From the Roman Empire to the present: Two millennia of pollen-based environmental changes and climate-human interactions in the Po Delta area (NE Italy)

Published Version:
Cacciari, M., Amorosi, A., Marchesini, M., Marvelli, S., Rossi, V. (2024). From the Roman Empire to the present: Two millennia of pollen-based environmental changes and climate-human interactions in the Po Delta area (NE Italy). THE HOLOCENE, 34(9), 1225-1241 [10.1177/09596836241254487].

Availability:
This version is available at: https://hdl.handle.net/11585/1002728 since: 2025-01-22

Published:
DOI: http://doi.org/10.1177/09596836241254487

(Article begins on next page)

From the Roman Empire to the Present: two millennia of pollen-based environmental changes and climate-human interactions in the Po Delta area

Marco Cacciari[a*], Alessandro Amorosi[a], Marco Marchesini[b,c], Silvia Marvelli[c], Veronica Rossi[a]
a) Department of Biological, Geological and Environmental Sciences (BiGeA), University of Bologna, Piazza di Porta San Donato 1, 40126, Bologna, Italy
b) Department of Human and Social Sciences, University of Ferrara, via Ercole I d'Este 32, 44121 Ferrara, Italy
c) Laboratorio di Palinologia, C.A.A. – Centro Agricoltura e Ambiente "Giorgio Nicoli", via Marzocchi 17, 40017 San Giovanni in Persiceto (BO), Italy

Keywords: prodelta, Po Plain, wetlands, river floods, Late Antiquity, pollen, Little Ice Age

ABSTRACT
Holocene prodelta lobes are key sedimentary archives of environmental change that can be used effectively for high-resolution palynological investigations, as they: *i)* consist almost entirely of mud, *ii)* represent stratigraphically expanded successions, and *iii)* are strictly related to river dynamics, thus reflecting vegetation changes in river catchments. In this study, we focused on the ~20 m-thick prodelta succession of the modern Po Delta (NE Italy), fed by two river branches (Volano and Goro) that were mostly active during the past two millennia, a period of rapid acceleration of natural resources' exploitation and climate variability. Forty-eight samples with mean temporal resolution of 50 years were analysed. Eleven ecological groups and four pollen zones were identified, with distinct peaks of the secondary-primary pollen ratio marking major floods during the Volano-Goro lobe switching and the Little Ice Age. Five vegetation phases were detected since the 1st century AD. In the framework of a patchy natural-cultural landscape, patterns of wetland expansion/contraction reflect the combined effect of cool-wet oscillations (LALIA – Late Antique Little Ice Age), land management (reclamations) and river avulsion. Forest dynamics document warm conditions during the so-called "Roman Climate Optimum" and "Medieval Warm Period", although minor cool-wet episodes occurred in tune with solar minima, and bipartite climate conditions (cool-moist followed by cool-dry) characterized the LALIA. Since the 14th century, despite human-induced forest shrinking, peaks of montane vegetation followed a centennial-scale cyclicity likely influenced by solar minima and major plagues.

Introduction

Decoding the dynamic interactions between environmental variability, climate oscillations and human activities through the last millennia is fundamental for the development of landscape conservation and restoration strategies. This fascinating, but challenging, task requires a multi-proxy approach, a firm chronological framework and appropriate stratigraphic archives (eg, Dearing, 2006; Zanchetta, 2013; Dubois et al., 2018; Roberts et al., 2019).

As a hotspot of the world civilization, the Mediterranean region hosts a myriad of archaeological sites that preserve the record of an enduring relationship among environment, climate and societal evolution. Several in-site or site-proximal (*sensu* Mayoral et al., 2020) sedimentary successions have been studied through the geoarchaeological analysis of cores and trenches, searching for evidence of the natural-to-cultural landscape shift. These studies (eg, Marriner et al., 2008; Goiran et al., 2010; Kaniewski et al., 2013, 2022; Pepe et al., 2013; Pint et al., 2015; Sarti et al., 2015; Shumilovskikh et al., 2016; Ghilardi et al., 2018) benefitted from a multivariate dataset, including lithological (eg, grain-size, geochemistry, magnetic susceptibility) and palaeobiological (eg, molluscs, meiofauna, palynomorphs, diatoms) data, as well as manufactured materials and historical documents. However, off-site archives accumulated in inland and coastal wetlands (ie, lakes, marshlands and peatlands, lagoons) have commonly furnished a longer and relatively continuous record of landscape changes, ensuring the documentation of "pre-impact" conditions and the earliest advent of the anthropogenic forcing (eg, Di Rita and Magri, 2012; Vittori et al., 2015; Di Rita et al., 2022; Susini et al., 2023).
Within these mud-dominated successions, well-preserved palaeobiological proxies enable the reconstruction

of ecosystems ("one physical systems" *sensu* Tansley, 1935; Richter and Billings, 2015) variability and drivers at millennial to sub-millennial timescales (eg, Bellotti et al., 2016; Ejarque et al., 2016; Melis et al., 2018; D'Orefice et al., 2020; Rossi et al., 2021). Pollen and spores, in particular, are considered key indicators, as their stratigraphic distribution tracks changes in past vegetation communities in relation to changes in natural conditions (eg, drainage patterns, coastline configuration, precipitation, temperature) and/or land-use (eg, Di Rita and Magri, 2012; Mercuri and Sadori, 2013; Mercuri et al., 2013; Sadori, 2013).

Moreover, the environmental-facies signal, which is particularly strong within paludal (Cacciari et al., 2020; Amorosi et al., 2021), alluvial (Marchesini et al., 2010) and lake margin (Sadori et al., 2004) settings, is strongly influenced by local conditions (eg, water-table level, degree of humidity, salinity), possibly shadowing climate and anthropic footprints. By contrast, marine records from the shelf or in proximity of river mouths proved effective in investigating environmental dynamics in relation to climatic fluctuations and human activities (Di Rita et al., 2018; Michelangeli et al., 2022).

In this regard, following a source-to-sink perspective, prodelta lobes can represent promising sedimentary archives for a comprehensive landscape reconstruction, as they preserve palynomorphs that reflect the palaeovegetation of the river basin (or, at least, of its distal portion) with no need to weigh the facies signal of the hosting deposit. Although rather underexplored, Mid-Late Holocene prodelta successions also guarantee a good preservation of palynomorphs and a high-resolution record, owing to the fine-grained nature of their deposits and high accumulation rates (up to cm/yr). The high potential of prodelta pollen assemblages and the predominant role played by river courses as vectors for pollen grains onto river-influenced shelves have been documented by Beaudouin et al. (2005, 2007) from the subaqueous portion of the Rhône Delta (Gulf of Lions, W Mediterranean).

In this study, we examine the historical record of the Po Delta (N Adriatic Sea; Figure 1), one of the largest Mediterranean deltaic systems, which also proved to be sensitive to changing human land-use in its catchment (Maselli and Trincardi, 2013; Stefani, 2017; Ninfo et al., 2018). Specifically, we focus on the last two millennia, which have seen an increasing intermixture of human activities and climate variability on the landscape, and the transition from a state of nature-domination to one of human-domination (Zanchetta, 2013 and references herein) associated with a lengthy and intense settlement since proto-historic times (Anthony et al., 2014). Our main objective is to foster knowledge of the long-term processes that determined the present landscape configuration by exploiting the palynological record of a prodelta succession accumulated in the Po Delta (Figure 1A). With the support of a robust stratigraphic and geomorphological framework furnished by previous works (eg, Stefani and Vincenzi, 2005; Correggiari et al., 2015; Amorosi et al., 2017, 2019a), we specifically aim to: *i)* explore the potential of delta lobes to preserve relatively continuous palynological archives and *ii)* investigate the interaction among vegetation patterns, river dynamics, climate and human activities during the last ~2000 years.

Study area

Geological and stratigraphic setting

[insert Figure 1]

The ~650 km-long Po River flows from West to East across the wide alluvial Po Plain (watershed of ~74,500 km^2) and empties into the Adriatic Sea, a narrow (~200 x 800 km), microtidal (tidal range currently < 1 m; Sedrati et al., 2011) basin elongated between the Italian and the Balkan peninsulas (Figure 1A). The Po Delta is part of a broad coastal area bounded by the Adige River Delta and the Venice Lagoon to the north and by the Northern Apennines to the south. Its delta plain, located below the mean sea level for about half of its extension, outstretches up to ~30 km inland of the present coastline and includes several wetlands, partly reclaimed, ancient river branches and beach ridges (Correggiari et al., 2005; Figure 1A).

The Quaternary sedimentary fill of the Po Basin consists of vertically stacked transgressive-regressive cycles composed of alternating shallow-marine and continental deposits developed under a Milankovitch-scale forcing (ie, 100 kyr oscillations; Amorosi et al., 2004). A weakly developed palaeosol formed during the

Younger Dryas and overlain by backstepping estuarine deposits demarcates the Holocene transgressive surface (Amorosi et al., 2017; Figure 1B).

Following the relative sea-level (RSL) stabilisation around 8-7 kyrs BP (Vacchi et al., 2016), a complex pattern of delta outbuilding and shoreline progradation characterised the coastal system (Figure 1B). The activation and abandonment of delta lobes, testified by geological data and historical sources, reflect repeated episodes of channel avulsion and shifting along a > 70 km wide coastal stretch under the influence of subsidence, climate fluctuations and human land-use (eg, Correggiari et al., 2005; Stefani, 2017; Cremonini, 2021). Specifically, a three-fold delta progradation was reconstructed (Amorosi et al., 2019b). After the filling of the Po estuary through bay-head delta progradation (Bruno et al., 2017) around 7000 yrs BP, a shallow, wave-dominated deltaic-coastal system with extensive inter-distributary wetlands weakly prograded (~2.5 m/yr) south of the modern Po Delta under the combined influence of fluvial avulsions and longshore drift. During this period, several Po River branches were alternately active (eg, Po di Adria, Po di Spina, Po di Primaro).

Since about 2000 yrs BP, a rapidly prograding (up to ~15 m/yr) set of lobes has accumulated into ~30 m-deep waters (Amorosi et al., 2019b; Figure 1A-B). The oldest delta lobe of the Roman Republican Age is ascribed to the Po di Ariano (the present-day Po di Goro), while the Po di Volano lobe mostly prograded from the Late Roman to the Early Middle Age (Ciabatti, 1967; Correggiari et al., 2005; Figure 1A). This fluvial network remained stable until the 12th century AD (~800 yrs BP), when a strong hydraulic reorganization promoted by a major avulsion (known as "Ficarolo avulsion") ultimately placed the Po River system into its present-day position. This event led to: *i)* the abandonment of the Volano lobe at the advantage of the Goro lobe and *ii)* the activation of the Po di Fornaci outlet in a northern position. The subsequent, increasing sediment supply towards the Venice Lagoon forced the Senate of the Venice Republic to operate the Porto Viro diversion (1600-1604 AD), marking the onset of the Modern Age delta (Stefani, 2017). From the 17th to the first decades of the 20th century, the strongest period of delta building took place largely due to enhanced human-induced sediment production in the river catchment (Maselli and Trincardi, 2013). At present, the highest mass accumulation rates on the N Adriatic shelf are recorded close to the active Po outlets (up to 3.3 g/cm^2/yr, Frignani et al., 2005; Figure 1A), among which the Pila branch shows the highest water (~60% of the total) and sediment discharge values (~75%).

Present-day vegetation and climate

The study area (Figure 1A) is characterised by a sub-Mediterranean climate with a certain degree of continentality. The maximum annual precipitation is 778 mm/yr (minimum values in July and August) and the mean annual temperature is ~13.2 °C, with a thermal excursion of ~22 °C between July–January (Ubaldi, 2003). The vegetation is mainly composed of cultivated fields, mostly wheat (*Triticum*) and chard (*Beta vulgaris* L.), with poplar (*Populus*) and willow (*Salix*) woods along river channels. Exceptions to this monotonous landscape are: *i)* many exotic taxa, mainly spreading from railways, roads and gardens (Alessandrini et al., 2011), and *ii)* the Mesola Great Wood, a remnant of the former coastal meso-Mediterranean holm oak forest historically extended along the N Adriatic coastline (Cortesi, 2005). From a broad perspective, the Po Plain falls into the Central European phytogeographic region. However, because of the proximity to the Mediterranean region, the local vegetation shares intermediate features, as the sub-Mediterranean climate allows for the mixing of continental elements from the alluvial plain with Mediterranean taxa typical of the coastal vegetation (Piccoli et al., 1983; Corbetta et al., 1984; Ferrari et al., 1985; Bassi, 2004). As a whole, three main vegetation belts occur (Pignatti, 1979; Ferrari, 1997): *i)* ericaceous dwarf shrublands above the timberline (~1800 m above sea level), *ii)* beech woods, and *iii)* mixed mesic oak woods.

Late Holocene vegetation patterns

According to Accorsi et al. (1999, 2004), a general increase in anthropic exploitation of natural habitats took place in the Po Plain around the Middle-Late Holocene (Northgrippian-Meghalayan stages *sensu* Walker et al., 2018) boundary, roughly corresponding to the Eneolithic-Bronze Age transition (~4000 yrs BP). At that time, the relative homogeneity of the mixed oak-holm oak forest, typical of the climate optimum (~10000-5000 yrs BP – Marcott et al., 2013), was replaced by a gradually patchier landscape, with open areas spreading from the main settlements and mainly devoted to cultivation of chestnut (*Castanea*), walnut (*Juglans*), vine (*Vitis*), olive (*Olea*) and cereals. Pollen data from the central Adriatic and from an archaeological site of the Po Plain (Terramara di Montale) document that this process was triggered by an aridification trend dated to the VI millennium BP (Mercuri et al., 2012) and fostered by Bronze Age societies (Cardarelli, 1992; Cremaschi, 2014). After several cycles of settlement flourishing and abandonment, these ancient societies maintained a general trend of forest depletion (Brown 2003). The decline of the forest cover continued up until the Bronze-Iron Age transition when, around the limit between Subboreal and Subatlantic (~2.8 kyrs BP, coincident with the ~2.8 ka Event *sensu* Bond et al., 1998), the Oroboreal Conifer vegetation belt in the Northern Apennines disappeared, with the exception of a few remnant populations (Chiarugi, 1958). During the Subatlantic, the regional vegetation landscape became even more open, with the lowland mixed-oak forest continuously shrinking mainly depending on cultivation of the drained soils of the alluvial plain, where mesic forests preferably grew (Accorsi et al., 1999), and on the Apennines (Vescovi et al., 2010). Wet environments spread as well, with willow substituting black alder (*Alnus glutinosa* (L.) Gaertn.) as the main component of hygrophilous woods. The anthropisation continued during the last two millennia, as land reclamation became one of the most prominent human activities, both in the plain and on the mountains, from the Roman Age onwards (Marchesini and Marvelli, 2009; Vescovi et al., 2010).

Material and methods

To explore the Late Holocene landscape dynamics of the Po Delta and their related forcing factors, palynological analyses were undertaken on a tens m-thick shallow-marine succession, mostly composed of fine-grained (silty clay to sandy silt) prodelta deposits (core EM13; Figure 1) and well-constrained into a regional stratigraphic framework (Figure 1B; Amorosi et al., 2017, 2019a, b). The 35 m-long core EM13 was recovered in the southern portion of the modern delta plain, few kilometres inland from the present coastline (Figure 1A; 44°51′50′′ N, 12°17′05′′ E). Meiofauna analyses (benthic foraminifers and ostracods; Barbieri et al., 2021) have refined facies characterization, allowing to identify a retrogradational-progradational stacking pattern of shallow-marine deposits above poorly drained floodplain-swamp muds of Early Holocene age. Transgressive barrier sands are overlain by a thin (few centimetres thick) offshore interval passing up-section to a ~20 m-thick prodelta succession typified by the superposition of two distinct lobes fed by the Volano and the Goro river branches during the last ~2000 years (Amorosi et al., 2019a; Barbieri et al., 2021). Prodelta muds grade upward into delta front sands (~3 m-thick) and delta plain deposits, 2 m-thick, cap the cored succession (Figures 1B, 2).

