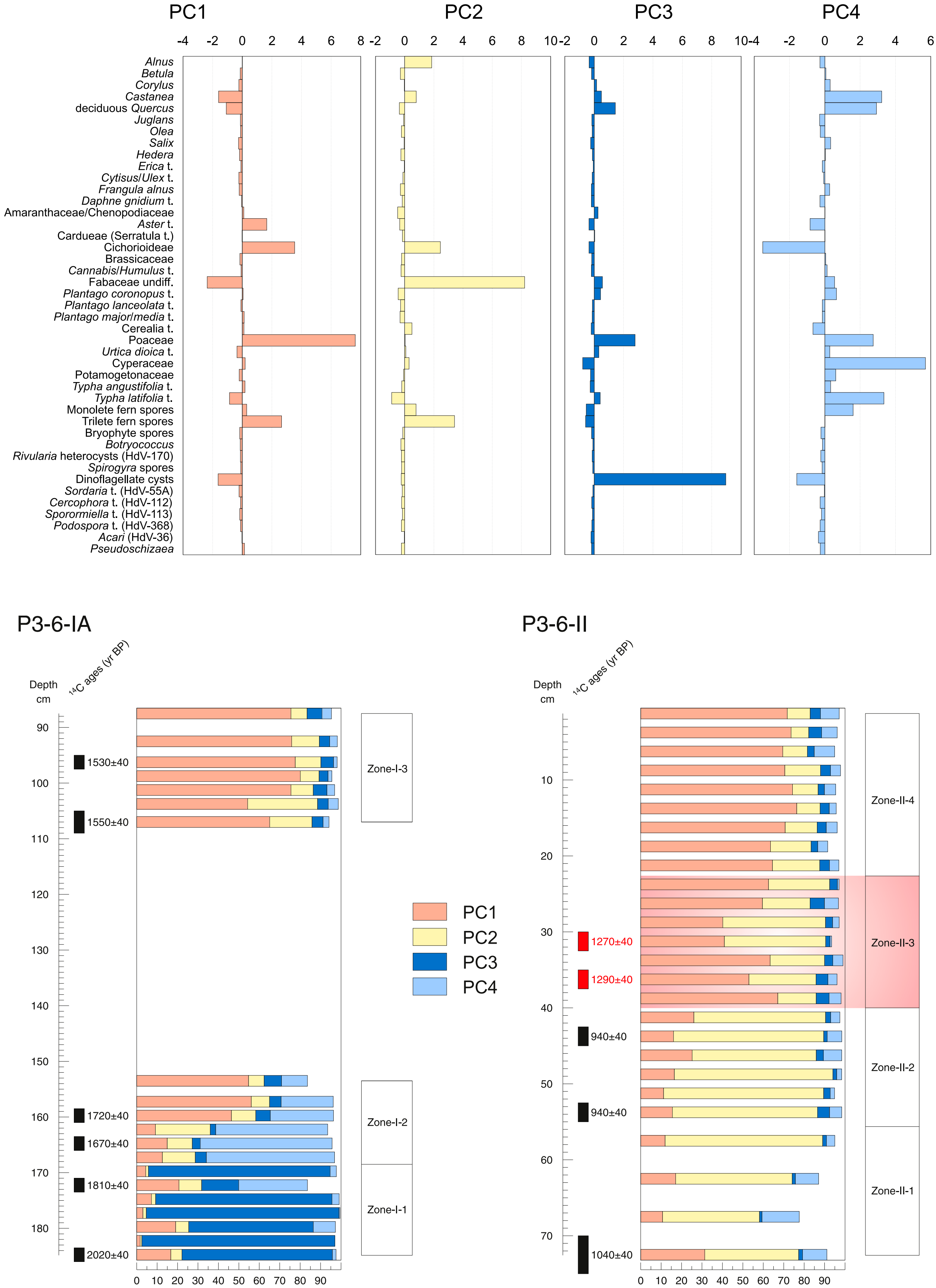

Figure 6. Principal component analysis results (transposed matrix) of the palynological dataset of the two pedo-sedimentary profiles analysed from the *O Areal* Roman-saltworks (P3-6-IA and P3-6-II). Left: Factors scores of the four principal components obtained (selected taxa, the factor scores for all taxa are in Figure SI4). Right: Communalities (squared factor loadings) of the four principal components explaining the variation of the palynological signal. Radiocarbon dates that present reversal results in P3-6-II are indicated in red, as well as the zone that must have been reworked (Zone-II-3).

from P3-6-I profile, while five from P3-6-II profile. The dated layers correspond with basal sands or with the accumulation of fine sediments. P3-6-I has a longer chronological framework dated from 111 BC-AD 84 to AD 430-605, with a coherent chronological sequence. Glazed ceramics in the topmost samples of P3-6-I suggest that the top of the profile belongs to the 17th century AD (Costa-Casáis et al., 2008). In contrast, in P3-6-II the radiocarbon results reveal that the sediments are not stratigraphically coherent, and they are all post-Roman.

The stratigraphical, geochemical and palynological results suggest that the bottommost part of P3-6-I was formed within a marine sedimentary environment and that terrestrialisation occurred afterwards during the rest of P3-6-I and P3-6-II. This terrestrialisation occurs in an environment in which the interaction of both marine and terrestrial processes took place and where some phases were more influenced by the former or latter processes.

The extracted PC3 after the PCA_{tr} is likely to be related to the presence of Dinocysts, explaining most of the variance in Zone-IA-1 (Figure 6). The stratigraphical and geochemical properties of the sediment suggest a marine influence. Layer-I-1 consists of banded silt and sand that shows high OM content, with large Br and extremely low pH values (Figure 3). Dinoflagellates are part of marine plankton, and the principal source of Br is the ocean, appearing in soils/sediments as organo-halogen compounds (e.g. Martínez Cortizas et al., 2016, 2021). The extremely acidic pH values are a feature of sulphate-acid soils, typical of intertidal environments (Tallón-Armada, 2012; Tallón-Armada et al., 2013). Accordingly, Layer-I-1 is interpreted as a layer of marine sands. Radiocarbon dates frame this marine phase between 111 BC-AD 84 and AD 126-262. This phase is confined within the archaeological structures of the Roman saltworks (Castro Carrera et al., 2019), therefore representing the use of the saltworks between the 1st century BC and the 3rd century AD.

PC4 indicates a shift towards the presence of typical wetland plants, such as sedges and bulrush, in Zone-IA-2 (Figure 6). Stratigraphical and geochemical data show organic-rich fine silty sediment that marks the evolution of the marine environment to a sulphate-acid coastal marsh with strong terrestrial influence in Layer-I-2, characterised by the decreasing OM indicators and Br (Figure 3). The coastal marsh would have been fed by low energy terrestrial water that transported and deposited fine-grained sediment. From an archaeological point of view, this layer was identified as the fill of the saltworks topmost layer. Two radiocarbon dates obtained for this layer (AD 325-442 and AD 304-414) indicate a Late Roman Empire chronology. The *salinae* abandonment would have triggered the coastal environment restructuration from a more marine to a more terrestrial-influenced one up to at least the onset of the 5th century AD. The sedimentation of fine materials was fast as shown by the two overlapping radiocarbon dates.

During the post-Roman period, a layer of sand was deposited on the coastal marsh (Layer-I-3). The sands in this Layer-I-3 transition from darker to lighter colours and imply a change from a low-energy marine-terrestrial-dominated environment to an aeolian-dominated white dune system as seen in the extremely low Br and OM content, as well as higher pH. This layer was deposited relatively quickly dated between AD 304–414 and AD 426–595. Layer-I-4 consists of silt and very fine sand and where low Br and OM values slightly increase. The layer represents a rapid stabilisation of the sedimentary system and the development of a lagoon over approximately two centuries judging by the dates AD 426–595 and AD 430–605. Layer-I-5 comprises sand with an extremely low OM content that indicates the reactivation of the aeolian processes from AD 426–595 up to the 17th century AD (based on the presence of glazed ceramics). Palynomorphs are not well preserved in sandy contexts, so just the samples with a larger silt presence were analysed, and they mainly correspond to the lagoon layer. Palynological data points to a stronger influence of terrestrial processes as well in Zone-IA-3. PC1 explains most of the variance, with the dominance of an open landscape.

Palaeoenvironmental data also indicate a strong terrestrial influence in the P3-2-II profile. Stratigraphical and geochemical data show that P3-6-II records the infilling of a small depression with fine sediment. P3-6-II presents more silty layers than P3-6-I. However, radiocarbon dates in this profile do not follow a coherent sequence as in P3-6-I. The basal date was taken from the bottom part of Layer-II-1 and corresponds with a layer of marine sands (AD 941-1048) that comprise banded sand and organic silt and an extremely acidic pH. The remaining four dates were performed at Layer-II-2, Layer-II-3a and Layer-II-3b, that consist of organic silt with pH ranging from acidic to neutral and that are interpreted as lagoon phases. The two dates in Layer-II-2 and Layer-II-3a show the same age (AD 1025-1179), while the two dates in Layer-II-3b show a chronological inversion for this layer (AD 426–595 and AD 430–605). Finally, Layer-II-4 is not dated and consist in sands and silt that are reconstructed as a grey dune.