Palynological analysis

Forty-eight samples were collected from the 27 m-thick shallow-marine succession, generally avoiding coarse (sandy) layers and intervals. As sampling spacing in prodelta muds was about 50 cm, only the finest fractions of transgressive barrier and delta front sands were sampled in order to collect the best-preserved pollen assemblages. Samples were prepared and analysed at "Centro Agricoltura e Ambiente – CAA Giorgio Nicoli", San Giovanni in Persiceto (Italy) following the standard extraction technique of Lowe et al. (1996): about 8 g of dry sediment were weighed; a *Lycopodium* tablet was added to calculate palynomorphs concentrations; after a mechanical disruption in a 10% Na-pyrophosphate solution, samples were filtered through a 0.5 mm sieve and a 5 µm nylon filter, then chemically treated (HCl, acetolysis, Na-metatungstate heavy liquid, HF, ethanol). Following evaporation at 60°C in a stove, microscope slides were prepared with glycerine jelly and paraffin.

On average, 300 pollen grains were counted for each sample and recognised under an optical microscope at 400x magnification (1000x when needed) using general morphological keys (Faegri et al., 1989; Moore et al., 1991), pollen atlases (Reille, 1992, 1995, 1998) and a huge pollen keys miscellanea stored at the CAA laboratory. Pollen percentages were calculated on the total pollen sum. Monilophyta/Lycopodiophyta (ferns) spores were recognised using the same references for pollen grains, while Bryophyte spores were identified following Boros et al. (1993). Algal (*Pseudoschizaea*) and fungal (*Glomus*) remains were also recognised using CAA's miscellanea, while dinocysts were considered as a single group. Palynomorphs percentages are reported in Supplemental Table 1, available online.

Percentages of non-pollen palynomorphs (NPPs) were counted on the total pollen sum plus themselves, allowing for a correct down-weighting of their presence (Berglund and Ralska-Jasiewiczowa, 1986).

Differently, secondary (II) grains (ie, reworked pollen) were recognised *via* taxonomical determination, when possible, mainly using Tschudy and Scott (1969) as a general reference, and because of their enhanced reddening due to acetolysis, when their determination was not possible. Their percentages were calculated with respect to the sole total pollen sum and the ratio against primary (I) pollen deposition (ie, pollen production coeval to sedimentation) was determined. Despite their use as palaeobiogeographic and palaeotectonic proxies (Streel and Bless, 1980; Strother et al., 2017; Korasidis et al., 2022), secondary grains are generally neglected in Quaternary studies. Nevertheless, peaks in the II-I ratio can reflect periods of enhanced erosion and transport within the drainage basin (Lòpez-Merino et al., 2017).

Ecological characterisation and pollen spectra

Pollen and spore taxa were assigned to one or more ecological groups (EGs), taking into account autoecological features and the present-day regional vegetation physiognomy (Cacciari et al., 2020 and reference herein; Supplemental Table 1). Ecological groups are summarised in Table 1.

[Insert Table 1]

The relative abundance of individual groups was stratigraphically plotted to track vegetation dynamics through time and to support inferences about wetlands expansion/contraction, climate conditions and human land-use. Other EGs, as DT (Deciduous Trees), including broadleaves not strictly representative of the mixed-oak forest, and the physiognomic groups T (trees), sh (shrubs), L (lianas) and H (herbs), were not used for the elaboration of pollen spectra.

Cluster analysis

To improve the identification of pollen zones (PZs), a stratigraphically constrained cluster analysis (CONISS, Figure 2) was performed on a matrix composed of EGs relative percentages plus the secondary grains, as this technique is considered the best suited to highlight even subtle vegetation changes within uniform sedimentary successions (Grimm, 1987). To streamline the dataset, Q+M and hyg+hel+hyd were put together into two groups. The former group (Q+M) is broadly indicative of broadleaves forests, while the latter better reflects the general presence of humid environments on land (Table 1). By contrast, Ac was split in three components, corresponding to distinct human practices: chestnut (signal of anthropisation on hillslopes), cereals (the main signal of strong human footprint in the plain) and all other cultivated taxa (mainly arboriculture). Two samples out of 48 were excluded because too scarce (pollen sum < 100 grains). The Unweighted paired-group method with arithmetic averaging (UPGMA) as root Correlation as similarity index (Gosgens et al., 2021) was applied, similar to other palynological studies (eg, Kaniewski et al., 2012). Correlation was chosen because of the temporal proximity of samples and, thus, of the strong relationship between subsequent pollen assemblages. Cluster analysis was carried out using PAST v. 4.05 (Hammer et al., 2001).

Dating

[Insert Table 2]

Four AMS ^{14}C dates, obtained from mollusc shells and wood fragments, are available from the studied succession (Table 2). Conventional ages were calibrated using the IntCal20 (wood) and Mixed Marine NoHem (shell) curves (Reimer et al., 2020). The age-depth model was performed with RStudio in R 4.1.3 using the package rBacon v2.3.9.1 (Blaauw and Christen, 2011) by running millions of Markov Chain Monte Carlo iterations to generate weighted mean age estimates every 5 cm. To better constrain the model, calendar ages BP with a 2-sigma error were used and changes in accumulation rates were based on the core stratigraphy (Supplemental Figure 1, available online). Additional stratigraphic data supported the chronology in the uppermost 10 meters (Figure 2): *i)* the record of *Zea mays* pollen at ~6.5 m core depth (post-16th century AD; Cazzola, 1988) and *ii)* the subaerial exposure of the sand ridge, corresponding to the delta front – delta plain boundary (estimated age: half 18th century AD; Ciabatti, 1967). The integrated chronology is reported as centuries AD (Figure 2) to examine the linkage between vegetation changes and historical events, also exploiting the rich archaeobotanical literature available for the study area (see section Study area).

Results

Chronology and accumulation rates

[insert Figure 2]

Above transgressive marine deposits (beach sands + offshore muds), the age-depth model indicates that the prograding deltaic succession covers a time-interval spanning from about the 1st century AD up to the Contemporary Age (Figure 2). Radiocarbon dates are stratigraphically coherent (Figure 2; Table 2) and no major hiatuses were identified within the sequence of vertically stacked delta lobes, as also previously highlighted by the meiofauna (Barbieri et al., 2021). At the core site, the oldest lobe fed by the Volano branch remained active for about one millennium since the Imperial Age to the Early-Late Middle Ages transition, leading to the deposition of a 10 m-thick prodelta muddy interval. An accumulation rate of ~0.8 cm/yr typified the Imperial-Late Roman period (*sensu* Cremonini et al., 2013). Since the 5th century AD (Late Roman-Late Antiquity transition), the accumulation rate rapidly increased for the main portion of the prodelta (upper Volano and Goro lobes, ~1.3 cm/yr in Figure 2). A net accumulation rate of ~7.1 cm/yr is estimated for the Goro delta front transition + delta front, which developed between the 17th-18th centuries (Figure 2). The delta plain, generally placed post-18th century (Figure 2), was significantly subject to human interventions (eg, reclamation, embankment reinforcement).

Palynology

A total of 18258 palynomorphs belonging to 235 taxa were recognised (13501 pollen grains - 165 taxa, 700 fern spores – 11 taxa, 308 Bryophyte spores – 17 taxa, 3278 secondary grains – 42 taxa and 471 NPPs). We chose to group genera and/or species with the same ecology in a single taxon to better highlight the (palaeo)ecological role of each Family. As a result, 108 Tracheophyte, 11 Monilophyte/Lycopodiophyte and 13 Bryophyte agglomerated taxa (referred to as “taxa” from here onwards, Supplemental Table 1) define the primary palynomorph deposition. Across the studied succession, the vegetation is quite homogeneous and can be generally ascribed to a meso-hygrophilous woodland (mean ~34%) patchily alternating with partially or totally submerged wetlands, mesophilous grasslands and cultivated areas. A CONISS cut at the 0.75 value of similarity allows to identify four PZs numbered in stratigraphic order. The CA-derived subdivisions of PZs 4 and 2 further testify a certain amount of variability, in terms of both ecology and taxonomical composition (Figures 3-6). The PZs, inclusive of any sub-zones, are reported as follows. According to the age-depth model (Figure 2), pollen associations are showed along a continuous time scale in Supplemental Figure 2 (available online).

[insert Figure 3]

PZ 4 (26.20–23 m)
This zone encompasses a variety of facies associations, including transgressive barrier sands, offshore muds and prodelta muds related to the earliest phase of the Volano lobe progradation. This variability is reflected by: *i)* remarkable fluctuations in pollen concentrations, though remaining fairly high (I grains around 9k grains/g, II grains around 1.5k grains/g), and *ii)* the occurrence of three sub-zones (PZ 4c-a; Figure 3). The II-I ratio is constantly low throughout the zone, which encompasses the Imperial-Late Roman period (1st-5th centuries AD) with the exception of the transgressive barrier whose age is poorly defined (~9000-8000 cal. yrs BP; Amorosi et al., 2017).

- PZ 4c: the woody component is dominated by mesophilous and thermophilous trees (Q+M: ~23-26%), with a significant amount of montane (~15-18%) and hygrophilous (around 10%) taxa. Herbs are mainly represented by hygro-helo-hydrophytes (~18-21%) and pasture-meadow taxa (~15-22%), with a peak

- (~6%) of halophytes in the lowermost sample. Cultivated taxa (mainly *Hordeum* group) are scarce, although an increasing trend from ~1% to ~5% is evident. This sub-zone is mostly representative of a sub-Mediterranean mesic (holm oak/mixed-oak/alder) forest with a strong montane component. High amounts of hygro-helo-hydrophytes suggest a widespread occurrence of wetlands, whereas the halophytes peak is consistent with the proximity to back-barrier environments (transgressive barrier sands). The anthropic influence is low, but rising up in the sample dated to the 1st century AD.
- 4b and 4a: the Q+M and hyg+hel+hyd groups show distinct vertical trends, the former increasing (up to ~30%) upwards, while the latter decreasing (down to ~18%). This co-variance is different in magnitude between the sub-zones, as in PZ 4a the wetland herbaceous community reaches the second highest peak (~40%) of the whole succession. Comparable amounts of Hyg (mean ~7.5%), Mt (mean ~13%) and pm (mean ~21%) are also encountered, although the Mt taxonomical composition differs, as alders are partially substituted by *Abies*, *Pinus mugo/sylvestris*, other Pinaceae and *Fagus* (~6%, 2%, 10% and 2%, respectively) within PZ 4a (Figure 4). The Ac group, fluctuating around 7-8%, shows remarkable compositional differences between the sub-zones (Figures 3, 6). Within PZ 4b, high values of *Castanea* (5-7%) point to a strong development of chestnut arboriculture on the hills and mountains; moreover, the concomitant appearance of *Avena-Triticum* group, *Juglans regia* (L.), *Morus alba* and *Vitis* suggests lowland cultivations (~1-2% each). Upwards, (PZ 4a) the cultural landscape shows a higher differentiation, as *Vitis* peaks at its highest (5%, suggesting a wide diffusion since its scarce pollen productivity), while *Cannabis sativa* (L.) and *Panicum miliaceum* (L.) appear (Figure 6). These sub-zones document centennial phases of sub-Mediterranean oak forest contraction at the advantage of wetlands and a widespread human exploitation at first (4b – Imperial period) on the reliefs, then (4a – Late Roman period) on the plain.

[insert Figure 4]

PZ 3 (23–19 m)

This zone includes prodelta muds supplied by the Volano branch over ~300 years, between the Late Roman-Late Antiquity transition and the beginning of the Early Middle Ages (~5th-8th centuries AD). PZ 3, with low values of both pollen concentrations (I grains around 6k and II ~0.5k) and II-I ratio, is characterised by an upward contraction of the woody component. Q+M abundances strongly decrease (up to 8%) and a similar, but less pronounced, trend typifies the Mt and Hyg groups (Figure 3). However, montane vegetation remains rather high, commonly around 15%, with the lower portion of PZ 3 typified by montane alders and, to a lesser extent, *Fagus*, *Betula* and *Abies*, whereas the upper portion mainly contains pines, with *Pinus mugo* (Turra) in small proportion (Figure 4). By contrast, high amounts of hyg+hel+hyd (~20-30%) and pm (~21-33%) are encountered throughout the interval, the latter increasing upwards, prevalently with Cichorioideae and wild Poaceae (Figures 3, 5). Cultivated taxa, mainly represented by cereals (eg, *Hordeum* group; Figure 6) and chestnut, are relatively scarce (~1.5-4%), but clearly increase upwards (~7.5-9.5%). The palynological content points to an expansion of wetlands and anthropised areas, mainly crop fields and associated pastures (eg, Cichorioideae), at the expenses of mesic forests.

[insert Figure 5]

PZ 2 (19–1.3 m)

PZ 2 encompasses the latest stages of the Volano activity (8th-11th century) and the subsequent progradation of the Goro lobe up to its emersion, occurred at the beginning of the 19th century (Figures 2-3). Pollen concentrations are highly variable (I grains ~0.1-19.5k and II ~0.1-3.4k) as well as the II-I ratio; this latter shows a high mean value (~35%) accompanied by a series of distinct peaks (> 50%) throughout the interval. Five sub-zones are identified (PZs 2e-a; Figure 3).

- PZ 2e: this sub-zone, chronologically ascribed to the Early Middle Ages (8th-10th century), shows a decreasing-increasing trend of meso-thermophilous trees (mainly *Corylus avellana* and *Quercus ilex*), hygrophilous trees (mainly *A. glutinosa* (L.) Gaertn. and *Salix*), and cultivated taxa (ie, *Cannabis*, *Juglans*, *Vitis*, cereals and *Castanea*) (Figures 4, 6). This trend is roughly mirrored by the abundance of pasture-meadow herbs. The hyg+hel+hyd group is well-represented (around 15-20%), although it drops toward the top. Montane taxa stabilise around 7-10%, with the exception of a peak (~15% made of *Fagus*, *Abies* and *Pinus*) towards the bottom of the sub-zone (around the 9th century) coincident with the highest amount of hygro-helo-hydrophytes. *Salix*, typically thriving in fluvial environments, ranges high (~5-7%). Secondary grains are abundant (around 25%), with an increasing trend towards the top, where a pronounced peak (48%) occurs. This sub-zone highlights the establishment of an open, meso-hygrophilous wood during a period of intense fluvial activity.

- PZ 2d: this sub-zone, spanning the 11th-13th centuries, is characterised by low pollen concentrations (~5k and 2k, respectively) and generally high secondary grains (around 30%, peaking atop alongside dinoflagellates; Figure 6) with many reversals between concentrations and ratio, suggesting repeated fluctuations in sediment delivery to the basin. The EGs are also highly variable. Montane taxa, despite ranging around 12%, show a single peak towards the bottom (16%) mainly made of *Alnus incana* (L.) Moench. (7-8%), *A. viridis* (Chaix) and *Fagus* (3% each); upwards, these taxa are partially substituted by *Betula* and, subordinately, pines (Figure 4). In the lower part of the sub-zone, M+Q ranges around 20% and then declines; this trend is mirrored by hyg+hel+hyd (from 12% to 28%). Woody hygrophytes remain around low values (~5-9%). Cultivated taxa are also highly fluctuating, as chestnut is nearly absent at the bottom, whereas *Cannabis* (5% peak), *Juglans* and lesser cereals are significantly present. Then, a chestnut peak is recorded in parallel with a decrease of lowland cultivated taxa, after which a decreasing trend of Ac mirrors the increase of hyg+hel+hyd. A semi-sterile sample, mainly composed of secondary grains (~150%), caps the sequence. This sub-zone documents complex vegetation dynamics depicting a meso-hygrophilous woodland with open, cultivated areas shifting to a scarcely anthropised landscape strongly occupied by wetlands.
- PZ 2c: this sub-zone, spanning more than half of the Goro prodelta lobe, is chronologically ascribable to the Middle Ages-Modern Age transition (13th-17th centuries). Low pollen concentrations (~3-6k) are paralleled by high amounts of secondary grains (~1-2.2k) and high values of the II-I ratio (mean ~35%, with several peaks around ~45-55%). The Mt group invariably shows relatively low percentages (~7-8%), although a series of poorly pronounced peaks (9-10%), alternatively composed of montane alders and Pinaceae, occur. The M+Q group (~16-20%) and Hyg (~7-11%, mainly *Salix*) are well represented and co-vary synchronously. Hygro-helo-hydrophytes show an increasing trend in the lower half of the sub-zone (17-25%) and then decrease. The pm group ranges high, though fluctuating (mean 28%), with Cichorioideae making up one third of its composition (Figure 5). After a near-disappearance of cultivations at the bottom, an opposite trend of chestnut growth and cereal drop is recorded up to the half of the subzone, above which a widespread increase of cultivated trees (both on the mountains and in the lowlands) is recorded (up to ~10%); cereals remain scarce, instead. The pollen content points to a vegetation landscape shaped by a meso-hygrophilous forest with recurring dry and/or damp clearances. An overall, intense fluvial activity is suggested by the abundance of *Salix* and of secondary grains.
- PZ 2b: this sub-zone records a major step in the Goro lobe progradation, tracked by the transition to delta front sands dated around the 17th-18th centuries. Owing to the coarser grain-size, pollen concentrations are persistently low (I around 3k, II around 1k), whereas the II-I ratio is high (around 30%). Among the EGs, pm shows a high mean value (28%). Montane taxa (alders, beech and shrubby pines) range around 12% in the lower portion and decrease around 7% upwards. The M+Q and Hyg groups are also relatively low (mean values 23% and 7%, respectively), but both make a peak atop (30% and 10%, respectively), as well as the hygro-helo-hydrophytes that range around 19%. Cultivated taxa altogether remain scarce (~4%), with the exception of one peak (10%) in the upper portion, mainly due to lesser cereals (*Panicum* dominating over *Hordeum* group, *Secale cereale* (L.) and *Avena-Triticum*; Figure 6). This sub-zone depicts a meso-hygrophilous, open woodland with predominant prairies and damp areas.
- PZ 2a: this sub-zone corresponds to delta front sands deposited during the 18th-19th centuries. Pollen concentrations are low (I ~6k, II < 1k, except for a single peak at 3.4k), especially at the uppermost boundary, where concentrations drop to near zero and the II-I ratio reaches very high percentages (~160%). Indicators of disturbed environments dominate, oscillating around 10-25%. Cultivated plants are also well-represented (5-12%), especially with lesser cereals (2-4%; *Hordeum* group and *Panicum*) in the lower portion, though *Cannabis* and *Juglans* are also present. Montane taxa show remarkable percentages only at the base (~13%) and within the semi-sterile sample atop (36%). Lowland trees are significantly low (M+Q ~6-13%, Hyg ~3-6%), whereas hyg+hel+hyd and pm range ~19-23% and ~17-26%,

respectively. This sub-zone corresponds to an open prairie, with crop fields and orchards plus a few scattered wood remnants.

[insert Figure 6]

PZ 1 (uppermost 1.3 m)
Ascribed to the last two centuries (19th-20th), this zone coincides with delta plain deposits. Despite the dominance of hyg+hel+hyd herbs (mean value ~40%), pollen assemblages in the two analysed samples show distinct features. Specifically, the lower sample is marked by abundant montane taxa (~19%), mainly pines (Figure 4), and cultivations are well represented (~8%; mainly *Hordeum* group, *Juglans* and *Vitis* in Figure 6). Dinoflagellates are very abundant (5-20%) and follow the main peak of secondary grains (~125%), suggesting a high degree of transportation also from back-barrier environments altogether with a low primary pollen concentration. The upper sample shows high pollen concentrations (I ~25k, II ~1.6k) and hyg+hel+hyd herbs at their highest value in the whole succession (~50%), whereas Ac, M+Q and Hyg groups nearly disappear. According to the sedimentary facies, pollen suggests a landscape dominated by wetlands with mesophilous prairies separating damp areas.

Discussion

The stratigraphically expanded record of Volano and Goro prodelta lobes (Figure 2), as well as their key role as traps for fine-grained sediments (Trincardi, 2004), allows the sub-centennial scale examination of vegetation dynamics over the last two millennia. According to the age-depth model, the mean temporal resolution within prodelta muds (PZs 4b-2c) ranges between ~25-70 years. This takes us towards the human time-scale, making it possible to compare vegetation changes with historical (natural or human-induced) events documented in the literature (Figure 7). The resolution of pollen data further increases at the transition to the delta front where, however, the coarser grain-size hampers palynomorphs' preservation and the chronological accuracy is low due to a lack of radiocarbon ages (Figure 2). A similar temporal inaccuracy affects modern delta-plain samples.
The taxonomical variations encountered within Po delta lobes are interpreted to reflect changes in vegetation that occurred upstream, in the Po River catchment, as rivers represent the main vectors of pollen deposition on fluvial-influenced shelves (Beaudouin et al., 2007; Brown et al., 2007). However, the mode of transportation of pollen grains is a complex matter and no options should be completely discarded: if, on one hand, the southward-directed Adriatic longshore currents (Harris et al., 2008; Figure 1A) might have brought a minor and taxonomically similar pollen contribution from the Venetian Plain (Blasi et al., 2014), on the other hand the airborne pollen rain around a subaqueous delta location would remain buoyant on the sea surface for a long time before sinking and becoming buried by the pollen-rich riverine plume. Contextually, we can exclude a pervasive interference by flood events on the pollen record, since secondary and primary concentrations change coherently through time (Figure 3). Instead, the highest secondary peaks (ie, II-I ratio > 100%), invariably paralleled by high amounts of dinoflagellates, can be considered a good proxy of major river floods accompanied by intense erosion and transport processes downstream to the coastal areas. The highest peaks occur invariably within the Goro lobe succession, which records frequent flood events clustering around two main time-intervals: *i)* the Volano-to-Goro lobe switching (Ficarolo avulsion; Figure 1) and *ii)* the Little Ice Age, a climate oscillation characterised by a general decrease in temperatures, an increase in precipitations and a growing frequency of river floods in Europe (Glaser et al., 2010; Büntgen et al., 2011). As a whole, five historical phases of vegetation landscape are discussed below in relation to well-known changes in palaeohydrography, palaeoclimate and human frequentation in the Po Plain (Figure 7).

[insert Figure 7]

Imperial – Late Roman Age (1st-5th centuries)
The most prominent features of the landscape are the widespread presence of lowland forests (mixed oak-alder-willow) and the reduced degree of anthropisation in the plain (Figure 7). Such a climate optimum-like

vegetation, also attested from several archaeological sites of the study area (Bandini Mazzanti et al., 2001; Marchesini and Marvelli, 2009; Bosi et al., 2019), is consistent with the so-called "Roman Climate Optimum" (RCO) and it is interpreted to reflect high afforestation also due to sedges and woodlands in areas devoted to flood management and drainage. During the whole Roman Period, a complex centuriated landscape, including dry (cultivated or not) and damp clearances, typified the Po Plain (Cremaschi et al., 1980; Malaguti et al., 2010; Marchesini and Marvelli, 2017, 2018), though human settlements also occupied the reliefs along river axes (Scagliarini Corlaita, 1989).

A major phase of wetland expansion is recorded at the end of the 3rd century (Figure 7). Although settlement contraction and decreasing land management left riverbed aggradation unchecked during the Late Roman period (Cremonini et al., 2013), the peak in hygro-helo-hydrophytes is so striking (~40% - PZ 4a; Figures 3, 5) as to suggest climate-human interplay. This hypothesis is consistent with the coeval expansion of conifer woods in the study area (mainly *Abies* in Figure 4; Marchesini and Marvelli 2009), an inferred period of enhanced rainfall in central Italy (Bini et al. 2020 and references herein) and with flood activity in the Po Plain (eg, Stefani and Vincenzi, 2005; Bosi et al., 2019).

The varied cultural landscape (Figures 3, 6) is representative of the so-called "*piantata*", the typical Mediterranean polyculture (Butzer, 2005) practiced by the Romans, which lasted until the Middle Ages (Sereni 1957; Bottazzi 1990; Boriani and Bufferli, 1999). Close to the end of the Late Roman (end 4th-5th century), the near-disappearance of cultivated taxa likely reflects a major settlement collapse due to the invasions of Visigoths and Huns a few decades from one another (Figure 7). Interestingly, the general opposite behaviour of chestnut and cereals suggests complex societal dynamics of land abandonment in the plain (cereal decrease) in favour of more protected and defendable settlements on the hills (chestnut increase), as also documented on the Alps (Furlanetto et al., 2018) and in the whole Po Plain (Ortalli, 1992). Despite being present in the region before the Roman Age (Accorsi et al., 2004), during this period a similar expansion of chestnut arboriculture is also attested in central and southern Italy (Di Pasquale et al., 2010; Squatriti, 2013; Di Rita et al., 2018; Michelangeli et al., 2022). Therefore, an interplay between local traditions and a northward expansion of sylviculture may be taken into account.

Late Antiquity (5th-6th centuries)

The bipartite nature of montane forests (from broadleaves-fir to pines) and the complex taxonomical turnovers (PZ 3, Figure 3) suggest a period of climate variability and increased humidity at the Late Roman–Late Antiquity transition, followed by drier and possibly cooler conditions on the mountains (expansion of pines; Figure 4). Our inference is consistent with archaeobotanical findings (Accorsi et al., 1999; Marchesini et al., 1998, 1999a, b) and in tune with climate features of a cool period known as Late Antique Little Ice Age-LALIA (Figure 7; Büntgen et al., 2011, 2016; Peregrine, 2020). Moreover, cooler-wetter conditions are recorded by several Italian pollen sequences (Sadori et al., 2016; Di Rita et al., 2018; Kaniewski et al., 2022). Nonetheless, the anthropic presence (mostly lowland cultivations) expands: despite the dominance of *Avena-Triticum* and *Hordeum* groups, the significant appearance of the lesser cereal *Panicum miliaceum* (L.) may suggest complex, site-dependent agricultural practices typical of impoverished cultural landscapes (Montanari, 1979, 1988). *Cannabis, Juglans* and *Vitis* are also significant, confirming the spread of human settlements in the plain. The anthropic pollen signature can be specifically related neither to the relative societal stability of the Ostrogothic Kingdom nor to the first phases of the Ravenna Exarchate (Ravegnani 2004) because the expected settlement contraction during the second half of the 6th century (Gothic Wars, Justinian Plague, Langobard invasion, as in Ostrogorsky, 1963) cannot be detected (Figures 3, 7). This is possibly due to site-dependent conditions, as the remaining population likely moved to the coastline and to the main river in order to benefit protection by the Roman fleet.

At the same time, wetlands expanded likely in relation to both natural (ie, LALIA climate variability) and anthropic forcing factors, a possible evidence of the aforementioned collapse of territorial management following the end of the Western Roman Empire (Veggiani, 1979, 1990; Cremonini, 1990). This in turn also promoted river avulsions in the plain during the 5th and 6th centuries (Bruno et al., 2013; Cremonini et al., 2013; Bosi et al., 2019).

Early Middle Ages (7th-10th centuries)

The transition to the Early Middle Ages is also marked by widespread wetlands sustained by a combined climate-human factor and diffuse agriculture activities in the plain (Figure 7). Then, the socio-economic disruption, following the final Langobard onslaught against the Byzantines and the conquest of the Ravenna Exarchate (Ravegnani 2004), likely determined a sharp drop in lowland cultivations (cereals and arboriculture) in favour of chestnut during the late 7th century (Figures 3, 7). A mid-8th century peak in cereal cultivation, ascribable to the last phases of the Langobard Kingdom, was followed by the shift to a more natural landscape, as arboriculture became the main cultural feature both on the hills and in the plain. This scarce lowland anthropisation was common in Northern Italy, as the vast majority of the countryside had a sparse population organised in villages around the so-called "*pieve*" (Bacchini, 1708; Andreolli, 1989; Bonacini, 1989). Indeed, in a context of recurring turmoil (Langobard-Byzantine wars, rapid rise and fall of the Carolingian Empire, Feudal Anarchy), minor bishopric buildings provided some institutional stability. According to local archaeological investigations (ie, spread of lowland forests, in Marchesini et al., 1999), hygrophilous woods generally co-dominated with oak woods suggesting long-lasting warm-moist conditions culminating with the so-called "Medieval Warm Period" (MWP; Figure 7). However, a prominent, though single, peak in montane taxa (PZ 2e, Figure 3), age-modelled to the 9th century, points to a cool-wet oscillation already depicted in the Alpine and Apennine regions (Holzhauser et al., 2005; Nicolussi et al., 2009; Mensing et al., 2016).

During the 10th century, a main phase of wetlands shrinking occurred, while afforestation and cultivations increased. This vegetation change fits well with the prolonged phases of land reclamation carried out by the Benedict monks from the Pomposa Abbey (the so-called "Pomposan Island" between Goro and Volano channels; Leoni, 1984; Ferraresi, 2004).

Late Middle Ages (11th-15th centuries)

The onset of the Late Middle Ages is in vegetational continuity with the late Early Middle Ages, as the effects of the Pomposan reclamation continued (scarcity of wetlands at the benefits of cultivations; Figures 3, 7). A relatively limited spread of crops and orchards was a boon for lowland forests, as the climate-optimum like vegetation continued to thrive up until the late 11th century, documenting the MWP signature into the Late Middle Ages.

Two subsequent peaks in montane alders and beech, chronologically coincident to the Oort solar minimum (second half of the 11th century; Figure 7), may suggest complex, long-term climate-fluvial environment interactions, as during the 12th century a major landscape change occurred in tune with an episode of intense river network reorganisation in the lower Po Plain (Zanella, 1983; Cremonini, 1988). The Ficarolo avulsion, historically dated to 1152 AD, but triggered by subsequent episodes of fluvial avulsion (Veggiani et al., 1990; Correggiari et al., 2005), left a trace in the pollen record *via* the expansion of wetlands (upper PZ 2d in Figure 3; Figure 7). Accordingly, a general spreading of fluvial-related environments is recorded in the inland portion of the plain by archaeological pollen sequences (Marchesini et al., 2003; 2008b; Marvelli et al., 2011). This interpretation is coherent with the decrease of cultivated species toward the second half of the 12th century, documenting a phase of land abandonment under the forcing of fluvial dynamics and the evidence of recurring floods (II-I ratio peaks; Figures 3, 7).