Regarding the chronological inversion, a discontinuity at 40 cm between the silty layers within Layer-II-3 was observed in the stratigraphical and geochemical results, and for that reason the 3a and 3b separation was done. Palynological zones also showed a boundary at 40 cm between Zone-II-2 and Zone-II-3. While most of the variance in the palynological dataset is explained by PC2 in Zone-II-1 and Zone-II-2 (corresponding to Layer-II-1, Layer-II-2 and Layer-II-3a), PC1 dominates in Zone-II-3 (Layer-II-3b) and Zone-II-4 (Layer-II-4). Both components indicate the presence of open landscapes, although PC2 shows an influence of freshwater. Climate seems to have been related to the rearrangement of the sedimentary layers. After AD 1025–1179 part of the buried, older lagoon sediments located at more elevated topographical settings may have been exhumed, eroded, and redeposited during one of the latest episodes of dune formation, explaining the deposition of older layers above Layer-II-3a, causing the reversal in the radiocarbon dates in Layer-II-3b.

Discussion

Chronology of the O Areal Saltworks and Anthropogenic Activities During Roman Times

The reconstructed marine sediments of the bottom-most part of P3-6-I (Zone-IA-1 ≈ Layer-I-1) are confined within the archaeological structures of the Roman saltworks (Figure 2). Radiocarbon dating of the marine interval indicates that saltworks were operational between the 1st century BC and the 3rd century AD, during the Early Roman Empire. Refining the chronology for the construction of the *salinae* was possible, as the ceramic remains found in the contexts before the *salinae* pavement suggest that the saltworks would have been constructed between AD 50 and 70, so during the 1st century AD (Castro Carrera et al., 2019). It is more difficult to disentangle a precise chronology on when the saltworks complex was abandoned, as no ceramics have been found to establish a firm date. However, a necropolis indicated that burials occurred on top of the crystallisation ponds since the mid-4th century AD (Valle Abad, Fernández Fernández, and Acuña Piñeiro, 2020), so the saltworks' demise most likely occurred earlier enough to allow sediments to seal the area (Castro Carrera et al., 2019). This supports the radiocarbon chronology that dates the end of marine phase to the second half of the 2nd century AD or the first half of the 3rd century AD.

The anthracological study of architectonical timbers that survived in their original position during the production of salt in *O Areal* (Martín-Seijo and Teira-Brión, 2010; Martín-Seijo and Carrión Marco, 2012; Martín-Seijo, 2019; Figure 2) indicates that posts and planks delimiting the salt evaporation ponds were made of oak, alder, and sweet chestnut. These taxa were detected palynologically (Zone-IA-1, Figure 4), indicating the local use of timber resources, typical for other Roman timber structures and wooden objects in NW Iberia (Martín-Seijo and Carrión Marco, 2012). Saltwork activities were, for sure, not the only human activities transforming the environment in the area, including the subsistence of those working in the local fishing and salting industries (Castro Carrera, 2007, 2008; Currás, 2017). The large values of P during the Early Roman Empire, together with the presence of *Rivularia* heterocysts (HdV-170), could be linked to an additional input of phosphates from farming (Figure 7), as cyanobacteria point to phosphate-eutrophication (van Geel, Odgaard, and Ralska-Jasiewiczowa, 1996). Agropastoral activities also were practised with the presence of Cerealia t., *Urtica dioica* t., and spores of dung fungi. Sweet chestnut and walnut pollen increased in abundance during Roman times suggesting that arboriculture and/or the management of wild resources for food took place in the area, a common practice in NW Iberia (Costa Vaz et al., 2016; Peña-Chocarro et al., 2019; López-Merino et al., 2008, 2009, 2010, 2014; Silva-Sánchez, Martínez Cortizas, and López-Merino, 2014).

The inferred coastal marsh in Zone-IA-2 (≈ Layer-I-2) of P3-6-I indicates the onset of the terrestrialisation process during the Late Roman Empire. This process of terrestrialisation is also identified in the *Hospital* and *Toralla* galaico-roman archaeological sites located in the Ría de Vigo (Martínez Cortizas and Costa Casais, 1997; Tallón-Armada, Costa-Casais, and Taboada, 2015). The study of wood and seeds collected in the *O Areal* allowed the identification of the plant resources during the Late Roman Empire after the abandonment of the saltworks at the end of the 3rd-onset of the 4th century AD. The area was briefly used as a dumping ground and numerous botanical remains have been exceptionally well-preserved in waterlogged conditions (Martín-Seijo, 2019; Martín-Seijo and Teira-Brión, 2010; Teira-Brión, 2010, 2022). Anthracological data points to the importance of deciduous *Quercus* and woody Fabaceae as fuel, with the palynological data confirming that the wood was most likely of local origin by the presence of deciduous *Quercus* and *Cytisus/Ulex* t. (Zone-IA-2, Figure 4). Carpological data highlights the large quantities of cereals (*Panicum miliaceum* mainly, together with *Triticum aestivum/durum* and *Hordeum vulgare*), and sweet chestnut and walnut nuts indicative of arboriculture and/or the management of wild resources. Other carpological remains of cultivated and fruit-bearing species such as *Ficus carica*, *Pinus pinea*, *Olea europaea*, *Vitis vinifera* and several species of *Prunus* (*P. avium*, *P. avium/cerasus*, *P. domestica* subsp. *insititia* and *P. persica*) and, even *Cucumis melo* together with weeds were identified (Teira-Brión, 2022). Pollen of *Olea europaea* is more abundant during Roman times (Zone-IA-1 and Zone-IA-2, Figure 4) than afterwards. The more thermic conditions of the RWP would have allowed the spread of thermophilous species and, perhaps, the cultivation of Mediterranean crops or their deliberated

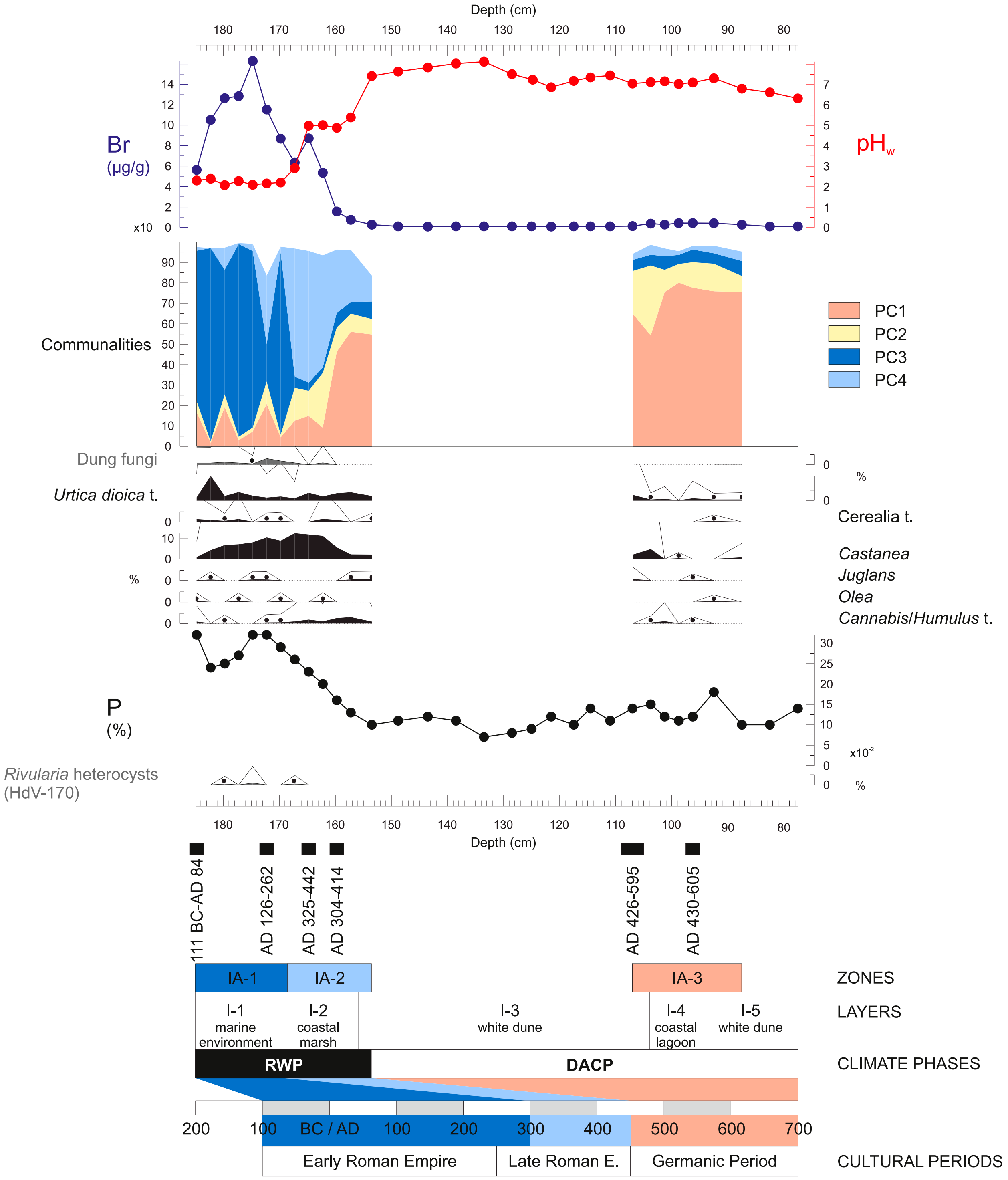

Figure 7. Records of environmental change and anthropogenic impact during Roman times, and soon after, after the multi-proxy study of the pedo-sedimentary profile P3-6-IA from the *O Areal* saltworks. The curve of dung fungi is the sum of *Sordaria* t. (HdV-55A), *Sporormiella* t. (HdV-113), and *Podospora* t. (HdV-368). The filled silhouettes show the percentage curves of the taxa, while the white silhouettes show the ×10 exaggeration curves. Dots stand for percentages below 0.5%. Calibrated age intervals, palynological zones, stratigraphic layers, and cultural periods are also included alongside climate phases (RWP: Roman Warm Period, DACP: Dark Ages Cold Period).

management (López-Merino et al., 2014; Silva-Sánchez et al., 2014). However, commercial exchange has been documented for *Olea* in other northern Iberian archaeological settings such as the Roman port of Irún (Basque Country; Peña-Chocarro and Zapata, 1996, 2005). Although salt production may have ended, and dung fungi indicative of grazing also decreased, other anthropogenic indicators are still recorded during the second half of the Roman period in the studied profiles (Figure 7). These indicators are mostly related to crops, with the presence of the same taxa as those during the Early Roman Empire, and with the addition of *Cannabis/Humulus* t. in the assemblage.