After this event, the last interval of the Late Middle Ages is typified by the expansion of lowland forests and by a century-long retraction of wetlands in favour of crop fields, likely due to an inferred land reclamation phase following the Ficarolo avulsion. Similar to our record, inland archaeological sites of late Medieval age (Forlani and Marvelli, 1999; Guarnieri, 1999; Marchesini et al., 1999) attest to open, in-site anthropised landscapes with *Vitis*, *Juglans*, *Vicia faba* (L.) and cereals.

A renewed trend of wetland expansion occurred around the 14th-15th century transition after a single, minor peak in montane forests falling into the temporal window of the Wolf solar minimum and suggesting a likely, although feeble, LIA footprint for this phase of landscape naturalisation (Figure 7). In this context, the late 14th-early 15th century record of crop fields substitution by montane cultivations would reflect land depopulation and abandonment, in favour of a sparser settlement on the mountains (Capitani et al., 1981) due to the Great Plague of 1348 (drop of ~1/3 of European population, Sussman, 2011; Schmid et al., 2015).

Modern–Contemporaneous Ages (16th-20th centuries)

A common feature of our pollen assemblages after ~13th century is a generally lower amount of montane taxa compared to previous times (means ~9% *vs* ~13%; Figure 3). This is a rather peculiar feature, since after the MWP-LIA transition (13th-14th century) an opposite effect would be expected under natural forcing (Figure 7). This may be explained by the population boom from the Late Medieval Age onwards that led to the depletion of the montane vegetation (Vescovi et al., 2010), mainly aimed at building large fleets and/or for poor-quality fuel for iron forging in absence of coal (Sorbelli, 1911; Cacciavillani, 1988). In this context, even subtle peaks of montane vegetation could reflect climatic variations, implying expansions of an artificially shrunk forest community. Interestingly, montane vegetation peaks show an estimated centennial-scale cyclicity (Figure 7) following the time-intervals of the Spörer (end of the 15th, the 16th-17th century transition), Maunder and Dalton solar minima (early 17th-18th century transition and late 19th century, respectively). Montane alders alternately peak with pines, pointing to a mixed wet-dry signal up to the 17th century, although lowland forests show a strong hygrophilous community. Afterwards, the pine-dominated montane vegetation suggests cool and dry conditions culminating during the Dalton minimum (Figure 4), the coldest LIA phase (Holzhauser et al., 2005). An overall climate-fluvial teleconnection can also be inferred, as peaks in montane vegetation commonly overlap with peaks in secondary deposition and drops in pollen concentrations (Figures 3, 7).

Wetlands shrinking typified the plain landscape up to the end of 17th century, due to an extensive campaign of land reclamations carried out by the Estensi family (Duchy of Ferrara) who managed their possessions not only as farming estates but also as wilderness areas devoted to game reserves (Cazzola, 1982). This postponed the most recent, strong deforestation phase, paralleled by a series of peaks in anthropisation, from the 18th century onwards (Figure 7). Coherently with recent land reclamations (Giacomelli, 1989), the final emersion of the delta (Ciabatti, 1967; Bondesan et al., 1995; Amorosi et al., 2019a) is testified by a facies-related dominance of wetland pollen dated to the last two centuries (Figure 7).

A brief, but severe, reduction of landscape anthropisation is age-modelled to the end of 17th century, as both montane trees and disturbance indicators increase at the expenses of cultivated taxa. It likely reflects the combined interplay of climate (Spörer minima) and disease (the Manzoni's 1630-3 plague) that is also supposed to determine the olive cultivation disappearance in the whole region (Boriani and Bufferli, 2002).

Conclusions

Po delta lobes, especially their muddy portions (prodelta deposits), are powerful sedimentary archives for high-resolution reconstructions of fluvial, anthropic and climate dynamics in the Po Plain, although limited to the activity period of the feeding river branches. The major outcomes of this study can be summarised as follows:

- Stratigraphic variations of key ecological groups (meso-thermophilous taxa; woody hygrophytes; hygro-helo-hydrophyte herbs; pasture-meadow herbs; cultivated taxa and montane taxa) robustly document the environmental shifts of a complex natural-cultural landscape, shaped at a sub-centennial timescale by fluvial processes and societal dynamics under the umbrella of changeable climate conditions, since the 1st century AD (Imperial Roman).
- Rivers represent the main vector of primary (I) and secondary (II) pollen supply to the shelf. Peaks in the II-I pollen ratio mark phases of river network reorganisation (Volano-Goro lobe switching) or climate deterioration (LIA).
- As pollen grains derive from the catchment *via* river fluxes, the anthropic signal encased downstream within delta lobes is weaker than in classic archaeological pollen sequences, but highly informative about the average extent (ie, settlements patterns) and types (eg, polyculture; relative proportion between lowland and montane cultivations) of agricultural practices. The typical Roman polyculture characterises the cultural landscape of both the Roman and Medieval periods, although local conditions (ie, sparse settlements) affected its extension and composition from the Western Roman Empire collapse onwards, mainly due to societal turmoil.
- A climate optimum-like forest with both dry and damp clearances characterises the Roman centuriated landscape of the Po Plain, confirming general warm conditions during the "Roman

Climatic Optimum". However, the expansion of wetlands around the end of the 3rd century AD likely reflects the combined effect of a cool-wet climate oscillation and decreasing land management.

- Wetlands strongly expanded between the 6th-7th centuries AD under both natural (LALIA climate variability) and anthropic (collapse of territorial management) forcing factors. The pollen record (montane taxa) suggests a bipartite climate oscillation, typified by cool-moist and then cool-dry conditions.
- During the Middle Ages, the expansion-contraction cycles of wetlands mainly reflect reclamation activities and a major event of Po River drainage reorganization ("Ficarolo avulsion"). The climate footprint seems feeble, as long-lasting warm conditions are inferred by a mixed oak meso-hygrophilous woodland also during the "Medieval Warm Period". However, peaks in montane taxa suggest cool-wet oscillations in phase with solar minima (9th century; 11th century and 14th century).
- Despite a human-induced shrinking of the forest community, distinct peaks of montane vegetation occurred during the LIA with a centennial-scale cyclicity following solar minima and possibly influenced by the two major plagues of the 14th and 17th centuries.

Acknowledgements

We thank two anonymous reviewers for their constructive comments and suggestions. We would like to thank Giulia Barbieri and Stefano Claudio Vaiani for the profitable discussions about palaeoenvironmental inferences on EM13. We also acknowledge valuable collaboration with the team of palynologists and archaeobotanists at "Centro Agricoltura e Ambiente G. Nicoli" laboratory (Italy). Finally, MC is indebted to Giulia Barbieri and Alessandro Chiarucci for precious piece of advice in elaborating the age-depth model.

Funding

The authors received no financial support for the research, authorship and/or publication of this article.

Declaration of conflicting interests

The Authors declare that there are no conflicting interests.

Supplemental Material statement

Palynomorphs percentages, age-depth model support graphs and pollen groups' percentage diagrams plotted against chronology are available online as Supplementary material.

Supplemental Material captions

Supplemental Figure 1. Age-depth model original graph. Priors: Memory defines how much the accumulation rate of a particular depth in a core depends on the depth above it (Blaauw and Christen, 2011). Acc. rate panel shows the accumulation rate prior as defined per intervals listed bottom-to-top; acc.shape is the shape of the distribution curve of the accumulation rates (1.5 is default). The iteration panel pictures how well the Markov Chain Monte Carlo fits with given priors at an increasing number of iterations (the more uniform the oscillations, the better the model). Boundaries (dotted horizontal lines) in the model were set at 22.45 m (meiofauna-based variation in bottom conditions due to changes in river inputs, following Barbieri et al., 2021), 6.43 m (prodelta – delta front transition/delta front boundary) and 1.31 m (delta front transition/delta front – delta plain boundary).

Supplemental Figure 2. Pollen groups' percentage diagram of EM13 plotted against chronology, including the pollen zonation identified *via* CONISS. The temporal attribution of each sample derives from the age-depth model. The subdivision in terms of centuries AD is also shown (see also Figure 3).

Supplemental Table 1: Percentages of pollen, spores and other NPPs of core EM13. The ecological characterisation of some taxa may be controversial and deserves some explanation: *Castanea*, even though living on the hills, was counted as Anthropic cultivated (Ac) and not as Montane (Mt) because during the last two millennia it was mainly cultivated and, thus, bears no climatic significance. *Beta* was considered halophyte (hal) instead of Ac because its relative abundance is always too low to be considered of anthropic origin. Similarly, other chenopods were also considered hal instead of Anthropic spontaneous (As) due to the proximity of the coast. *Posidonia* and *Ruppia* were assigned to the halophyte group, though strictly hydrophyte (hyd), because they live in saltwater at a few meters of depth in the sea.

References

Accorsi CA, Bandini Mazzanti M, Forlani L, Mercuri AM, Trevisan Grandi G, 1999. An overview of Holocene forest pollen flora/vegetation of the Emilia-Romagna region – Northern Italy. Archivio Geobotanico 5 (1–2), 3–27.

Accorsi CA, Bandini Mazzanti M, Forlani L, Mercuri AM, Trevisan Grandi G, 2004. Holocene forest vegetation (pollen) of the Emilia Romagna plain – northern Italy. In: Pedrotti F, Gehu JM (eds.), La végétation postglaciaire du passé et du présent. Syngenèse, synécologie et synsystématique. Colloques Phytosociologiques 28, 1–103.

Alessandrini A, Morelli V, Pellizzari M, 2011. Ecologia e flora ferroviaria, con particolare riferimento alle aree di "Ferrovie Emilia-Romagna", in Orlandi P, Tozzi Fontana M (eds.), Ferrovie dell'Emilia-Romagna. Paesaggio, natura, storia: 51-73. Istituto per i Beni artistici, culturali e naturali della regione Emilia-Romagna. Compositori ed., Bologna.

Amorosi A, Barbieri G, Bruno L, Campo B, Drexler TM, Hong W, Rossi V, Sammartino I, Scarponi D, Vaiani SC, Bohaks KM, 2019a. Three-fold nature of coastal progradation during the Holocene eustatic highstand, Po Plain, Italy – close correspondence of stratal character with distribution patterns. Sedimentology 66, 3029–3052.

Amorosi A, Bini M, Giacomelli S, Pappalardo M, Ribecai C, Rossi V, Sammartino I, Sarti G, 2013a. Middle to late Holocene environmental evolution of the Pisa coastal plain (Tuscany, Italy) and early human settlements. Quaternary International 303, 93-106.

Amorosi A, Bruno L, Cacciari M, Campo G, Rossi B, 2021. Tracing marine flooding surface equivalents across freshwater peats and other wetland deposits by integrated sedimentological and pollen data. International Journal of Coal Geology 246, 103830.

Amorosi A., Bruno L, Campo B, Costagli B, Dinelli E, Hong W, Sammartino I, Vaiani SC, 2019b. Tracing clinothem geometry and sediment pathways in the prograding Holocene Po Delta system through integrated core stratigraphy. Basin Research 32, 206-215.

Amorosi A, Bruno L, Campo B, Morelli A, Rossi V, Scarponi D, Hong W, Bohacs KM, Drexler TM, 2017. Global sea-level control on local parasequence architecture from the Holocene record of the Po Plain, Italy. Marine and Petroleum Geology 87, 99-111.

Amorosi A, Colalongo ML, Fiorini F, Fusco F, Pasini G, Vaiani SC, Sarti G, 2004. Palaeogeographic and palaeoclimatic evolution of the Po Plain from 150-ky core records. Global and Planetary Change 40, 55-78.

Amorosi A, Dinelli E, Rossi V, Vaiani SC, Sacchetto M, 2008. Late Quaternary palaeoenvironmental evolution of the Adriatic coastal plain and the onset of the Po River Delta. Palaeogeography Palaeoclimatology Palaeoecology 268, 80–90.

Andreolli B, 1989. Proprietà signorili e lavoro contadino. Le basi dell'insediamento medievale. In: Adani G. (ed.), Insediamenti rurali in Emilia-Romagna Marche. Amilcare Pizzi Ed., Cinisello Balsamo (MI).

Anthony EJ, Marriner N, Morhange C, 2014. Human influence and the changing morphology of Mediterranean deltas and coasts over the last 6000 years: from progradation to destruction phase? Earth-Science Reviews 139, 336-361.

Bacchini B, 1708. Agnelli qui et Andreas... Liber Pontificalis, seu vitae pontificum ravennatum. Modena 1708.

Bandini Mazzanti M, Bosi G, Marchesini M, Mercuri AM, Accorsi CA, 2001. Quale frutta circolava sulle tavole emiliano-romagnole nel periodo romano? Suggerimenti dai semi e frutti rinvenuti in siti archeologici. Atti Società Naturalisti e Matematici in Modena 131, 63-92.

Barbieri G, Rossi V, Vaiani SC, Dasgupta U, Amorosi A, 2021. Quantitative paleoecology in shallow-marine settings: the value of ostracods and foraminifers from the Holocene North Adriatic record. Palaeogeography, Palaeoclimatology, Palaeoecology 572, 110408.

Bard E, Raisbeck G, Yiou F, Jouzel J, 2000. Solar irradiance during the last 1200 years based on cosmogenic nuclides. Tellus 52B, 985-992.

Bassi A, 2004. Guida alla flora della Pineta di San Vitale. Longo ed., Ravenna.

Beaudouin C, Suc JP, Cambon G, Toouzani A, Giresse P, Pont D, Aloïsi JC, Marsset T, Cochonat P, Duzer D, Ferrier J, 2005. Present-day rithmic deposition in the Grand Rhone prodelta (NW Mediterranean) according to high-resolution pollen analyses. Journal of Coastal Research 21(2), 292-306.

Beaudouin C, Suc JP, Escarguel G, Mireille A, Charmasson S, 2007. The significance of pollen signal in present-day marine terrigenous sediments: the example of the Gulf of Lions (western Mediterranean Sea). Geobios 40, 159-172.

Bellotti P, Calderoni G, Dall'Aglio PL, D'Amico C, Davoli L, Di Bella L, D'Orefice M, Esu D, Ferrari K, Bandini Mazzanti M, Mercuri AM, Tarragoni C, Torri P, 2016. Middle-to late-Holocene environmental changes in the Garigliano delta plain (central Italy): which landscape witnessed the development of the *Miturnae* Roman colony? The Holocene 26(9), 1457-1471.

Berglund BE, Ralska-Jasiewiczowa M, 1986. Handbook of Holocene palaeoecology and palaeohydrology. Wiley-Interscience. John Wiley & Sons Ltd, Chichester (1986).

Bini M, Zanchetta G, Regattieri E, Isola I, Drysdale RN, Fabiani F, Genovesi S, Hellstrom JC, 2020. Hydrological changes during the Roman Climatic Optimum in northern Tuscany (Central Italy) as evidenced by speleothem records and archaeological data. Journal of Quaternary Science 35, 791-802.

Blaauw M, Christen JA, 2011. Flexible paleoclimate age-depth models using an auto regressive gamma process. Bayesian Analysis 6 (3), 457-474.

Blasi C, Capotorti G, Copiz R, Guida D, Mollo B, Smiraglia D, Zavattero L, 2014. Classification and mapping of the ecoregions of Italy. Plant Biosystems 148 (6), 1255–1345.

Bonacini P, 1989. Pievi, monasteri e conventi. L'organizzazione ecclesiastica del territorio rurale. In: Adani G (ed.), Insediamenti rurali in Emilia-Romagna Marche. Amilcare Pizzi Ed., Cinisello Balsamo (MI).