No carpological remains for *Cannabis/Humulus* t. have been found in the *O Areal* during Late Roman Empire. Both *Cannabis* (hemp) and *Humulus* (hop) are dioecious plants of the Cannabaceae family. As far as we know, domestication and cultivation of hop (*Humulus lupulus*) was first recorded in Medieval times (see Behre, 1999) and Romans just used the plant they called *Lupum salictarium* growing wild, more for amusement rather than food (Pliny 1906, NH, 21.86.7). As hop is native of Europe, its palynological presence could be related to the natural regional vegetation. Male individuals of *Cannabis* (hemp) have been (pre-)historically used for its fibres (McPartland, Guy, and Hegman, 2018). Its pollen presence could be indicative of its cultivation for textiles. Although the *Cannabis/Humulus* pollen type cannot guarantee that it comes just from hemp (Rull and Vegas-Vilarrúbia, 2014 and references therein), the fact that it is found together with cultivated cereals, fruit-bearing species and weeds (McPartland et al., 2018), allow us to consider that its cultivation in the surroundings of the *O Areal* is plausible. The retting process – that is undertaken in pools or channels – of hemp stems is necessary for extracting fibres, but it is known to pollute waters. Although the pollen percentages of *Cannabis/Humulus* t. do not allow us to reconstruct retting *in situ* in the marsh, it is likely that retting elsewhere could also be related to the coastal water eutrophication detected during Roman times (Figure 7). Hemp cultivation is ancient practice (McPartland et al., 2018), and the Greeks and Romans expanded its use in Europe (McPartland et al., 2018; Mercuri, Accorsi, and Bandini Mazzanti, 2002). However, no Roman hemp cultivation and pollution triggered by hemp retting is reconstructed in Iberia (Rull et al., 2023), although it has been undoubtedly detected in Medieval times (since AD 600) in the NE Iberia Lake Estanya (Riera, Wansard, and Julià, 2004, 2006) and Lake Montcortès (Rull et al., 2021). However, as Rull (2022) points out, '*The lag of sufficient localities also hinders knowing what happened on the IP [Iberian Peninsula] with Cannabis during the large gap between post-glacial times and the Middle Ages*'. Our results could be a starting point to fill this gap.

The scale of impact of Romans on the environment was not only restricted to saltworks and agropastoral activities. NW Iberia is well known for other anthropogenic activities, such as metal mining (Domergue, 1987). Metal mining has left a mark on past landscapes both geomorphologically and on the vegetation (López-Merino et al., 2010, 2011, 2014; Orejas and Sánchez-Palencia, 2002). Numerous records of atmospheric metal pollution as recorded by local peat and sediment archives exist (Hillman et al., 2017; Kylander et al., 2005; Martínez Cortizas et al., 1997, 1999, 2002, 2013; Silva-Sánchez and Armada, 2023), while the Roman population was also impacted by the levels of metal pollution as unravelled by the geochemical analysis of human archaeological bones (Álvarez-Fernández, Martínez Cortizas, and López-Costas, 2020; López-Costas et al., 2020). It is, therefore, quite apparent, that the scale of human impact during Roman times in NW Iberia was profound, ranging from landscape transformation (e.g. opening due to agropastoral activities) to water eutrophication as well as atmospheric metal pollution. This complex system of resource exploitation and induced environmental impact during the Roman period has been reconstructed using multi-proxy palaeoenvironmental approaches on other Iberian archives, e.g. archaeological sediments in NW Spain (López-Merino et al., 2010), La Molina mire in N Spain (López-Merino, Martínez Cortizas, & López-Sáez, 2011, 2014; Martínez Cortizas et al., 2013), Somolinos Lake in central Spain (Currás et al., 2012).

Palaeoenvironmental Contextualisation of the Last two Millennia Human Activities

Palynological studies in Ría de Vigo's marine sediment cores have shown that the Late Holocene is characterised by strong human interference on the landscape, as low arboreal percentages point to an established open landscape (Figures 4 and 5; Desprat, Sáchez Goñi, & Loutre, 2003; Muñoz Sobrino et al., 2007, 2014). However, environmental changes were not restricted to landscape-scale vegetation changes but also to local coastal ones. We have reconstructed two millennia of environmental change from a marine to a terrestrialised setting (Figure 8).

Roman Times

Palynological, stratigraphical and geochemical records show an environment with strong marine influence during the Early Roman Empire, when saltworks were active. This period was characterised by the climatic amelioration of the RWP with elevated temperature and, during the first half, low precipitation in NW Iberia (Martínez Cortizas et al., 1999). A warmer and drier climate, together with a higher sea level, would explain the location of solar evaporation ponds in saltwork complexes on the Atlantic coast during the Early Roman Empire. However, although the environmental conditions for sea salt evaporation were optimal during the Early Roman Empire, there is a pre-Roman history of sea salt evaporation and use. The presence of the so-called removable sea salt sinks (that could evaporate the water using fire) in the northern coast of Portugal provides evidence for sea salt evaporation regionally since the Bronze Age between the late 3rd millennium to the mid-2nd millennium BC (Bettencourt et al., 2020). A possible Roman salting factory in the nearby *A Lanzada* archaeological site also suggests salt usage in the 2nd century BC

(Rodríguez Martínez et al., 2011), hence before the RWP. Therefore, why did salt evaporation flourished in the area by Romans building long-term saltworks complexes? Firstly, the stabilisation of the sea level after the rapid rise from the Early Holocene meant the consolidation of a stable, suitable coastal environment for building the saltworks. The pedo-stratigraphical study of other profiles in the *O Areal* from ca. 2000 BC to AD 400 suggests that sea level was relatively stable at the onset of the Roman times, this study also reconstructing saltworks during the Early Roman Empire (Tallón-Armada et al., 2018). Although climate was surely an especially important factor for the consolidation and expansion of salt production, the larger demand of salted fish would have been another crucial factor during Roman times. Therefore, an activity that is known to have started regionally during the Bronze Age, intensified under the administrative and economic restructuring of the Roman period, taking advantage of the more suitable climatic conditions of the RWP.

During the Late Roman Empire (3^{rd} to 5^{th} centuries AD), Martínez Cortizas et al. (1999) reconstructed a relative decrease in temperatures and a significant increase in humidity within the RWP. Schellekens et al. (2011) also detected a wet period at AD 270–385 in a NW Iberian mire using molecular vegetation markers. This could imply the worsening of the conditions for salt precipitation due to a shortening of the evaporation period, leading to the abandonment of the saltworks in the area and an influx of eroded sediments linked to the increased precipitation. This influx would have triggered coastal reconfiguration and the development of a marsh between the 4^{th} and the early-5^{th} centuries AD. The abandonment of the saltworks was not only coeval to this climate deterioration, but also to a known period of economic recession starting in the 3^{rd} century AD that involved a ruralisation of the economy and a demise in commercial and maritime trade, including the salted-fish industry throughout the Empire (see Wilson, 2009). Salting facilities were abandoned in many places (see Wilson, 2009 for the Roman Empire, see Currás, 2017 for NW Iberia). On the Atlantic coasts of Portugal and Galicia those remaining were remodelled or only partially used (Bombico, 2015; Currás, 2017; Pinto, Magalhães, and Brum, 2014 and references therein). Some of them did survive in the 4^{th}-5^{th} centuries AD, e.g. the saltwork at *Toralla* (Pérez Losada et al., 2007), close to the *O Areal* saltworks. Therefore, it is likely that a mix of reasons converged to produce the abandonment of the *salinae*, from the fall in demand for salted fish to the environmental conditions that might have made more difficult to sustain salt evaporation.

During both the Early and the Late Roman Empire, the landscape was already open. However, arboreal pollen has higher percentages compared to other periods (Zone-IA-1 and Zone-IA-2; Figure 8). PC3 and PC4 explain a sizeable portion of the variance in Zone-IA-1 and Zone-IA-2 respectively. PC3 indicates the local prevalence of marine conditions within regionally open oak woodlands, and PC4 suggests the local presence of hydro-hygrophyte vegetation within regionally open woodlands comprising sweet chestnut and oak. Therefore, both the Early and Late Roman Empire landscapes are characterised by mesophilous trees in an open landscape. The larger importance of mesophilous trees compared with Zone-IA-3, which has a post-Roman chronology, agrees with the increased pollen influx of mesophiles detected by Desprat et al. (2003) in the Ría de Vigo during the RWP.