Bond G, Showers W, Cheseby M, Lotti R, Almasi P, deMenocal P, Priore P, Cullen H, Hajdas I, Bonani G, 1998. A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. Science 278, 1257–1266.

Bondesan M, Favero V, Viñals ML, 1995. New evidence of the evolution of the Po-Delta coastal plain during the Holocene. Quaternary International 29/30, 105-110.

Boriani ML, Bufferli E, 1999. La vegetazione delle corti rurali della pianura bolognese. Strenna Storica Bolognese 44, 121-148.

Boriani ML, Bufferli E, 2002. L'olivo nel territorio bolognese: da presenza colturale a presenza paesaggistica. Strenna Storica Bolognese 52, 77-106.

Boros A, Jàrai-Komlòdi M, Tòth Z, Nilsson S, Pòcs T, 1993. An atlas of recent European Bryophyte spores. Scientia Publishing, Budapest 1993.

Bosi G, Labate D, Rinaldi R, Montecchi MC, Mazzanti M, Torri P, Riso PF, Mercuri AM, 2019. A survey of the Late Roman period (3rd-6th century AD): Pollen, NPPs and seeds/fruits for reconstructing environmental and cultural changes after the floods in Northern Italy. Quaternary International 499, 3-23.

Bottazzi G, 1990. L'evoluzione del paesaggio agrario di età romana. In: Civiltà Padana II, 65-97.

Brown AG, Carpenter RG, Walling DE, 2007. Monitoring fluvial pollen transport, its relationship to catchment vegetation and implications for palaeoenvironmental studies. Rewiew of Palaeobotany and Palynology 147, 60-76.

Bruno L, Amorosi A, Curina R, Severi P, 2013. Human-landscape interactions in the Bologna area (Northern Italy) during the mid-late Holocene with focus on the Roman period. The Holocene 23, 1558-1569.

Bruno L, Bohacs KM, Campo B, Drexler TM, Rossi V, Sammartino I, Scarponi D, Hong W, Amorosi A, 2017. Early Holocene transgressive palaeogeography in the Po coastal plain (Northern Italy). Sedimentology 64, 1792–1816.

Büntgen U, Myglan VS, Charpentier Ljungqvist F, McCormick M, Di Cosmo N, 2016. Cooling and societal change during the late antique Little Ice age from 536 to around 660 AD. Nature Geoscience 9, 1-7.

Büntgen U, Tegel W, Nicolussi K, McCormick M, Frank D, Trouet V, Kaplan JO, Herzig F, Heussner KU, Wanner H, Luterbacher J, Esper J, 2011. 2500 Years of European climate variability and human susceptibility. Science 331, 578-582.

Butzer KW, 2005. Environmental history in the Mediterranean world: cross disciplinary investigation of cause-and-effect for degradation and soil erosion. Journal of Archaeological Science, 32, 1773-1800.

Cacciari M, Amorosi A, Marchesini M, Kaniewski D, Bruno L, Campo B, Rossi V, 2020. Linking Holocene vegetation dynamics, palaeoclimate variabilità and depositional patterns in coastal successions: insights from the Po Delta plain of northern Italy. Palaeogeography, Palaeoclimatology, Palaeoecology 538, 109468.

Cacciavillani I, 1988. La proprietà collettiva nella montagna veneta sotto la Serenissima. Signum Padova Editrice, 1988.

Capitani O, Manselli R, Cherubini G, Pini AI, Chittolini G, 1981. Comuni e Signorie: istituzioni, società e lotte per l'egemonia. UTET, Torino 1981, 693 pp., in: Galasso G, (ed.), Storia d'Italia, vol. 4.

Cardarelli A, 1992. Le età dei metalli nell'Italia settentrionale. In: Guidi A, Pipemo M (eds.), Italia preistorica, 366-419. Bari 1992.

Cazzola F, 1982. Produzioni agricole e rendimenti unitari dei cereali nel Ferrarese a metà Quattrocento: la castalderia ducale di Casaglia (1451-1459). In: Zangheri R. (ed.), Studi in memoria di Luigi Dal Pane, CLUEB, Bologna.

Cazzola F, 1988. L'introduzione del mais in Italia e la sua utilizzazione alimentare (sec. XVI-XVIII). In: *La préparation alimentaire des céréales.* Rapports présentés à la Table ronde, Ravello, au Centre Universitaire pour les Bien culturels, avril 1988. PACT 26, 1991, 109-127. Ed. D. Fournier, 1992.

Chiarugi A, 1958. Ricerche sulla vegetazione dell'Etruria. XI: una seconda area relitta di vegetazione di Pigella (Picea excelsa Lam.) sull'Appennino Settentrionale. Nuovo Giornale Botanico Italiano 65, 23–42.

Ciabatti M, 1967. Ricerche sull'evoluzione del delta padano. Giornale di Geologia 34 (2), 381-406.

Corbetta F, Puppi G, Speranza M, Zanotti AL, 1984. Vegetational outlines of North Adriatic coasts. Acta Botanica Croatica 43, 191-206.

Correggiari A, Cattaneo C, Trincardi F, 2005. Depositional patterns in the late Holocene Po delta system. River deltas – Concept, models and examples. In: SEPM Special Publications 83, pp. 365–392.

Cortesi P,2005 (ed.). Il Boscone della Mesola. Minerva Ed., Bologna.

Cremaschi M, Bernabò Brea M, Tirabassi J, D'Agostini A, Dall'Aglio PL, Magri S, Baricchi W, Marchesini A, Nepoti S, 1980. L'evoluzione della pianura emiliana durante l'Età del Bronzo, l'Età Romana e l'Alto Medio Evo: geomorfologia ed insediamenti. Padusa (1980), 1-106.

Cremaschi M, Pizzi C, Valsecchi V, 2006. Water management and land use in the terramare and a possible climatic co-factor in their abandonment: the case study of the terramara of Poviglio Santa Rosa (Northern Italy). Quaternary International 151, 87-98.

Cremonini C, 1988. Specificità dell'alto Ferrarese nella problematica evolutiva dell'antica idrografia padana inferiore. In: Berti F, Gelichi S, Steffé G (eds.), Bondeno e il suo territorio dalle origini al Rinascimento, 17-24. Grafis Edizioni.

Cremonini S, 1990. Cenni storico-idrografici sul territorio argentano. In: Acque e uomini nelle plaghe di Padusa. Quaderni di campotto 1, 23-31.

Cremonini S, 2021. Problematiche geomorfologiche relative all'evoluzione paleo idrografica padana predeltizia di età tardoantiva (V-VII sec.). In: Buora M, Magnani S, Villa L (eds.), Italia settentrionale e regioni dell'arco alpino tra V e VI secolo d.C. Edizioni Università di Trieste, 2022.

Cremonini S, Labate D, Curina R, 2013. The late-antiquity environmental crisis in Emilia region (Po river plain, Northern Italy): geoarchaeological evidence and paleoclimatic considerations. Quaternary International 316, 162-178.

D'Orefice M, Bellotti P, Bertini A, Calderoni G, Censi Neri P, Di Bella L, Fiorenza D, Foresi LM, Louvari MA, Rainone L, Vittori C, Goiran JP, Schmitt L, Carbonel P, Preusser F, Oberlin C, Sangiorgi F, Davoli L, 2020. Holocene evolution of the Burano paleo-lagoon (southern Tuscany, Italy). Water 12, 1007; doi:10.3390/w12041007.

Dearing CA, 2006. Climate-human-environment interactions: resolving our past. Climate of the Past 2, 187-203.

Di Pasquale G, Allevato E, Russo Ermolli E, Coubray S, Lubritto C, Marzaioli F,2010. Reworking the idea of chestnut (Castanea sativa Mill.) cultivation in Roman times: new data from ancient Campania. Plant Biosystem 144(4): 865–873.

Di Rita F, Magri D, 2012. An overview of the Holocene vegetation history from the central Mediterranean coasts. Journal of Mediterranean Earth Sciences 4, 35-52.

Di Rita F, Ghilardi M, Fagel N, Vacchi M, Warichet F, Delanghe D, Sicurani J, Martinet L, Robresco S, 2022. Natural and anthropogenic dynamics of the coastal environment in northwestern Corsica (western Mediterranean) over the past six millennia. Quaternary Science Reviews 278, 107372.

Di Rita F, Lirer F, Bonomo S, Cascella A, Ferraro L, Florindo F, Insinga DD, Lurcock PC, Margaritelli G, Petrosino P, Rettori R, Vallefuoco M, Magri D, 2018. Late Holocene forest dynamics in the Gulf of Gaeta (central Mediterranean) in relation to NAO variability and human impact. Quaternary Science Reviews 179, 137-152.

Dubois N, Saulnier Talbot É, Mills K, Gell P, Battarbee R, Bennion H, Chawchai S, Dong X, Francus P, Flower R, Gomes DF, Gregory Eaves I, Humane S, Kattel G, Jenny JP, Langdon P, Massaferro J, McGowan S, Mikomägi A, Thi Minh Ngoc N, Sandaruwan Ratnayake A, Reid M, Rose N, Saros J, Schillereff D, Tolotti M, Valero Garcès B, 2018. First human impacts and responses of aquatic systems: a review of palaeolimnological records from around the world. The Anthropocene Review 5(1), 28-68.

Ejarque A, Julià R, Reed JM, Mesquita Joanes F, Marco Barba J, Riera S, 2016. Coastal evolution in a Mediterranean microtidal zone: mid to late Holocene natural dynamics and human management of the Castellò lagoon, NE Spain. PLoS ONE 11(5), e0155446.

Faegri K, Iversen J, Krzywinski K, 1989. Textbook of pollen analysis. John Wiley and Sons, Chichester.

Ferraresi G, 2004. S. Maria di Pomposa tra acque e terre (secoli IX-XI). I quaderni del MAES 7, 37-56.

Ferrari C, 1997. The vegetation belts of Emilia Romagna (Northern Italy). Allionia 34, 219–231.

Ferrari C, Gerdol R, Piccoli F, 1985. The halophilous vegetation of the Po Delta (northern Italy). Vegetatio 61, 5-14.

Forlani L, Marvelli S, 1999. Archeopalinologia del fossato di bonifica tardo-medievale ad Argenta. In: Guarnieri C (ed.), Il Tardo Medioevo ad Argenta. Lo scavo di via Vinarola – Aleotti. Quaderni di Archeologia dell'Emilia-Romagna 2, pp. 172-183.

Frignani M, Langone L, Ravaioli M, Sorgente D, Alvisi F, Albertazzi S, 2005. Fine-sediment mass balance in the western Adriatic continental shelf over a century time scale. Marine Geology 222-223, 113-133.

Furlanetto G, Ravazzi C, Pini R, Vallè F, Brunetti M, Comolli R, Novellino MD, Garozzo L, Maggi V, 2018. Holocene vegetation history and quantitative climate reconstructions in a high-elevation oceanic district of the Italian Alps. Evidence for a middle to late Holocene precipitation increase. Quaternary Science Reviews 200, 212-236.

Ghilardi M, Psomiadis D, Andrieu Ponel V, Colleu M, Sotiropoulos P, Longo F, Rossi A, Amato V, Gasse F, Sinibaldi L, Renard M, Bicket A, Delanghe D, Demory F, Fleury J, 2018. The Holocene 28(8), 1225-1244.

Giacomelli A, 1989. Insediamenti di bonifica in Emilia-Romagna. In: Adani G (ed.), Insediamenti rurali in Emilia-Romagna Marche. Amilcare Pizzi Ed., Cinisello Balsamo (MI).

Glaser R, Riemann D, Schönbein J, Barriendos M, Bràzdil R, Bertolin C, Camuffo D, Deutsch M, Dobrovolny P, van Engelen A, Enzi S, Halìčkovà M, Koenig SJ, Kotyza O, Limanòwka D, Mackovà J, Sghedoni M, Martin B, Himmelsbach I, 2010. The variabilità of European floods since 1500 AD. Climatic Change 101, 235-256.

Goiran JP, Tronchère H, Salomon F, Carbonel P, Djerbi H, Ognard C, 2008. Palaeoenvironmental reconstruction of the ancient harbors of Rome: Claudius and Trajan's marine harbors on the Tiber delta. Quaternary International 216, 3-13.

Gosgens M, Tikhonov A, Prokhorenkova L., 2021. Systematic analysis of cluster similarity indices: how to validate validation measures. Proceedings of the 38th International Conference of Machine Learning, PMLR 139, 2021.

Grimm EC, 1987. CONISS: a Fortran 77 program for stratigraphically constrained cluster analysis by the method of the incremental sum of squares. Computer and Geosciences 13, 13-35.

Guarnieri C (ed.), 1999. Il tardo Medioevo ad Argenta. Lo scavo di via Vinarola-Aleotti. Quaderni di Archeologia dell'Emilia-Romagna 2, 193-202.

Hammer O, Harper DAT, Ryan PD, 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 41 (1), 9 pp.

Harris CK, Sherwood CR, Signell RP, Bever AJ, Warner JC, 2008. Sediment dispersal in the Northwestern Adriatic Sea. Journal of Geophysical Research 113, C11S03.

Holzhauser H, Magny M, Zumbühl HJ, 2005. Glacier and lake-level variations in west-central Europe during the last 3500 years. The Holocene 15 (6), 789-801.

Kaniewski D, Marriner N, Sarti G, Bertoni D, Marchesini M, Rossi V, Lena A, Bivolaru A, Poukerman N, Vacchi M, Cheddadi R, Otto T, Luce F, Cottica D, Morhange C, 2022. Northern Adriatic environmental changes since 500 AD reconstructed at Aquileia (Italy). Quaternary Science Reviews 87, 107565.

Kaniewski D, van Campo E, Boiy T, Terral JF, Khadari B, Besnard G, 2012. Primary domestication and early uses of the emblematic olive tree: palaeobotanical, historical and molecular evidence from the Middle East. Biological Reviews 87, 885-899.

Kaniewski D, van Campo E, Guiot J, Le Burel S, Otto T, Baeteman C, 2013. Environmental roots of the Late Bronze Age Crisis. PLoS ONE 8(8), e71004.

Korasidis VA, Wing SL, Nelson DM, Baczynski AA, 2022. Reworked pollen reduces apparent floral change during the Paleocene-Eocene Thermal Maximum. Geology 50, 1398-1402.

Leoni G, 1984. Idrografia e bonifica del bacino del Reno. Notizie Storiche. Bologna, Grafiche A&B, 1994, p. 85.

Lòpez Merino L, Colàs Ruiz NR, Adame MF, Serrano O, Martìnez Cortizas A, Mateo MA, 2017. A six-thousand year record of climate and land use change from Mediterranean seagrass mats. Journal of Ecology 105, 1267-1278.

Lowe JJ, Accorsi CA, Bandini Mazzanti M, Bishop A, van der Kaars S, Forlani L, Mercuri AM, Rivalenti C, Torri P, Watson C, 1996. Pollen stratigraphy of seidment sequences from lakes Albano and Nemi (near Rome) and from the central Adriatic, spanning the interval from oxygen isotope stage 2 to the present day. In: Guilizzoni P, Oldfield F (eds.), Palaeoenvironmental analysis of Italian crater lake and Adriatic sediments. Memorie dell'Istituto Italiano di Idrobiologia 55, 71-98.