Medieval Times

Palaeoenvironmental and bioarchaeological research shows that the transition from Roman to Medieval times in Galicia meant a further climate deterioration that triggered soil erosion and woodland decline, together with a dietarian change (see López-Costas, 2021 and references therein). After the RWP, the so-called Dark Ages Cold Period (DACP) climate deterioration occurred. The DACP is characterised by abrupt temperature changes at the onset of the 5^{th} century AD and an irregular precipitation regime in NW Iberia, followed by intense cold and dry periods in the following centuries (Martínez Cortizas et al., 1999). Consequently, there was increased aeolian activity. Stratigraphic and geochemical data identify a continuation of the terrestrialisation process of the coastal environment after Roman times with sands of aeolian origin turning the coastal marsh into a dune system (white dune of Layer-I-3) coincident with a drop in the sea level. A short-term climate amelioration is detected in Galicia around the 6^{th} and 7^{th} centuries AD (Martínez Cortizas et al., 1999), and this is reflected in the reconstructed coastal lagoon in Layer-I-4. After this first phase of dune formation, a reactivation of the aeolian activity took place with the formation of a second dune phase (white dune of Layer-I-5). Layer-II-3b in P3-6-II also belongs to this cold interval and would indicate the development of a coastal lagoon. Intensification of continental soil erosion during this cold period, as indicated by the larger presence of *Pseudoschizaea* (Pantaleón-Cano et al., 1996), points to coastal sediment deposition linked to watercourses feeding the lagoon. There is no palynological data for the onset of the DACP (Layer-I-3, white dune) at the onset of the 5^{th} century AD, although palynological data are available from the mid-5^{th} century to the 7^{th} century AD at Layer-I-4 (coastal lagoon) and bottom of Layer-I-5 (white dune) in P3-6-IA (Zone-IA-3), as well as for the 7^{th}-8^{th} centuries AD at Layer-II-3b (coastal lagoon) in P3-6-II (Zone-

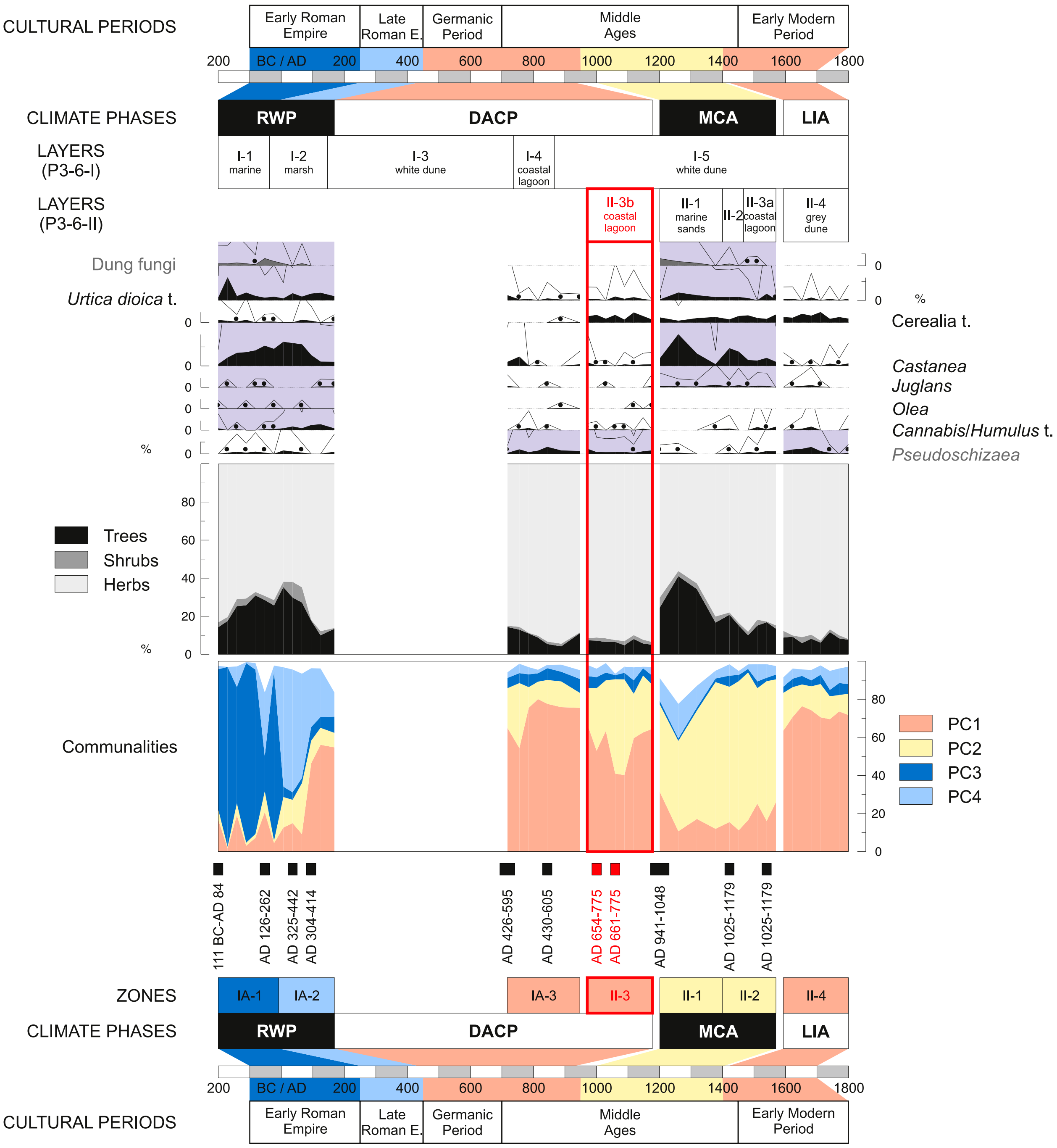

Figure 8. Palaeoenvironmental synthesis and Late Holocene climate framework obtained after the palynological study of the pedo-sedimentary profiles P3-6-IA and P3-6-II. The curve of dung fungi is the sum of *Sordaria* t. (HdV-55A), *Cercophora* t. (HdV-112), *Sporormiella* t. (HdV-113), and *Podospora* t. (HdV-368). The filled silhouettes show the percentage curves of the taxa, while the white silhouettes show the ×10 exaggeration curves. Dots stand for percentages below 0.5%. Calibrated age intervals, palynological zones, stratigraphic layers, and cultural periods are also included alongside climate phases (RWP: Roman Warm Period, DACP: Dark Ages Cold Period, MCA: Medieval Climate Anomaly, LIA: Little Ice Age). Radiocarbon dates that present reversal results in P3-6-II are shown in red, as well as the zone that must have been reworked (Zone-II-3) and that for this figure has been moved to its 'coherent' position.

II-3). Palynological data points to a stronger terrestrial influence, as PC1 explains most of the variance, reconstructing the dominance of herbs versus trees in an open landscape. This result agrees with the decreased pollen influx of mesophiles by Desprat et al. (2003) in the Ría de Vigo during the DACP.

A more open landscape seems to be mainly driven by climate as anthropogenic indicators during the DACP decreased, with Cerealia t. well represented. In fact, sweet chestnut and walnut cultivation/management ceased and the dung fungi indicative of grazing activities disappeared along with the lower incidence of *Urtica dioica* t (Figure 8). Although anthropogenic palynological indicators decreased after Roman times, it is likely that the intensification of the aeolian activity and the more terrestrial influence detected would have allowed the area to be used for burials, as the onset of the western cemetery of the *O Areal* is archaeologically recorded. Some of the cemetery structures were constructed directly on the beach sand or the remains of the salt complex (Iglesias Darriba et al., 2017). According to the ceramics, the coastal funerary site was used since the mid-4th century AD, when some of the burials were built over the *salinae* pavements and was no longer used by the mid-7th century AD (Valle Abad et al., 2020).

After the DACP, the Medieval Climate Anomaly (MCA) is detected in the palynological record in the Ría de Vigo (Desprat et al., 2003) as well as by coccolith and molecular biomarkers (Álvarez et al., 2005). It is called Medieval Climate '*Anomaly*' because its effects were not homogeneous everywhere, and while in SW Europe it meant a climate warming, in E Mediterranean areas meant a cooling (Lüning et al., 2019). The Mediterranean region of Iberia the period was dry, whereas in the Atlantic region it is thought to have been more humid (Moreno et al., 2012). Marine sands (Layer-II-1) were deposited from the 10th century AD, and a coastal lagoon formed (Layer-II-2 and Layer-II-3a) from the 11th century AD. Desprat et al. (2003) reconstructed a larger influx of mesophilous trees for this period, and in Zone-II-1 and Zone-II-2 a larger importance of arboreal taxa is detected. The higher percentages of *Alnus* associated to PC2 indicate freshwater (Figure 6). This could be linked to more humid conditions owing to an increase in precipitation that would have favoured the formation of watercourses transporting fine terrestrial sediments (i.e. silt) to the coast. Therefore, although during the MCA the marine influence is still important, terrestrial processes dominated the coastal environment. The climate amelioration during Medieval times was also accompanied by the rise in anthropogenic activities as seen by the records of Cerealia t., *Urtica dioica* t. and dung fungi. In addition, sweet chestnut and walnut presences are more important than during the earlier cold phase.

Post-Medieval Times

Finally, after the MCA a rapid oscillation to cold temperatures shows the onset of the Little Ice Age (LIA) (Groove, 1988). For Iberia, cold conditions are reconstructed together with alternating moisture regimes accompanied by droughts and floods since the onset of the fourteenth century AD (Oliva et al., 2018). The LIA has been reconstructed as one of the coldest recent periods in Galicia, with temperatures dropping down by ~2.5° C compared to present times (Martínez Cortizas et al., 1999). This erratic climate seems to have triggered the exhumation, erosion and redeposition of part of the buried, older lagoon sediments located at more elevated topographical settings after the twelth century AD, during one of the latest episodes of dune formation. This would explain the deposition of the older levels of Layer-II-3b above Layer-II-3a. The larger values of *Pseudoschizaea* in the top 20 cm of P3-6-II support an increase of soil erosion during the LIA. Renewed aeolian activity is detected with dune formation, i.e. Layer-II-4 corresponding to a grey dune with a low to moderate degree of paedogenesis. PC1 indicates the landscape dominance of herbs (Zone-II-4) in agreement with the lower tree pollen influx detected in the Ría de Vigo by Desprat et al. (2003). The extreme climate during the LIA triggered substantial socio-economic consequences in Iberia (Oliva et al., 2018), and in our area of study we detect a decrease in indicators of human activities: grazing seems to have stopped as dung fungi disappear, as well as the cultivation of sweet chestnut and walnut. However, cereal cultivation is present.

Conclusions

The location of the *O Areal* Roman *salinae* throughout the Atlantic coast of Iberia is of great cultural value owing to the exceptional archaeological preservation together with the associated pedo-sedimentary sequences. Palynological analyses of two pedo-sedimentary sequences from the *O Areal* saltworks, combined with geochemical and stratigraphical records, show that the sea level was higher during the Early Roman Period, when saltworks were active, as reconstructed by the large marine influence in the dataset presented here. The operation of the *salinae* was coeval with the flourishing of the fish-salting factories in NW Iberia. When a demise in the salting industry occurred, at the onset of the Late Roman Period, salt production may have ended at *O Areal*, and the *salinae* structures partially collapsed. The overlying silty layer reflects the development of a sulphate-acid marsh with hydro-hygrophytes and the onset of a transition from a marine to a more terrestrial environment. The diversity of sedimentary settings after Roman times highlights the variability due to the proximity to the coastline or topography. This is seen with the coeval development of a dune system in P3-6-I and a lagoon system in P3-6-II, although due formation finally seals both profiles.

Climate change during the RWP and socioeconomic changes in the Roman world related to the demand of fish-salted products and the establishment of maritime trading networks, most likely explain the rise and demise of the saltworks studied. The proxy data have provided a detailed picture of the long-term fluctuations that coastal environments face, both due to anthropogenic and climate impacts. In this case study, the strongest human-induced perturbations on the coast are detected during Roman times. Firstly, during the lifespan of the *salinae* at the Early Roman Empire, when saltworks and salting activities were accompanied by agriculture and husbandry, triggering the eutrophication of coastal waters. Second, during the Late Roman Empire, through crop cultivation. After that, changes in the coastal environment appear to be related to Late-Holocene climate variability. In tandem with climate, anthropogenic impact during the last two millennia was more sizeable during the warmer phases of the RWP and the MCA compared to the colder ones of the DACP and the LIA.

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References

Adshead, S. A. M. 1992. *Salt and Civilization*, 417. Basingstoke: Macmillan.

Alonso Villalobos, C., F. J. Gracia Prieto, and L. Ménanteau. 2003. "Las salinas de la Bahía de Cádiz durante la Antigüedad: visión geoarqueológica de un problema histórico." *SPAL – Revista de Prehistoria y Arqueología* 12: 317–332. doi:10.12795/spal.2003.i12.13.

Álvarez-Fernández, N., A. Martínez Cortizas, and O. López-Costas. 2020. "Atmospheric Mercury Pollution

Deciphered Through Archaeological Bones." *Journal of Archaeological Science* 119: 105159. doi:10.1016/j.jas.2020.105159.

Álvarez, M. C., J. A. Flores, F. J. Sierro, P. Diz, G. Francés, C. Pelejero, and J. Grimalt. 2005. "Millennial Surface Water Dynamics in the Ría de Vigo During the Last 3000 Years as Revealed by Coccoliths and Molecular Biomarkers." *Palaeogeography, Palaeoclimatology, Palaeoecology* 218: 1–13. doi:10.1016/j.palaeo.2004.12.002.

Behre, K. E. 1999. "The History of Beer Additives in Europe — A Review." *Vegetation History and Archaeobotany* 8: 35–48. doi:10.1007/BF02042841.

Bennett, K. D. 2009. "Documentation for Psimpoll 4.27 and Pscomb 1.03. C Programs for Plotting Pollen Diagrams and Analysing Pollen Data." The 14Chrono Centre, Archaeology and Palaeoecology, Queen's University of Belfast, Belfast, UK. http://www.chrono.qub.ac.uk/psimpoll/psimpoll.html.

Bettencourt, A. M. S., S. Luz, N. Oliveira, P. P. Simões, M. I. C. Alves, and E. Abad Vidal. 2020. "Produção de sal marinho na Idade do Bronze do Noroeste português. Alguns dados para uma reflexão." In *Arqueologia em Portugal. 2020 - Estado da Questão"*, edited by J. Morais Arnaud, C. Neves, and A. Martins, 987–100. Lisboa: Associação dos Arqueólogos Portugueses e CITCEM.

Birks, H. J. B., and A. D. Gordon. 1985. *Numerical Methods in Quaternary Pollen Analysis*, 317. London: Academic Press.

Bombico, S. 2015. "Salted Fish Industry in Roman Lusitania: Trade Memories Between *Oceanus* and *Mare Nostrum*." In *Heritages and Memories from the Sea*, edited by F. T. Barata and J. M. Rocha, 19–39. Évora: University of Évora.

Campos Carrasco, J. M., J. A. Pérez Macías, and N. O. Vidal Teruel. 1999. *Las Cetariae del litoral onubense en época romana*, 222. Huelva: Universidad de Huelva.

Carusi, C. 2008. "*Il sale nel mondo greco (VI a.C-III d.C). Luoghi di produzione, circolazione commerciale, regimi di sfruttamento nel contesto del Mediterraneo antico (Pragmateiai).*" *Edipuglia*, 324 pages. doi:10.1017/S0009840X13000838.

Castro Carrera, J. C. 2007. "La salina romana del yacimiento "O Areal", Vigo (Galicia): un complejo industrial salazonero altoimperial." In *Salsas y salazones de pescado en Occidente durante la Antigüedad", Actas del Congreso Internacional CETARIAE*, edited by L. Langóstena, D. Bernal, and A. Arévalo, 355–365. Oxford: British Archaeological Reports, International Series.

Castro Carrera, J. C. 2008. "La saline romaine de «O Area», Vigo (Galice): Architecture d'une installation industrielle de production de sel." In *Sel, eau et forêt d'hier à aujourd'hui"*, edited by O. Weller, A. Dufraisse, and P. Pétrequin, 381–399. Besançon: Presses Universitaires de Franche-Comté.

Castro Carrera, J. C., S. Prieto Robles, M. Sartal Lorenzo, Á Acuña Piñeiro, M. J. Iglesias Darriba, E. Rodríguez Sáiz, R. Tallón-Armada, and A. Férnandez Fernández. 2019. "La salina romana de evaporación solar de O Areal-Vigo (Galicia, España). Un ejemplo de arquitectura "efímera" conservada." In *Products and Perishable Materials in the Archaeological Record of Roman Times". Ephemeral Archaeology / Arqueología Efímera*, edited by A. Morillo Cerdán, M. Heinrich Hermanns, and J. Salido Domínguez, 127–142. Mainz am Rhein: Nünneric-Asmuc Verlag & Media.

Chevallier, R. 1991. "Réflexions sur le sel dans l'histoire romaine: un produit de première nécessité insaisissable." *Gerión. Revista de Historia Antigua* 53: 53–60. https://revistas.ucm.es/index.php/GERI/article/download/GERI9191220053A/14571/0.

Clark, J. G. D. 1952. *Prehistoric Europe: The Economic Basis*, 349. London: Methuen.

Costa-Casáis, M., R. Rodríguez Fernández, and A. Martínez Cortizas. 2007. *Toma de mostras e estudio paleoambiental da Unidade II, Parcela 3-6, correspondente ás salinas localizadas na Rúa Rosalía de Castro (Vigo)*. Preliminary report, 38 pages.

Costa-Casáis, M., R. Tallón Armada, C. Ferro Vázquez, J. Kaal, and A. Martínez Cortizas. 2008. *Estudo estratigráfico e xeoquímico do xacemento Unidade II Parcela P 3-6 da Rúa Rosalía de Castro (Vigo, Pontevedra)*. Report, 43 pages.

Costa Vaz, F., M. Martín-Seijo, S. Carneiro, and J. P. Tereso. 2016. "Waterlogged Plant Remains from the Roman Healing spa of Aquae Flaviae (Chaves, Portugal): Utilitarian Objects, Timber, Fruits and Seeds." *Quaternary International* 404 (Part A): 86–103. doi:10.1016/j.quaint.2015.09.063.

Currás, B. 2017. "The Salinae of O Areal (Vigo) and Roman Salt Production in NW Iberia." *Journal of Roman Archaeology* 30: 325–349. doi:10.1017/S1047759400074146.

Currás, A., L. Zamora, J. M. Reed, E. García-Soto, S. Ferrero, X. Armengol, F. Mezquita-Joanes, M. A. Marqués, S. Riera, and R. Julià. 2012. "Climate Change and Human Impact in Central Spain During Roman Times: High-Resolution Multi-Proxy Analysis of a Tufa Lake Record (Somolinos, 1280m asl)." *CATENA* 89: 31–53. doi:10.1016/j.catena.2011.09.009.

Desprat, S., M. F. Sáchez Goñi, and M.-F. Loutre. 2003. "Revealing Climatic Variability of the Last Three Millennia in Northwestern Iberia Using Pollen Influx Data." *Earth and Planetary Science Letters* 213: 63–78. doi:10.1016/S0012-821X(03)00292-9.

Domergue, C. 1987. *Catalogue des mines et des fonderies antiques de la Péninsule Ibérique*. Madrid.: Casa de Velázquez-Diffusion de Boccard.

Fernández Fernández, A., A. A. Rodríguez Nóvoa, P. Valle Abad, and N. Ruanova Álvarez. 2021. "La factoría de salazón romana de Praia do Naso (Illa de Arousa, Pontevedra)." *Minius* 26: 137–161. doi:10.35869/mns.v0i26.3932.