Malaguti C, Marchesini M, Casagrande L, Cobianchi V, Gobbo I, Marvelli S, Mura L, Rizzoli E, 2010. Il pozzo di Badia Polesine (Rovigo). In: Cipriano S, Pettenò E (eds.), Archeologia e tecnica dei pozzi per acqua dappa Pre-protostoria dell'Età Moderna. Antichità Altoadriatiche 70, Trieste Editreg 2011.

Marchesini M, Marvelli S, 2009. Ricostruzione del paesaggio vegetale e antropico nelle aree centuriate dell'Emilia-Romagna attraverso le indagini archeobotaniche. Agri centuriati 6.

Marchesini M, Marvelli S, 2017. Paesaggio vegetale e agricoltura nella Pianura padana in età romana. In: Lo Cascio E, Maiuro M (eds.), Popolazione e risorse nell'Italia del nord dalla romanizzazione ai Longobardi. Pragmateiai 28, Bari, pp. 289-304.

Marchesini M, Marvelli S, 2018. Paesaggio e ambiente in età romana nella bassa Pianura Padana. In: Cesarano M, Vallicelli VC, Zamboni L (eds.), Antichi Romani e romanità nelle terre del Delta del Po. Nuovi studi e prospettive di ricerca. Ricerche series maior 8, Bologna 2018, pp. 115-125.

Marchesini M, Forlani L, Giordani N, 1998. Reperti antraco/filologici del pozzo di Rubiera (53 m s.l.m., Reggio Emilia – Nord Italia) nell'età tardo antica: fine VI – metà VII sec. d.C. In: Accorsi CA, Bandini Mazzanti M, Labate D, Trevisan Grandi G (eds.). Studi in ricordo di Daria Bertolani Marchetti, Atti della Giornata di Studi (Formigine, 18 maggio 1996). Modena 1988, 375-383.

Marchesini M, Marvelli S, Bandini Mazzanti M, Accorsi CA, 1999. Spettri pollinici del pozzo deposito di Cognento (Modena) dal periodo tardo romano all'età moderna. In: Quaderni di Archeologia dell'Emilia-Romagna 3, 181-205.

Marchesini M, Marvelli S, Mancini A, Forlani L, 2003. Ricostruzione ambientale del paesaggio vegetale nella bassa pianura modenese-mantovana in età medievale. In: Perboni M (ed.), Terre di confine: il territorio di San Giovanni del Dosso e del destra Secchia nel Medioevo. SAP 29, 137-143, Mantova 2003.

Marchesini M, Marvelli S, Tura L, Baccarani G, Forlani L, Accorsi CA, 2008. Il contesto vegetazionale / ambientale emerso dalle indagini palinologiche. In: Guarnieri C. (ed.), Un approdo a Ferrara tra Medioevo ed Età Moderna: la barca di Porta Paola. Ante Quem, 25-40, Bologna 2008.

Marcott SA, Shakun JD, Clark PU, Mix AC, 2013. A reconstruction of regional and global temperature for the past 11300 years. Science 339, 1198-1201.

Marriner N, Morhange C, Sagieh Beydoun M, 2008. Geoarchaeology of Beirut's ancient harbour, Phoenicia. Journal of Archaeological Science 35, 2495-2516.

Marvelli C, Marchesini M, Lambertini F, Zampighi C (eds.), 2011. Aquae. La gesione dell'acqua oltre l'Unità d'Italia nella pianura emiliana. Celebrazione del 525° anno dello scavo del "Cavamento Foscaglia" 1478-2012. Guida alla mostra (11 giugno – 31 ottobre 2011, San Giovanni in Persiceto – BO). Museo Archeologico Ambientale, Bologna.

Maselli V, Trincardi F, 2013. Man made deltas. Science Reports 3, 1926. https://doi.org/10.1038/srep01926.

Melis RT, Di Rita F, French C, Marriner N, Montis F, Serreli G, Sulas F, Vacchi M, 2018. 8000 years of coastal changes on a western Mediterranean island: a multiproxy approach from the Posada plain of Sardinia. Marine Geology 403, 93-108.

Mensing S, Tunno I, Cifani G, Passigli S, Noble P, Archer C, Piovesan G, 2016. Human and climatically induced environmental change in the Mediterranean during the Medieval Climate Anomaly and Little Ice Age: a case study from central Italy. Anthropocene 15, 46-59.

Mercuri AM, Bandini Mazzanti M, Torri P, Vigliotti L, Bosi G, Florenzano A, Olmi L, Massamba N'siala I, 2012. A marine/terrestrial integration for mid-late Holocene vegetation history and the development of the cultural landscape in the Po valley as a result of human impact and climate change. Vegetation History and Archaeobotany 21, 353-372.

Mercuri AM, Marignani M, Sadori L, 2013. Palynology: the bridge between paleaoecology and ecology for the understanding of the human-induced global changes in the Mediterranean area. Annali di Botanica 3, 107-113.

Michelangeli F, Di Rita F, Celant A, Tisnérat Laborde N, Lirer F, Magri D, 2022. Three millennia of vegetation, land use and climate change in SE Sicily. Forests 13 (1), 102. doi:10.3390/f13010102.

Montanari M, 1979. L'alimentazione contadina nell'Alto Medioevo. Liguori, Napoli, 1979, 512 pp.

Montanari M, 1988. Alimentazione e cultura nel Medioevo. Laterza, Bari, 1988, 236 pp.

Moore PD, Webb JA, Collinson ME, 1991. Pollen analysis, 2nd. Blackwell Scientific Publications, Oxford.

Nicolussi K, Kaufmann M, Melvin TM, van der Plicht J, Schiessling P, Thurner A, 2009. A 9111 year long conifer tree-ring chronology for the European Alps. A base for climatic and environmental investigations. The Holocene 19 (6), 909-920.

Ninfo A, Ciavola P, Billi P, 2018. The Po Delta is restarting progradation: geomorphological evolution based on a 47-years Earth Observation dataset. Scientific Reports 8, 3457.

Ortalli J, 1992. Edilizia residenziale e crisi urbana nella tarda antichità: fonti archeologiche per la Cispadana. In: Corsi di Cultura sull'arte ravennate e bizantina 39, 557-605.

Ostrogorsky G, 1968. Storia dell'Impero Bizantino. Einaudi.

Pepe C, Giardini M, Giraudi C, Masi A, Mazzini I, Sadori L, 2013. Plant landscape and environmental changes recorded in marginal marine environments: the ancient Roman Harbour of Portus (Rome, Italy). Quaternary International 303, 73-81.

Peregrine PN, 2020. Climate and social change at the start of the Late Antique Little Ice Age. The Holocene 30(11), 1643-1648.

Piccoli F, Gerdol R, Ferrari C, 1983. Carta della vegetazione del Bosco della Mesola (Ferrara). Atti dell'Istituto Botanico e Laboratorio di Crittogamica, Serie 7, vol. 2, 3-23.

Pignatti S., 1979. I piani di vegetazione in Italia. Giornale Botanico Italiano 113, 411–428.

Ravegnani G, 2004. I bizantini in Italia. Il Mulino, Bologna.

Reille M, 1992. Pollen et spores d'Europe et d'Afrique du nord. Laboratoire de Botanique Historique et Palynologie, Marseille.

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

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

Reimer PJ, Austin WEN, Bard E, Bayliss A, Blackwell PG, Bronk Ramsey C, Butzin M, Cheng H, Lawrence Edwards R, Friedrich M, Grootes PM, Guilderson TP, Hajdas I, Heaton TJ, Hogg AG, Hughen KA, Kromer B, Manning SW, Muscheler R, Palmer JG, Pearson C, van der Plicht J, Reimer RW, Richards DA, Marian Scott E, Southon JR, Turney CSM, Wacker L, Adolphi F, Büntgen U, Capano M, Fahrni SM, Fogtmann Schulz A, Friedrich

R, Köhler P, Kudsk S, Miyake F, Olsen J, Reinig F, Sakamoto M, Sookdeo A, Talamo S, 2020. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0-55 cal kBP). Radiocarbon 62(4), 725-757.

Richter D deB, Billings, 2015. “One physical system”: Tansley’s ecosystem as Earth’s critical zone. New Phytologist 206, 900-912.

Roberts N, Woodbridge J, Palmisano A, Bevan A, Fyfe R, Shennan S, 2019. Mediterranean landscape change during the Holocene: synthesis, comparison and regional trends in population, land cover and climate. The Holocene 29(5), 923-937.

Rossi V, Barbieri G, Vaiani SC, Cacciari M, Bruno L, Campo B, Marchesini M, Marvelli S, Amorosi A, 2021. Millennial-scale shifts in microti dal ecosystems during the holocene: dynamics and drivers of change from the Po Plain coastal record (NE Italy). Journal of Quaternary Science 36(6), 961-979.

Sadori l, Giraudi C, Masi A, Magny M, Ortu E, Zanchetta G, Izdebski A, 2016. Climate, environment and society in southern Italy during the last 2000 years. A review of the environmental, historical and archaeological evidence. Quaternary Science Reviews 136, 173-188.

Sadori l, Giraudi C, Petitti P, Ramrath A, 2004. Human impact at Lago di Mezzano (central Italy) during the Bronze Age: a multidisciplinary approach. Quaternary International 113, 5-17.

Sarti G, Rossi V, Amorosi A, Bini M, Giacomelli S, Pappalardo M, Ribecai C, Ribolini A, Sammartino C, 2015. Climatic signature of two mid-late Holocene fluvial incisions formed under sea-level highstand conditions (Pisa coastal plain, NW Tuscany, Italy). Palaeogeography, Palaeoclimatology, Palaeoecology 424, 183-195.

Scagliarini Corlaita D, 1989. L’insediamento agrario in Emilia-Romagna nell’età romana. In: Adani G (ed.), Insediamenti rurali in Emilia-Romagna Marche. Amilcare Pizzi Ed., Cinisello Balsamo (MI).

Sedrati M, Ciavola P, Armarolai C, 2011. Morphodynamic evolution of a coastal microti dal barrier; the role of overwash: Bevano, Northern Adriatic Sea. Journal of Coastal Research. Specia Issue 64, 696-700.

Sereni E, 1957. Note per una storia del paesaggio agrario emiliano. In: Zangheri R. (editor), Le campagne emiliane nell’epoca moderna. Milano 1957, 27-53.

Shumilovskikh LS, Seeliger M, Feuser S, Novenko E, Schlütz F, Pint A, Pirson F, Brückner H, 2016. The Harbour of Elaia: a palynological archive for human environmental interactions during the last 7500 years. Quaternary Science Reviews 149(1), 167-187.

Sorbelli A, 1910. Il comune rurale dell’Appennino Emiliano nei secoli XIV e XV. Arnaldo Forni Editore, 1910.

Squatriti P, 2013. Landscape and change in early medieval Italy: chestnuts, economy, and culture. Cambridge University Press, New York, USA.

Stefani M., 2017. The Po Delta region: depositional evolution, climate change and human intervention during the last 5000 years. Landscapes and Landforms of Italy, pp 2-10. Springer International Publishing.

Stefani M, Vincenzi S, 2005. The interplay of eustasy, climate and human activity in the late Quaternary depositional evolution and sedimentary architecture of the Po Delta system. Marine Geology 222-223, 19-48.

Streel M, Bless MJM, 1980. Occurrence and significance of reworked palynomorphs. Mededelingen Rijks Geologische Dienst 32(10), 69-80.

Strother SL, Salzmann U, Sangiorgi F, Bijl PK, Pross J, Escutia C, Salabarnada A, Pound MJ, Voss J, Woodward J, 2017. A new quantitative approach to identify reworking in Eocene to Miocene pollen records from offshore Antarctica using red fluorescence and digital imaging. Biogeosciences 14, 2089-2100.

Susini D, Vignola C, Goffredo R, Totten DE, Masi A, Smedile A, De Martini PM, Cinti FR, Sadori L, Forti L, Fiorentino G, Sposato A, Mazzini I, 2023. Holocene palaeonvironmental and human settlement evolution in the southern margin of the Salpi lagoon, Tavoliere coastal plain (Apulia, southern Italy). Quaternary International 655, 37-54.

Sussman GD, 2011. Was the Black Death in India and China? Bulletin of the History of Medicine 85, 319-355.

Tansley AG, 1935. The use and abuse of vegetational concepts and terms. Ecology 16(3), 284-307.

Trincardi F, Cattaneo A, Correggiari A, 2004. Mediterranean prodelta systems. Natural evolution and human impact investigated by EURODELTA. Oceanography 17(4), 34-45.

Tschudy RH, Scott RA, 1969. Aspects of palynology. Wiley-Interscience, 1969.

Ubaldi D, 2003. Flora, fitocenosi e ambiente. In: Elementi di geobotanica e fitosociologia. CLUEB, Bologna.

Vacchi M, Marriner N, Morhange C, Spada G, Fontana A, Rovere A, 2016. Multiproxy assessment of Holocene relative sea-level changes in the western Mediterranean: sea-level variability and improvements in the definition of the isostatic signal. Earth Science Reviews 155, 172-197.

Veggiani A, 1979. Prove di un ciclo climatico di piovosità nell'Alto Medioevo nel cesenate. Studi Romagnoli 30, 87-101.

Veggiani A., 1990. Fluttuazioni climatiche e trasformazioni ambientali nel territorio imolese dall'alto medioevo all'etá moderna. In: Mancini F., Gioberti M., Veggiani A. (eds.), Imola nel Medioevo, 41-102.

Vescovi E, Kaltenrieder P, Tinner W, 2010. Late-glacial and Holocene vegetation history of Pavullo nel Frignano (Northern Apennines, Italy). Review of Palaeobotany and Palynology 160, 32-45.

Vittori C, Mazzini I, Salomon F, Goiran JP, Pannuzi S, Rosa C, Pellegrino A, 2015. Palaeoenvironmental evolution of the ancient lagoon of Ostia Antica (Tiber delta, Italy). Journal of Archaeological Science 54, 374-384.

Walker M, Head MJ, Berkelhammer M, Björck S, Cheng H, Cwynar L, Fisher D, Gkinis V, Long L, Lowe J, Newnham R, Rasmussen SO, Weiss H, 2018. Formal ratification of the subdivision of the Holocene Series/ Epoch (Quaternary System/ Period): two new Global Boundary Stratotype Sections and Points (GSSPs) and three new stages/ subseries. Episodes 41 (4), 213–223. https://doi.org/10.18814/epiiugs/2018/018016.

Zanella G (ed.), 1983. Riccobaldo of Ferrara: Chronica parva Ferrariensis. Serie monumenti. Regia. deputazione di storia patria per l'Emilia e la Romagna, sezione di Ferrara, 9, 241 pp.

Zanchetta G, 2013. The transition from natural to anthropogenic-dominated environmental change in Italy and the surrounding regions since the Neolithic: an overview. Quaternary International 303, 1-9.

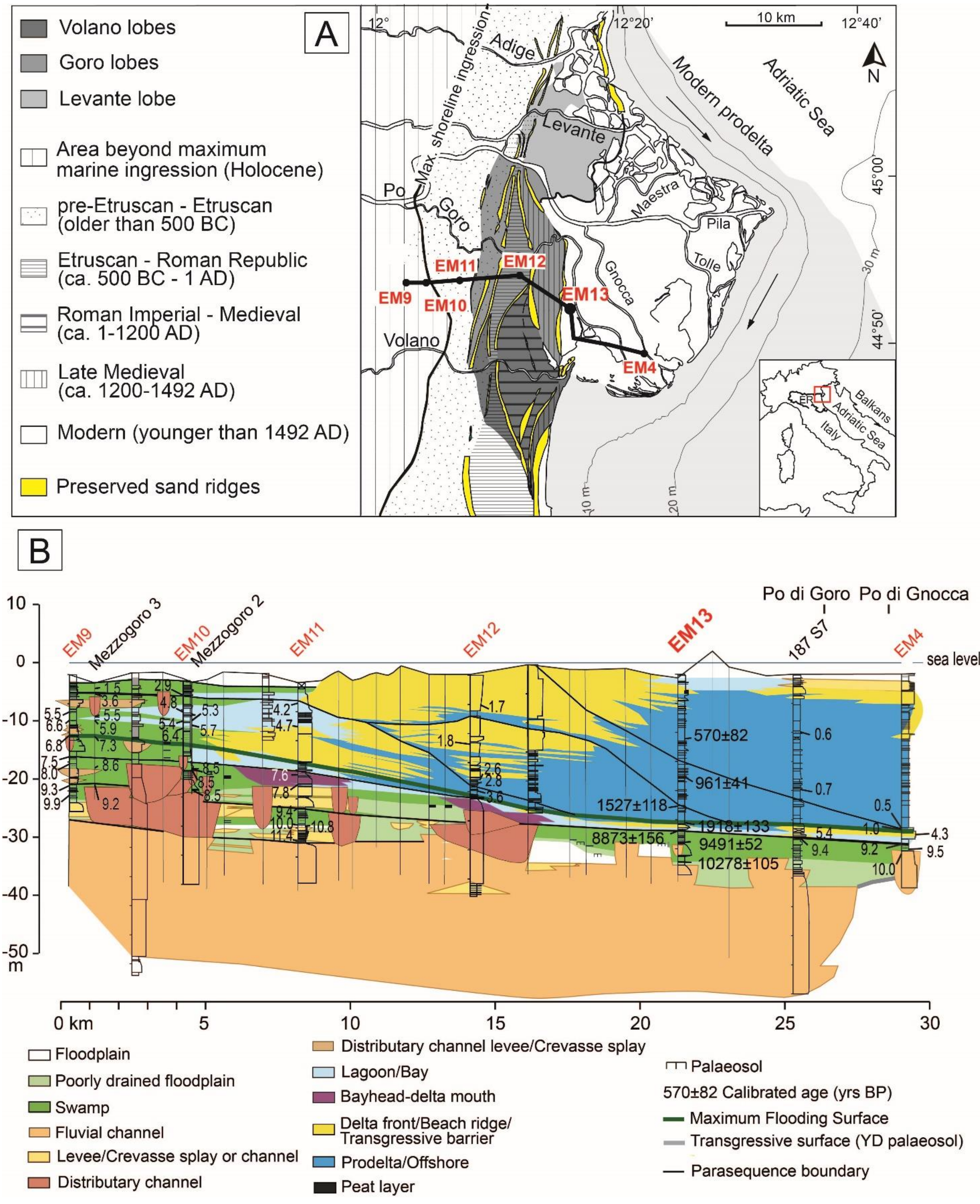


Figure 1. Geomorphological and stratigraphic setting of the Po Delta area. (A) Map showing the spatial distribution of the (palaeo)delta lobes (slightly modified after Ciabatti, 1967, and Barbieri et al., 2021), the location of core EM13 and the trace of the section shown in Figure 1B. Maximum shoreline ingression from Bruno et al. (2017), the modern prodelta from Correggiari et al. (2005). Black arrows highlight the Sdirected Adriatic longshore current. ER: Emilia-Romagna Region. (B) Stratigraphic section showing the Holocene depositional architecture of the Po Delta (slightly modified after Amorosi et al., 2017). Radiocarbon dates are rounded up except for core EM13, whose ages (see Table 2) are recalibrated after Reimer et al. (2020).

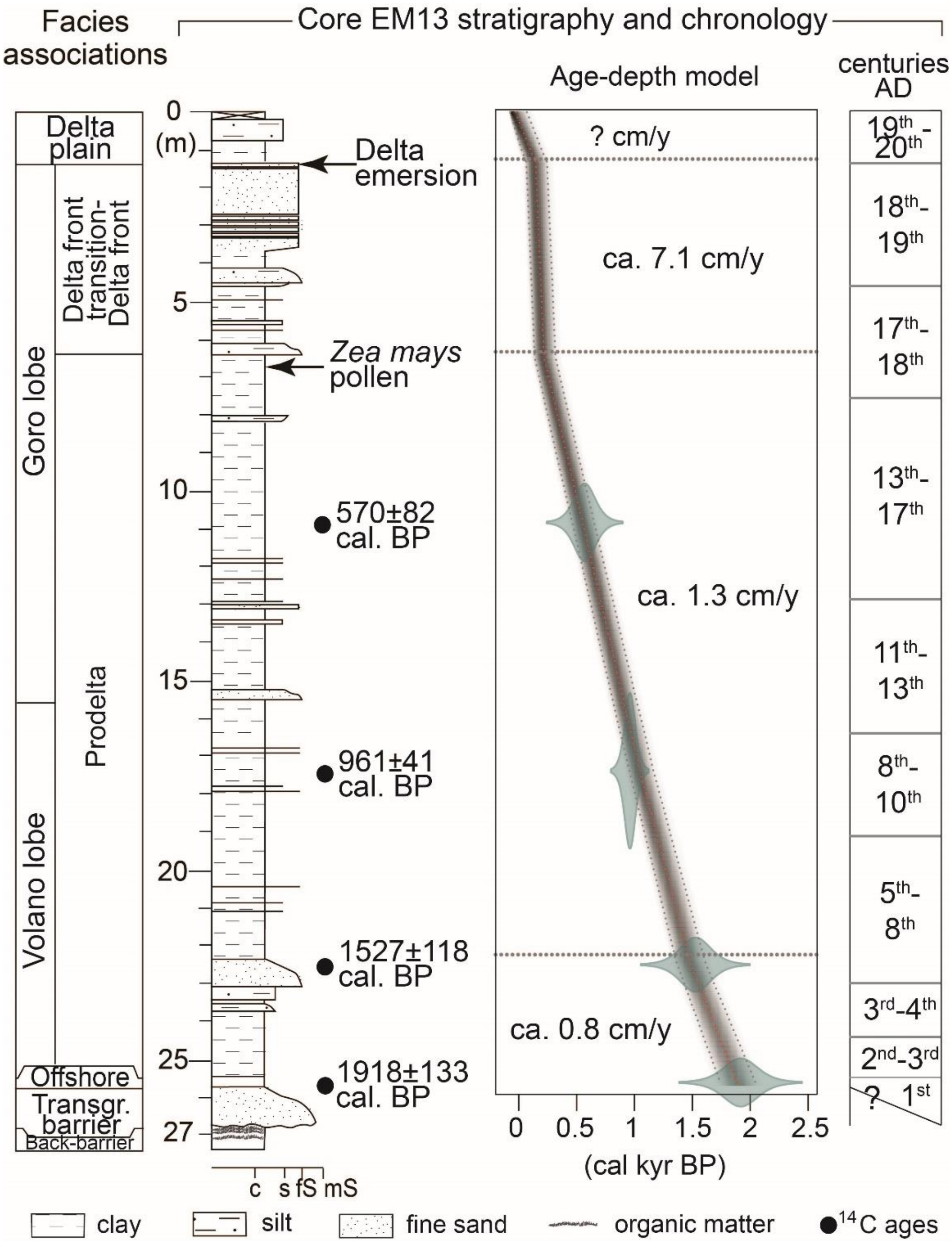


Figure 2. Stratigraphy, facies associations, age-depth model and chronological inferences of core EM13 (stratigraphic log and facies interpretation slightly modified after Barbieri et al., 2021).

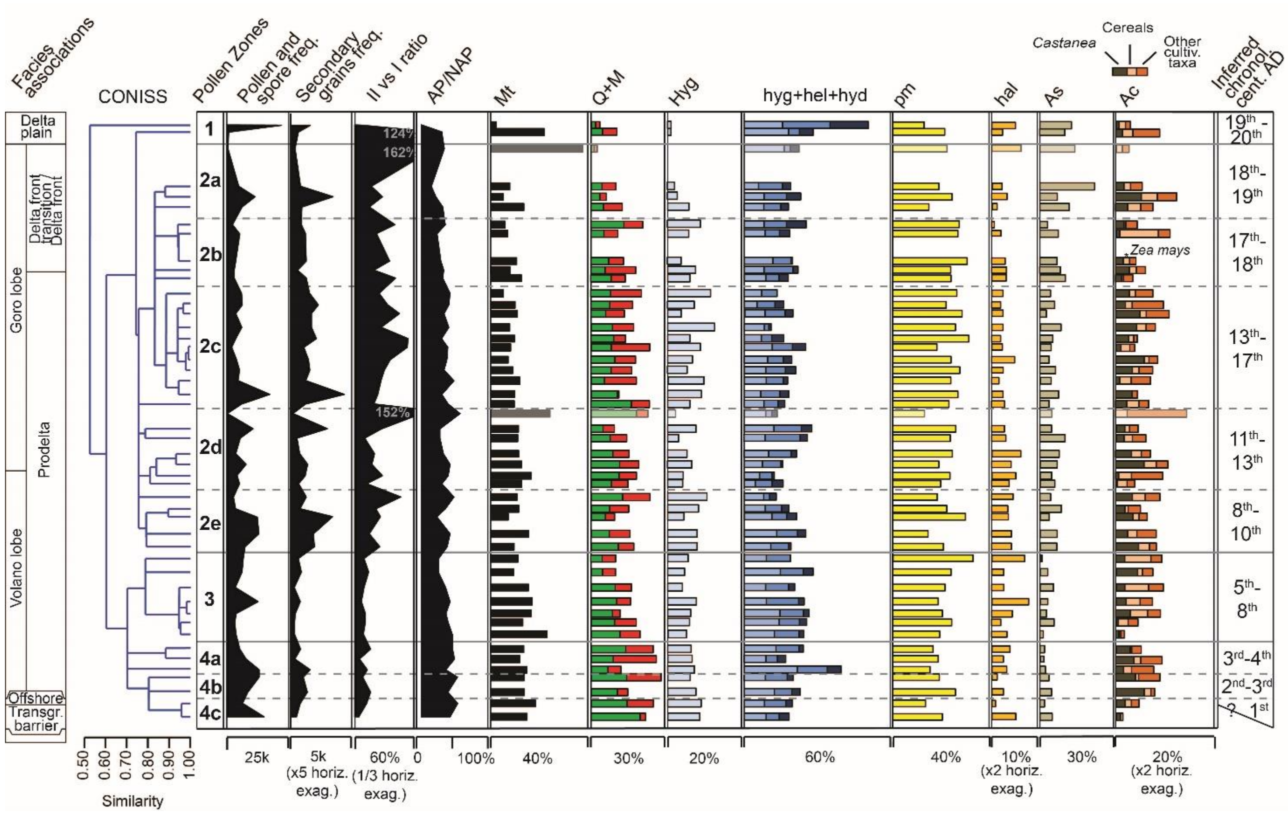


Figure 3. Main palynological features of core EM13, reported as relative abundances of pollen ecological groups (see text and Table 1), frequency of palynomorphs and AP/NAP ratio. The studied succession includes four main pollen zones, identified via CONISS and chronologically constrained on the basis of radiocarbon ages and additional markers (Figure 2).

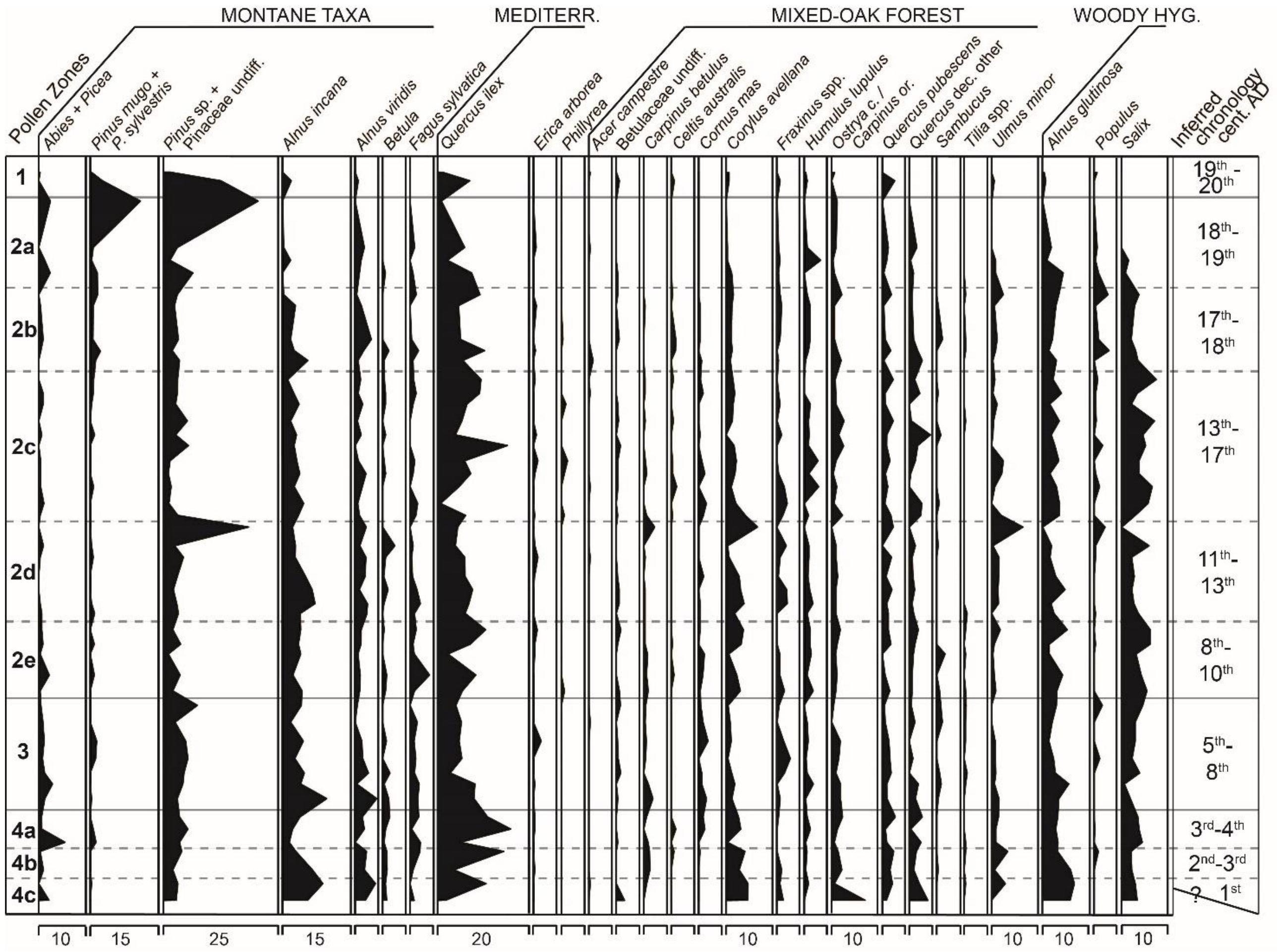


Figure 4. Pollen percentage diagram showing the relative abundances of the main tree taxa, belonging to the montane (Mt) and lowland (M, Q and Hyg) groups. Where unspecified, the scale bar represents a 5% measure unit.