Fernández Fernández, A., P. Valle Abad, and A. A. Rodríguez Nóvoa. 2022. "3D Photogrammetry as a Tool for Studying Erosive Processes at a Roman Coastal Site: The Case of the Roman Fish-Salting Plant at Sobreira (Vigo, Spain)." *Archaeological and Anthropological Sciences* 14: 32. doi:10.1007/s12520-022-01508-3.

Fernández Ochoa, C., and J. Martínez Maganto. 1994. "Las Industrias de Salazón en el Norte de la Península Ibérica en época Romana: Nuevas Aportaciones." *Archivo Español de Arqueología* 67: 115–134. doi:10.3989/aespa.1994.v67.429.

Fægri, K., and J. Iversen. 1989. *Textbook of Pollen Analysis, IV ed.* (K. Fægri, P.E. Kaland and K. Krzywinski Eds.). Chichester: Wiley.

Groove, J. M. 1988. *Little Ice Ages: Ancient and Modern*. 2nd ed. London: Routledge.

Guitián, F., and T. Carballas. 1976. *Técnicas de análisis de suelos*. Santiago de Compostela: Pico Sacro.

Harding, A. 2013. *Salt in Prehistoric Europe*, 162. Leiden: Sidestone Press.

Heiri, O., A. F. Lotter, and G. Lemacke. 2001. "Loss-on-ignition for Estimating Organic and Carbonate Content in Sediments: Reproducibility and Comparability of Results." *Journal of Paleolimnology* 25: 101–110. doi:10.1023/A:1008119611481.

Hillman, A.-L., M. B. Abbott, B. L. Valero-Garcés, M. Morellón, F. Barreiro-Lostres, and D. J. Bain. 2017. "Lead Pollution Resulting from Roman Gold Extraction in Northwestern Spain." *The Holocene* 27: 1465–1474. doi:10.1177/0959683617693903.

Horák-Terra, I., A. Martínez Cortizas, C. Fernandes Pinto da Luz, P. Rivas López, A. C. Silva, and P. Vidal-Torrado. 2015. "Holocene Climate Change in Central–Eastern Brazil Reconstructed Using Pollen and Geochemical Records of Pau de Fruta Mire (Serra do Espinhaço Meridional, Minas Gerais)." *Palaeogeography, Palaeoclimatology, Palaeoecology* 437: 117–131. doi:10.1016/j.palaeo.2015.07.027.

Iglesias Darriba, M. J. 2009. Avaliación arqueolóxica das parcelas 6, 10, 6 anexo e 3 anexo, da Unidade de Actuación I-06, Rosalía de Castro II, Vigo." In *Actuacións Arqueolóxicas. Ano 2007*, 174–175. Santiago de Compostela.

Iglesias Darriba, M. J. 2010. Avaliación arqueolóxica da parcela 3 da Unidade de actuación I-06 de Rosalía de Castro II, Vigo." In *Actuacións Arqueolóxicas, Ano 2008*, 206–207. Santiago de Compostela.

Iglesias Darriba, J., A. Acuña Piñeiro, J. C. Castro Carrera, S. Prieto Robles, M. A. Sartal Lorenzo, E. Rodríguez Sáinz, and A. Fernández Fernández. 2017. "Estudio preliminar de la salina romana de evaporación solar de O Areal-Vigo (Galicia, España)." *L'exploitation des ressources maritimes de l'Antiquité. Activités protductives et organitsation des territoires. Actes des XXXVII rencontres internationales d'archéologie et d'histoire d'Antibes*, 213–234.

Kylander, M. E., D. J. Weiss, A. Martínez Cortizas, B. Spiro, R. Garcia-Sanchez, and B. J. Coles. 2005. "Refining the pre-Industrial Atmospheric Pb Isotope Evolution Curve in Europe Using an 8000 Year old Peat Core from NW Spain." *Earth and Planetary Science Letters* 240: 467–485. doi:10.1016/j.epsl.2005.09.024.

Lagóstena Barrios, L. 2001. La producción de salsas y conservas de pescado en la Hispania romana (II a.C.–VI d.C.). Instrumenta 11; Publicacions i Edicions de la Universitat de Barcelona, pp. 503.

López-Costas, O. 2021. "Estilo de vida durante el priscilianismo: aproximaciones bioarqueológicas." *Gerión. Revista de Historia Antigua* 39 (2): 775–800. doi:10.5209/geri.78127.

López-Costas, L., M. Kylander, N. Mattielli, N. Álvarez-Fernández, M. Pérez-Rodríguez, T. Mighall, R. Bindler, and A. Martínez Cortizas. 2020. "Human Bones Tell the Story of Atmospheric Mercury and Lead Exposure at the Edge of Roman World." *Science of The Total Environment* 710: 136319. doi:10.1016/j.scitotenv.2019.136319.

López-Merino, L., S. A. G. Leroy, A. Eshel, V. Epshtein, R. Belmaker, and R. Bookman. 2016. "Using Palynology to Re-Assess the Dead Sea Laminated Sediments – Indeed Varves?" *Quaternary Science Reviews* 140: 49–66. doi:10.1016/j.quascirev.2016.03.024.

López-Merino, L., J. A. López-Sáez, D. Abel Schaad, F. J. Sánchez-Palencia, and G. S. Reher Díez. 2008. "Dinámica antrópica en El Bierzo (León) desde época romana: estudio palinológico de Castro Ventosa." *Polen* 18: 25–36. doi:10.14201/pol.v18i0.7397.

López-Merino, L., J. A. López-Sáez, F. J. Sánchez-Palencia, G.-S. Reher Díez, and S. Pérez Díaz. 2009. "Castaños, nogales y cereales: la antropización de los paisajes de Asturias y León en época romana." *Cuadernos de la Sociedad Española de Ciencias Forestales* 30: 93–99. doi:10.31167/csef.v0i30.10077.

López-Merino, L., A. Martínez Cortizas, and J. A. López-Sáez. 2011. "Human-induced Changes on Wetlands: A Study Case from NW Iberia." *Quaternary Science Reviews* 30 (19-20): 2745–2754. doi:10.1016/j.quascirev.2011.06.004.

López-Merino, L., A. Martínez Cortizas, G. S. Reher, J. A. López-Sáez, T. M. Mighall, and R. Bindler. 2014. "Reconstructing the Impact of Human Activities in a NW Iberian Roman Mining Landscape for the Last 2500 Years." *Journal of Archaeological Science* 50: 208–218. doi:10.1016/j.jas.2014.07.016.

López-Merino, L., L. Peña-Chocarro, M. Ruiz-Alonso, J. A. López-Sáez, and F. J. Sánchez-Palencia. 2010. "Beyond Nature: The Management of a Productive Cultural Landscape in Las Médulas área (El Bierzo, León, Spain) During pre-Roman and Roman Times." *Plant Biosystems* 144 (4): 909–926. doi:10.1080/11263504.2010.491976.

López-Merino, L., N. Silva-Sánchez, A. Martínez Cortizas, J. Kaal, and J. A. López-Sáez. 2012. "Post-disturbance Vegetation Dynamics During the Late Pleistocene and the Holocene: An Example from NW Iberia." *Global and Planetary Change* 92-93: 58–70. doi:10.1016/j.gloplacha.2012.04.003.

López-Sáez, J. A., and L. López-Merino. 2005. "Precisiones metodológicas acerca de los indicios paleopalinológicos de agricultura en la Prehistoria de la Península Ibérica." *Portugalia* 26: 53–64. https://ojs.letras.up.pt/index.php/Port/article/view/3812.

Lowe, B. 2018. "Manilus and the Logistics of Salting in the Roman World." *Journal of Maritime Archaeology* 13 (3): 467–480. doi:10.1007/s11457-018-9220-4.

Lüning, S., L. Schulte, S. Garcés-Pastor, I. B. Danladi, and M. Gałka. 2019. "The Medieval Climate Anomaly in the Mediterranean Region." *Paleoceanography and Paleoclimatology* 34: 1625–1649. doi:10.1029/2019PA003734.

Martins, J. F. F. 2019. *Construção, exploração, administração e dispersão territorial de salinae maritimae em época romana no Noroeste peninsular*. Master dissertation, Universidade de Coimbra, 342 pp.

Martín-Seijo, M. 2019. "Madera y sal: estructuras y objetos de madera recuperados en las salinas romanas de O Areal (Vigo, Galicia)." In *Products and Perishable Materials in the Archaeological Record of Roman Times". Ephemeral Archaeology / Arqueología Efímera*, edited by A. Morillo Cerdán, M. H. Hermanns, and J. Salido Domínguez, 179–192. Oppenheim: Nünneric-Asmuc Verlag & Media, Mainz am Rhein.

Martín-Seijo, M., and Y. Carrión Marco. 2012. "Shaping Wood: Woodworking During the Iron Age and Roman Period in the Northwest of the Iberian Peninsula." In *Wood and Charcoal. Evidence for Human and Natural History*, edited by E. Badal, Y. Carrión, M. Macías, and M. Ntinou (coords.), 135–144. Valencia: *SAGVNTVM* Extra-13.

Martín-Seijo, M., and A. Teira-Brión. 2010. "Análise dos restos arqueobotánicos das saíñas do Areal (Vigo, Pontevedra)." In *Guía de Arqueobotánica*, edited by M. Martín-Seijo, A. Rico Rey, A. Teira-Brión, I. Picón Platas, I. García González, and E. Abad Vidal, 3–143. Santiago de Compostela: Xunta de Galicia.

Martínez Cortizas, A., and M. Costa Casais. 1997. "Indicios de las variaciones del nivel del mar en la Ría de Vigo durante los últimos 3000 años." *Gallaecia* 16: 23–47.

Martínez Cortizas, A., C. Ferro Vázquez, J. Kaal, H. Biester, M. Costa Casais, T. Taboada Rodríguez, and L. Rodríguez Lado. 2016. "Bromine Accumulation in Acidic Black Colluvial Soils." *Geochimica et Cosmochimia Acta* 174: 143–155. doi:10.1016/j.gca.2015.11.013.

Martínez Cortizas, A., E. García-Rodeja, X. Pontevedra Pombal, J. C. Nóvoa-Muñoz, D. Weiss, and A. Cherbukin. 2002. "Atmospheric Pb Deposition in Spain During the Last 4600 Years Recorded by two Ombrotrophic Peat Bogs and Implications for the use of Peat as Archive." *Science of the Total Environment* 292 (1-2): 33–44. doi:10.1016/S0048-9697(02)00031-1.

Martínez Cortizas, A., I. Horák-Terra, M. Pérez-Rodríguez, R. Bindler, C. A. Cooke, and M. Kylander. 2021. "Structural Equation Modelling of Long-Term Controls on Mercury and Bromine Accumulation in Pinheiro Mire (Minas Gerais, Brazil)." *Science of The Total Environment* 757: 143940. doi:10.1016/j.scitotenv.2020.143940.

Martínez Cortizas, A., L. López-Merino, R. Bindler, T. Mighall, and M. Kylander. 2013. "Atmospheric Pb Pollution in N Iberia During the Late Iron Age/Roman Times Reconstructed Using the High-Resolution Record of La Molina Mire (Asturias, Spain)." *Journal of Paleolimnology* 50: 71–86. doi:10.1007/s10933-013-9705-y.

Martínez Cortizas, A., X. Pontevedra-Pombal, J. C. Nóvoa-Muñoz, and E. García-Rodeja. 1997. "Four Thousand Years of Atmospheric Pb, Cd and Zn Deposition Recorded by the Ombrotrophic Peat bog of Penido Vello." *Water, Air, and Soil Pollution* 100: 387–403. doi:10.1023/A:1018312223189.

Martínez Cortizas, A., X. Pontevedra Pombal, J. C. Nóvoa Muñoz, E. García-Rodeja, and W. Shotyk. 1999. "Mercury in a Spanish Peat bog: Archive of Climate Change and Atmospheric Metal Deposition." *Science* 284: 939–942. doi:10.1126/science.284.5416.939.

McPartland, J. M., G. W. Guy, and W. Hegman. 2018. "*Cannabis* is Indigenous to Europe and Cultivation Began During the Copper or Bronze age: A Probabilistic Synthesis of Fossil Pollen Studies." *Vegetation History and Archaeobotany* 27: 635–648. doi:10.1007/s00334-018-0678-7.

Mercuri, A., C. Accorsi, and M. Bandini Mazzanti. 2002. "The Long History of *Cannabis* and its Cultivation by the Romans in Central Italy, Shown by Pollen Records from Lago Albano and Lago di Nemi." *Vegetation History and Archaeobotany* 11: 263–276. doi:10.1007/s003340200039.

Mighall, T. M., A. Martínez Cortizas, H. Biester, and S. E. Turner. 2006. "Proxy Climate and Vegetation Changes During the Last Five Millennia in NW Iberia: Pollen and non-Pollen Palynomorph Data from two Ombrotrophic Peat Bogs in the North Western Iberian Peninsula." *Review of Palaeobotany and Palynology* 141: 203–223. doi:10.1016/j.revpalbo.2006.03.013.

Mighall, T. M., A. Martínez Cortizas, N. Silva-Sánchez, O. López-Costas, and L. López-Merino. 2023. "Climate Change, Fire and Human Activity Drive Vegetation Change During the Last Eight Millennia in the Xistral Mountains of NW Iberia." *Quaternary* 6 (1): 5. doi:10.3390/quat6010005.

Moore, P. D., J. A. Webb, and M. E. Collinson. 1991. *Pollen Analysis*. 2nd ed. Oxford: Blackwell Scientific Publications.

Moreno, A., A. Pérez, J. Frigola, V. Nieto-Moreno, M. Rodrigo-Gámiz, B. Martrat, P. González-Sampériz, et al. 2012. "The Medieval Climate Anomaly in the Iberian Peninsula Reconstructed from Marine and Lake Records." *Quaternary Science Reviews* 43: 16–32. doi:10.1016/j.quascirev.2012.04.007.

Muñoz Sobrino, C., S. García-Gil, J. B. Diez, and J. Iglesias. 2007. "Palynological Characterization of Gassy Sediments in the Inner Part of Ría de Vigo (NW Spain)." *New Chronological and Environmental Data. Geo-Marine Letters* 27: 289–302. doi:10.1007/s00367-007-0078-y.

Muñoz Sobrino, C., I. García-Moreiras, Y. Castro, N. Martínez Carreño, E. de Blas, C. Fernandez Rodríguez, A. Judd, and S. García-Gil. 2014. "Climate and Anthropogenic Factors Influencing an Estuarine Ecosystem from NW Iberia: New High Resolution Multiproxy Analyses from San Simón Bay (Ría de Vigo)." *Quaternary Science Reviews* 93: 11–33. doi:10.1016/j.quascirev.2014.03.021.

Nenquin, J. A. E. 1961. *Salt. A Study in Economic Prehistory. Dissertationes Archaeologicae Gandenses*. Vol. 6, 161 pages. Gent: De Tempel

Oliva, M., J. Ruiz-Fernández, M. Barriendos, G. Benito, J. M. Cuadrat, F. Domínguez-Castro, J. M. García-Ruiz, et al. 2018. "The Little Ice Age in Iberian Mountains." *Earth-Science Reviews* 177: 175–208. doi:10.1016/j.earscirev.2017.11.010.

Orejas, A., and F. J. Sánchez-Palencia. 2002. "Mines, Territorial Organization, and Social Structure in Roman Iberia." *American Journal of Archaeology* 106: 581–599. doi:10.2307/4126218.

Otero, X. L., and F. Macías. 2001. "Caracterización y clasificación de los suelos de marismas de la Ría de Ortigueira en relación con su posición fisiográfica y vegetación (Galicia-NO de la península ibérica)." *Edafología* 8 (3): 37–62. www.edafologia.net/revista/tomo8c/a37v8t.pdf.

Pantaleón-Cano, L., R. Pérez-Obiol, E. I. Yll, J. M. Roure, et al. 1996. "Significado de Pseudoschizaea en secuencias sedimentarias de la vertiente mediterránea de la Península Ibérica e islas Baleares." In *Estudios Palinológicos, XI Simposio de palinología (APLE)*, edited by M. B. Ruiz Zapata, 101–105. Alcalá de Henares: Universidad de Alcalá de Henares.

Peña-Chocarro, L., G. Pérez- Jordà, N. Alonso, F. Antolín, A. Teira-Brión, J. P. Tereso, E. M. Montes Moya, and D. López Reyes. 2019. "Roman and Medieval Crops in the Iberian Peninsula: A First Overview of Seeds and Fruits from Archaeological Sites." *Quaternary International* 499: 49–66. doi:10.1016/j.quaint.2017.09.037.

Peña-Chocarro, L., and L. Zapata. 1996. "Los recursos vegetales en el mundo romano: estudio de los macrorrestos botánicos del yacimiento calle Santiago de Irún (Guipúzcoa)." *Archivo Español de Arqueología* 69 (173-174): 119–134. doi:10.3989/aespa.1996.v69.237.

Peña-Chocarro, L., and L. Zapata. 2005. "Trade and new Plant Foods in the Western Atlantic Coast: The Roman Port of Irun (Basque Country)." In *Mar Exterior*, edited by M. Urteaga and M. J. Noain, 169–177. Roma: El occidente atlántico en época romana, Escuela Española de Historia y Arqueología en Roma - CSIC.

Pérez Losada, F., A. Fernández Fernández, and S. Vieito Covela. 2007. "Resultados preliminares das escavacións arqueolóxicas na villa romana de Toralla (Oia, Vigo)." *Castrelos* 13: 12–25.

Pinto, I. V., A. P. Magalhães, and P. Brum. 2014. "An Overview of the Fish-Salting Production Centre at Tróia (Portugal)." In *Fish & Ships: Production et* *commerce des salsamenta durant l'Antiquité*, edited by E. Botte and V. Leitch, 145–157. Aix-en-Provence: Publications du Centre Camille Jullian.

Pliny. 1906. "Natural History 21.86.7. Digital Version in the Packard Humanities Institute Latin Texts Online." In *Naturalis Historiae*, edited by K. F. T. Mayhoff. Lipsiae: Bibliotheca scriptorum Graecorum et Romanorum Teubneriana.

Provan, D. M. J. 2010. "Soil Phosphate Analysis as a Tool in Archaeology." *Norwegian Archaeological Review* 4: 37–50. doi:10.1080/00293652.1971.9965134.

Puche Riart, O. 2019. "Estado actual del patrimonio salinero español." In *II Congreso Internacional sobre la Sal, 15-16 November 2018*, 329–366. Madrid: Ciempozuelos.

Reille, M. 1992. *Pollen et Spores d'Europe et d'Afrique du Nord*. Marseille: Laboratoire de Botanique Historique et Palynologie, CNRS.

Reille, M. 1995. *Pollen et spores d'Europe et d'Afrique du Nord, Supplément 1*. Marseille: Laboratoire de Botanique Historique et Palynologie.

Reille, M. 1998. *Pollen et spores d'Europe et d'Afrique du Nord, Supplément 2*. Marseille: Laboratoire de Botanique Historique et Palynologie.

Reimer, P. J., W. E. N. Austin, E. Bard, A. Bayliss, P. G. Blackwell, C. Bronk Ramsey, M. Butzin, et al. 2020. "The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP)." *Radiocarbon* 62 (4): 725–757. doi:10.1017/RDC.2020.41.

Renault-Miskovsky, J., M. Girard, and M. Trouin. 1976. "Observations de quelques pollens d'Oléacées au microscope électronique à balayage." *Bulletin de l'Association française pour l'Étude du Quaternarie* 2: 71–86. doi:10.3406/quate.1976.1278.

Riera, S., J. A. López-Sáez, and R. Julià. 2006. "Lake Responses to Historical Land use Changes in Northern Spain: The Contribution of non-Pollen Palynomorphs in a Multiproxy Study." *Review of Palaeobotany and Palynology* 141 (1-2): 127–137. doi:10.1016/j.revpalbo.2006.03.014.

Riera, S., G. Wansard, and R. Julià. 2004. "2000-year Environmental History of a Karstic Lake in the Mediterranean Pre-Pyrenees: The Estanya Lakes (Spain)." *Catena* 55 (3): 293–324. doi:10.1016/S0341-8162(03)00107-3.

Rodríguez Martínez, R. M., R. Aboal Fernández, V. Castro Hierro, C. Cancela Cereijo, and X. M. Ayán Vila. 2011. "Una posible factoría prerromana en el noroeste. Primeras valoraciones de la intervención en el campo de A Lanzada (Sanxenxo, Pontevedra)." *Férvedes* 7: 167–173.

Rull, V. 2022. "Origin, Early Expansion, Domestication and Anthropogenic Diffusion of *Cannabis*, with Emphasis on Europe and the Iberian Peninsula." *Perspectives in Plant Ecology, Evolution and Systematics* 125670. doi:10.1016/j.ppees.2022.125670.

Rull, V., F. Burjachs, J. S. Carrión, A. Ejarque, S. Fernández, J. A. López-Sáez, R. Luelmo-Lautenschlaeger, et al. 2023. "Historical Biogeography of *Cannabis* in the Iberian Peninsula: A Probabilistic Approach Using Palynological Evidence." *Perspectives in Plant Ecology, Evolution and Systematics* 58: 125704. doi:10.1016/j.ppees.2022.125704.

Rull, V., and T. Vegas-Vilarrúbia. 2014. "Preliminary Report on a mid-19th Century *Cannabis* Pollen Peak in NE Spain: Historical Context and Potential Chronological Significance." *The Holocene* 24 (10): 1378–1383. doi:10.1177/095968361454096.

Rull, V., T. Vegas-Vilarrúbia, J. P. Corella, M. C. Trapote, E. Montoya, and B. Valero-Garcés. 2021. "A Unique Pyrenean Varved Record Provides a Detailed Reconstruction of Mediterranean Vegetationvand Land-use Dynamics Over the Last Three Millennia." *Quaternary Science Reviews* 268: 107128. doi:10.1016/j.quascirev.2021.107128.

Schellekens, J., P. Buurman, I. Fraga, and A. Martínez Cortizas. 2011. "Holocene Vegetation and Hydrologic Changes Inferred from Molecular Vegetation Markers in Peat, Penido Vello (Galicia, Spain)." *Palaeogeography, Palaeoclimatology, Palaeoecology* 299 (1-2): 56–69. doi:10.1016/j.palaeo.2010.10.034.

Schlesinger, W. H. 2000. *Biogeoquímica, un análisis del cambio global*, 1st ed., 170. Barcelona: Editorial Ariel.

Shumilovskikh, L., J. M. K. O'Keefe, and F. Marret. 2021. "An Overview of the Taxonomic Groups of non-Pollen Palynomorphs." In *Applications of Non-Pollen Palynomorphs: From Palaeoenvironmental Reconstructions to Biostratigraphy*, 13–61, edited by F. Marret, J. O'Keefe, P. Osterloff, M. Pound, and L. Shumilovskikh. London: Geological Society. Special Publications 511.

Silva-Sánchez, N. 2010. *Cambios ambientales en los últimos 3000 años en el sector occidental de la Sierra del Bocelo a partir de indicadores geoquímicos y palinológicos*. Santiago de Compostela: Universidade de Santiago de Compostela, Tesina.

Silva-Sánchez, N., and X.-L. Armada. 2023. "Environmental Impact of Roman Mining and Metallurgy and its Correlation with the Archaeological Evidence: A European Perspective." *Environmental Archaeology*. doi:10.1080/14614103.2023.2181295.

Silva-Sánchez, N., A. Martínez Cortizas, and L. López-Merino. 2014. "Linking Forest Cover, Soil Erosion and Mire Hydrology to Late-Holocene Human Activity and Climate in NW Spain." *The Holocene* 24: 714–725. doi:10.1177/0959683614526934.

Stuiver, M., P. J. Reimer, and R. W. Reimer. 2021. CALIB 8.2 [WWW program] at http://calib.org, accessed 2021-3-1.

Suárez Piñeiro, A. M. 2003. "La explotación del mar en la Galicia romana: el ejemplo de las instalaciones de salazón." *Cuadernos De Estudios Gallegos* 50 (116): 9–25. doi:10.3989/ceg.2003.v50.i116.120.

Tallón-Armada, R. 2012. Marco evolutivo dunha explotación salineira de época romana (Vigo, Pontevedra). Memoria de Licenciatura, Universidade de Santiago de Compostela, pp. 109.

Tallón-Armada, R., M. Costa-Casais, R. Blanco-Chao, T. Taboada Rodríguez, and A. Martínez Cortizas. 2018. "Paleoenvironmental Reconstruction of an Urban Archaeological Site: The Roman Salt Mines of Vigo, Northwest Iberia." *Geoarchaeology* 33 (1): 112–126. doi:10.1002/gea.21648.

Tallón-Armada, R., M. Costa-Casais, and T. Taboada. 2015. "Evolución de un sector costero durante la Alta Edad Media en el NW de la península Ibérica." *Estudos do Quaternário* 12: 27–38. http://www.apeq.pt/ojs/index.php/apeq.

Tallón-Armada, R., M. Costa-Casais, T. Taboada, and A. Martínez Cortizas. 2013. "Reconfiguración de la línea de costa en un sector de explotación salinera de época romana en el NO de España." In *Geotemas: Vii Jornadas de Geomorfología Litoral*, edited by G. Flor Rodríguez, G. Flor-Blanco, and L. A. Pando Gonzalez, 211–214. Oviedo: Sociedad Geológica de España.

Teira-Brión, A. 2010. "Wild Fruits, Domesticated Fruits. Archaeobotanical Remains from the Roman Saltworks at O Areal, Vigo (Galicia, Spain).” In *Des hommes et des plantes. Exploitation du milieu et gestion des resources végétales de la Préhistoire à nous jours, vol XXXe rencontres internationales d'archéologie et d'histoire d'Antibes*, edited by C. Delhon, I. Théry-Parisot, and S. Tiébault, 199–207. Antibes: Éditions APDCA.

Teira-Brión, A. 2022. “Understanding the Plant Economy in the Westernmost Territory of the Roman State Through Waste: The wet Site of O Areal (Vigo, Spain).” *Vegetation History and Archaeobotany* 31: 595–610. doi:10.1007/s00334-022-00878-x.

Ubera, J. L., C. Galán, and F. H. Guerrero. 1988. “Palynological Study of the Genus *Plantago* in the Iberian Peninsula.” *Grana* 27: 1–15. doi:10.1080/00173138809427728.

Urrutia, M. M., E. García-Rodeja, and F. Macías. 1989. “Determinación del pH en suelos de carga variable de Galicia.” *Anales de Edafología y Agrobiología* 48 (3-4): 219–228.

Valle Abad, P., A. Fernández Fernández, and Á Acuña Piñeiro. 2020. “Analysis of the Western Late-Roman Cemetery of O Areal: Example of an Atlantic Coastal Funerary Site in the Harbour of Vigo (Spain).” *Journal of Maritime Archaeology* 15: 393–414. doi:10.1007/s11457-020-09274-w.

van Geel, B. 2002. “Non-pollen Palynomorphs.” In *Tracking Environmental Change Using Lake Sediments. Volumen 3: Terrestrial, Algal, and Siliceous Indicators*, edited by J. P. Smol, H. J. B. Birks, W. M. Last, R.S. Bradley, and K. Alverson, 99–120. Dordrecht.: Kluwer Academic Publishers.

van Geel, B., B. V. Odgaard, and M. Ralska-Jasiewiczowa. 1996. “Cyanobacteria as Indicators of Phosphate-Eutrophication of Lakes and Pools in the Past.” *Pact* 50: 399–415. https://hdl.handle.net/11245/1.119983.

Vít, P., J. Douda, K. Krak, A. Havrdová, and B. Mandák. 2017. “Two new Polyploid Species Closely Related to *Alnus glutinosa* in Europe and North Africa – An Analysis Based on Morphometry, Karyology, Flow Cytometry and Microsatellites.” *Taxon* 66 (3): 567–583. doi:10.12705/663.4.

Weller, O. 2002. “The Earliest Rock Salt Exploitation in Europe. A Salt Mountain in Spanish Neolithic.” *Antiquity* 76 (292): 317–318. doi:10.1017/S0003598X0009030X.

Wilson, A. 2009. “Chapter 9: Approaches to Quantifying Roman Trade.” In *Quantifying the Roman Economy: Methods and Problems*, edited by A. Bowman, and A. Wilson. Oxford Studies on the Roman Economy. (online edn., Oxford Academic), doi:10.1093/acprof:oso/9780199562596.003.0009, accessed 6 Feb. 2023