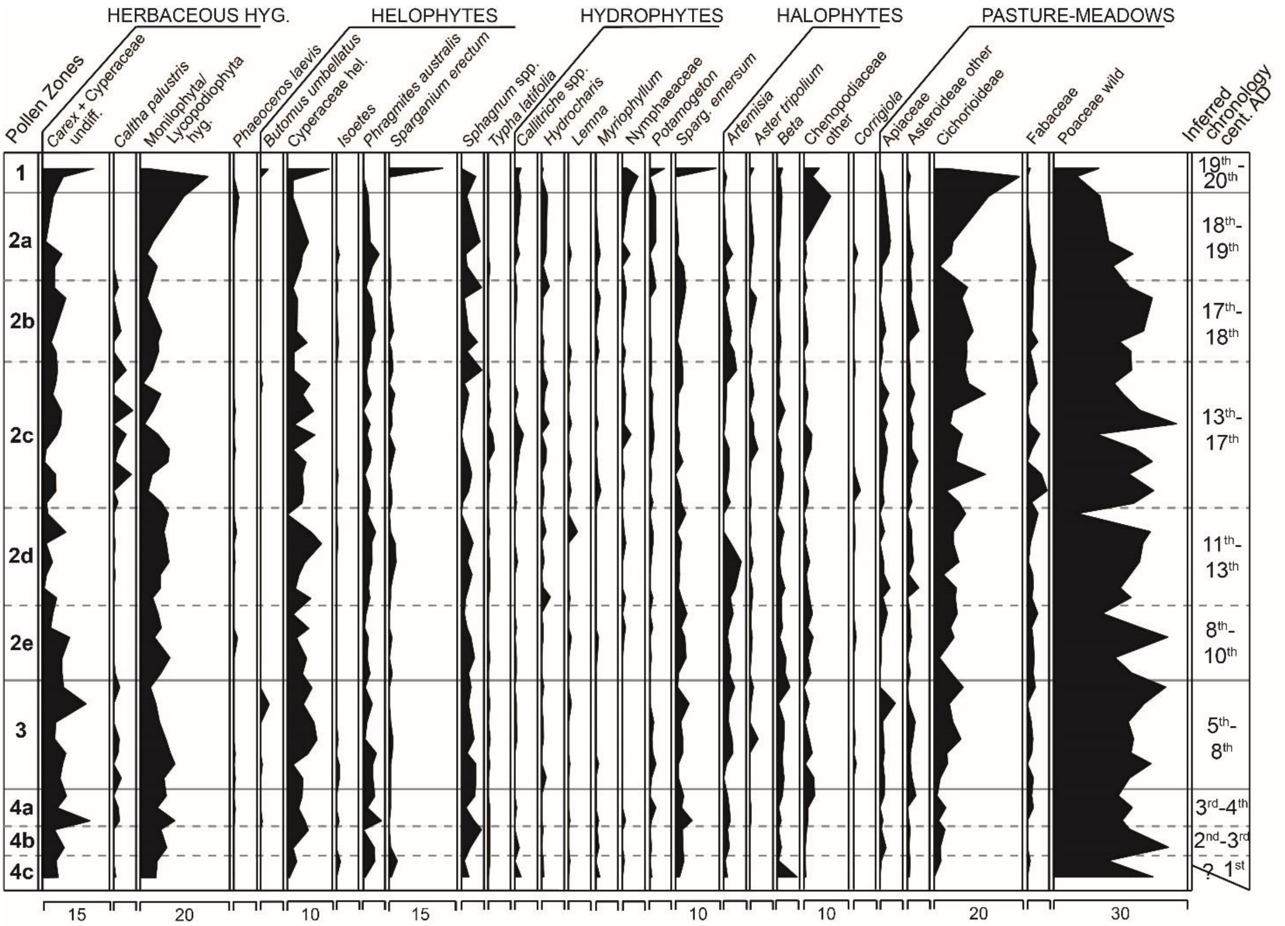


Figure 5. Pollen percentage diagram showing the relative abundances of the main herbaceous taxa, belonging to the wetland (hyg, hel, hyd) and well-drained (hal and pm) environmental groups. Where unspecified, the scale bar represents a 5% measure unit.

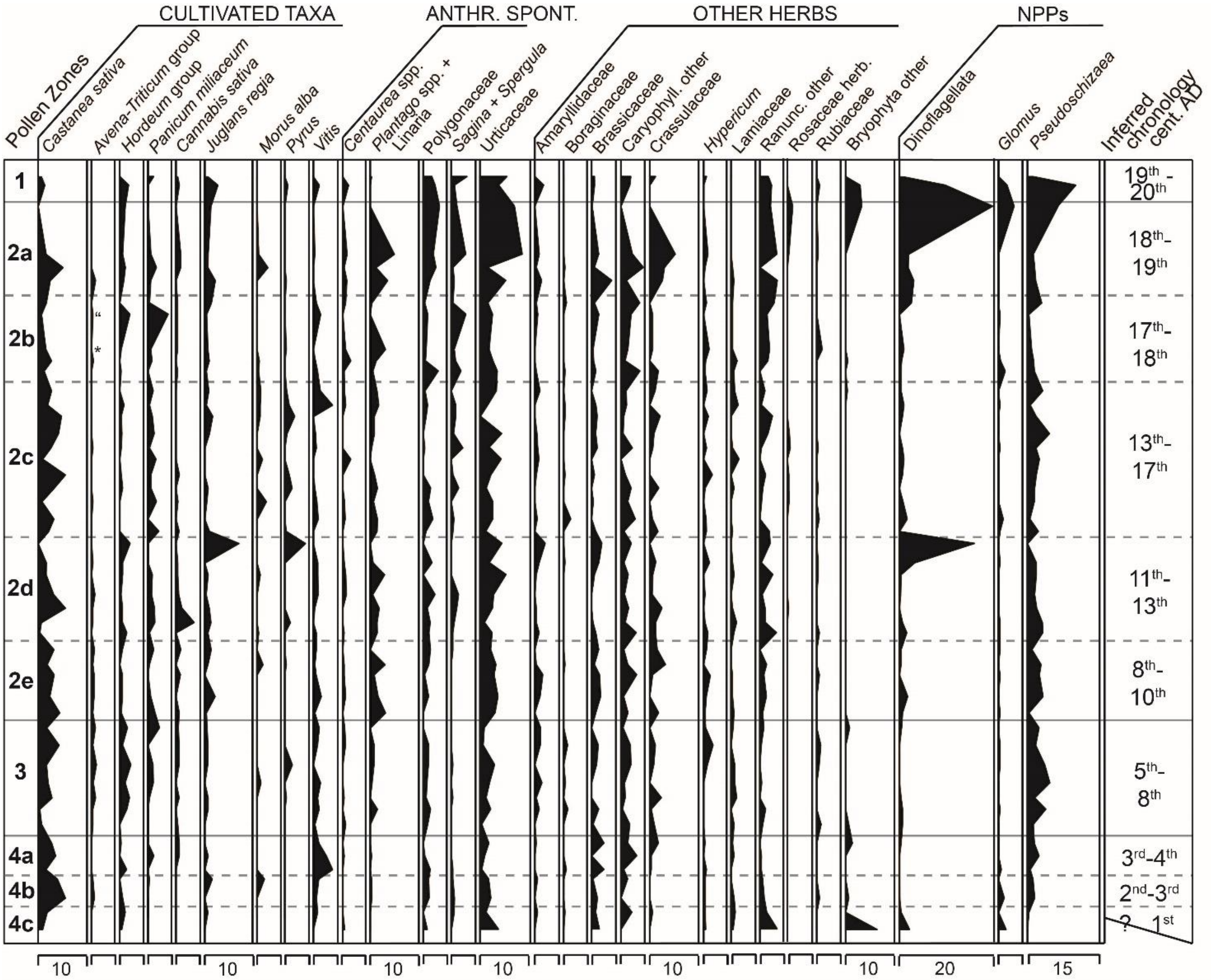


Figure 6. Pollen percentage diagram showing the relative abundances of the main herbaceous taxa, belonging to the Ac and As groups plus taxa not specifically belonging to any group/ubiquists; NPPs are also expressed. Where unspecified, the scale bar represents a 5% measure unit.

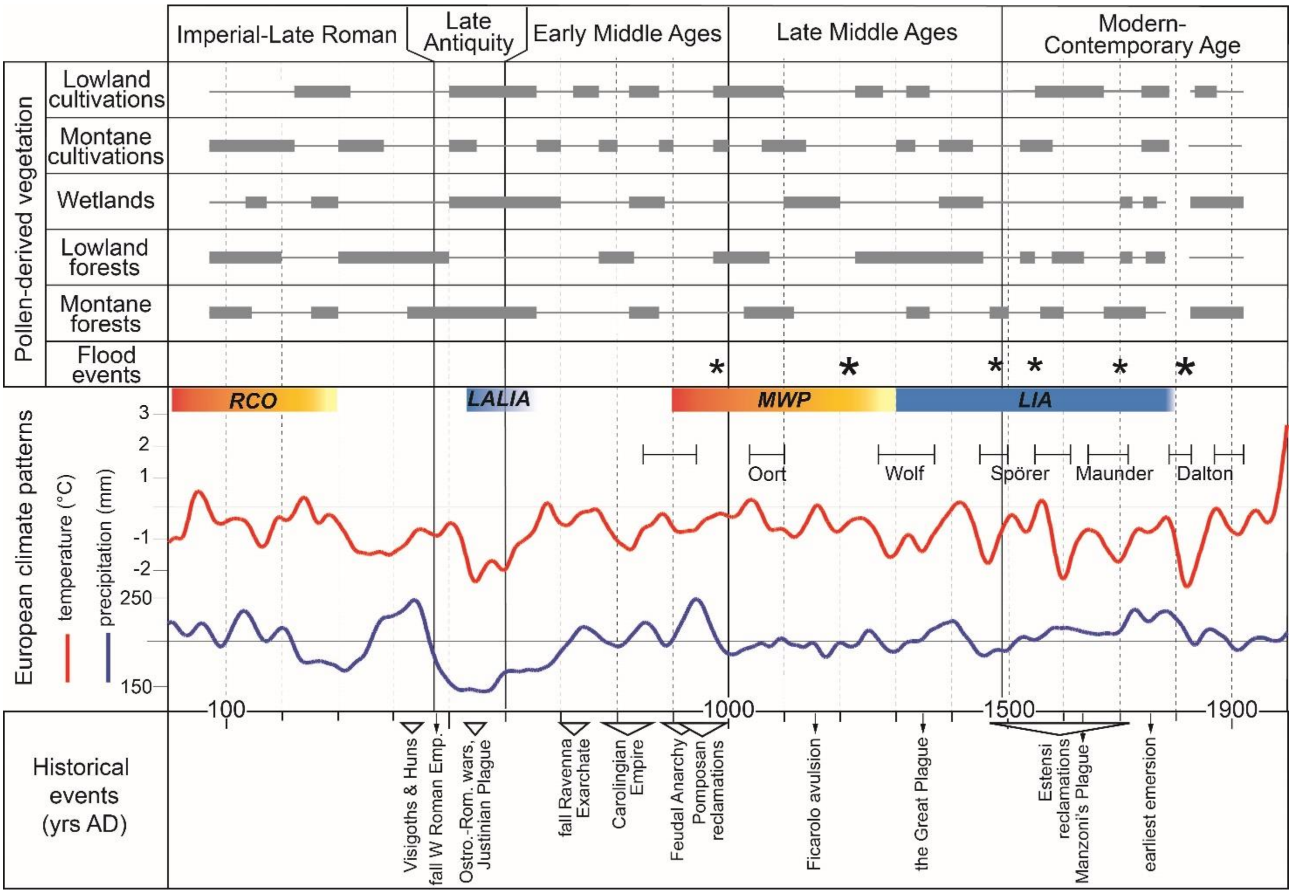


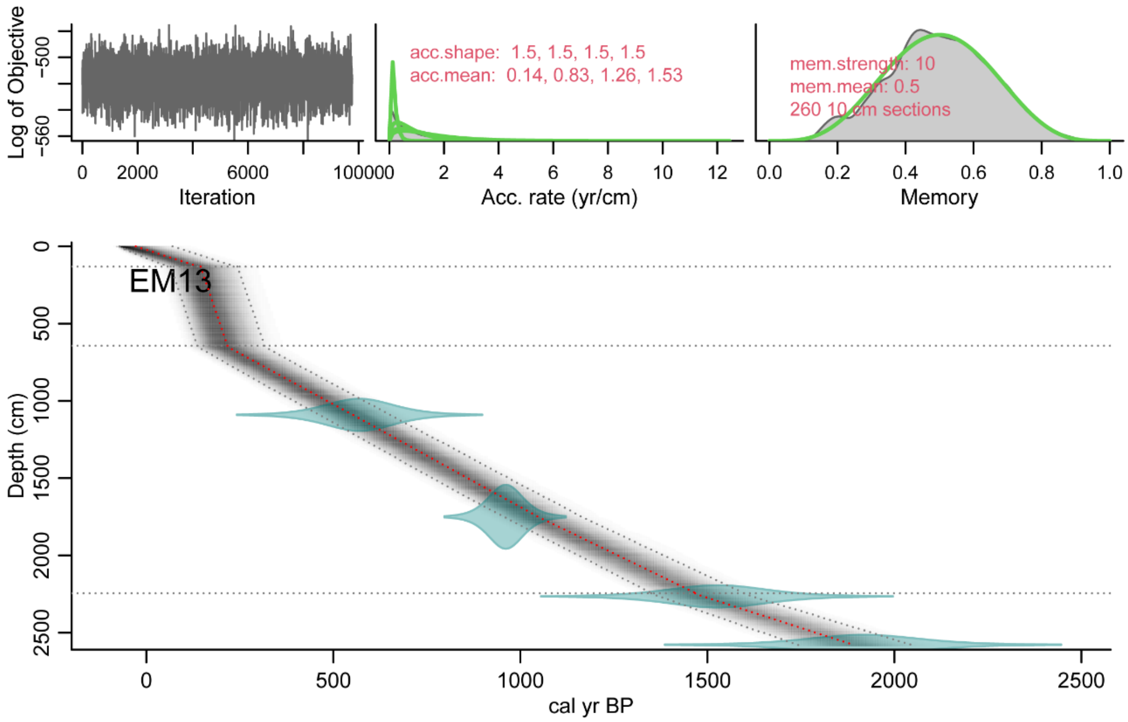
Figure 7. Comparison between the EM13 palynological record (vegetation patterns, flood events) with solar minima (sensu Bard et al., 2000) and European temperature and rainfall reconstructions (60-year low-pass filters from Büntgen et al., 2011). Bigger asterisks highlight major peaks in II/I ratio. At the bottom, the main historical events occurring in the Po delta plain are also shown. Grey bars were assigned on the base of the most dominant ecological groups within each chronologically and stratigraphically constrained pollen zone/sub-zone (see also Supplemental Figure 2).

Ecological group	Definition	Ecological significance
Mt	Montane taxa	High altitude woods
Q	Mixed oak forest	Mesophilous woods
M	Mediterraneans	Thermophilous woods
Hyg	Woody hygrophytes	Hygrophilous woods
hyg	Herbaceous hygrophytes	Hygrophilous grasslands
hel	Helophytes	Seasonally underwater herbs
hyd	Hydrophytes	Fully aquatic herbs
pm	Pasture-meadows	Mesophilous grasslands
hal	Halophytes	Saline-tolerant grasslands
As	Anthropic spontaneous	Disturbed grasslands
Ac	Anthropic cultivated	Crop fields / orchards-arboriculture (split into *Castanea*, cereals – ce, and other cultivated taxa)

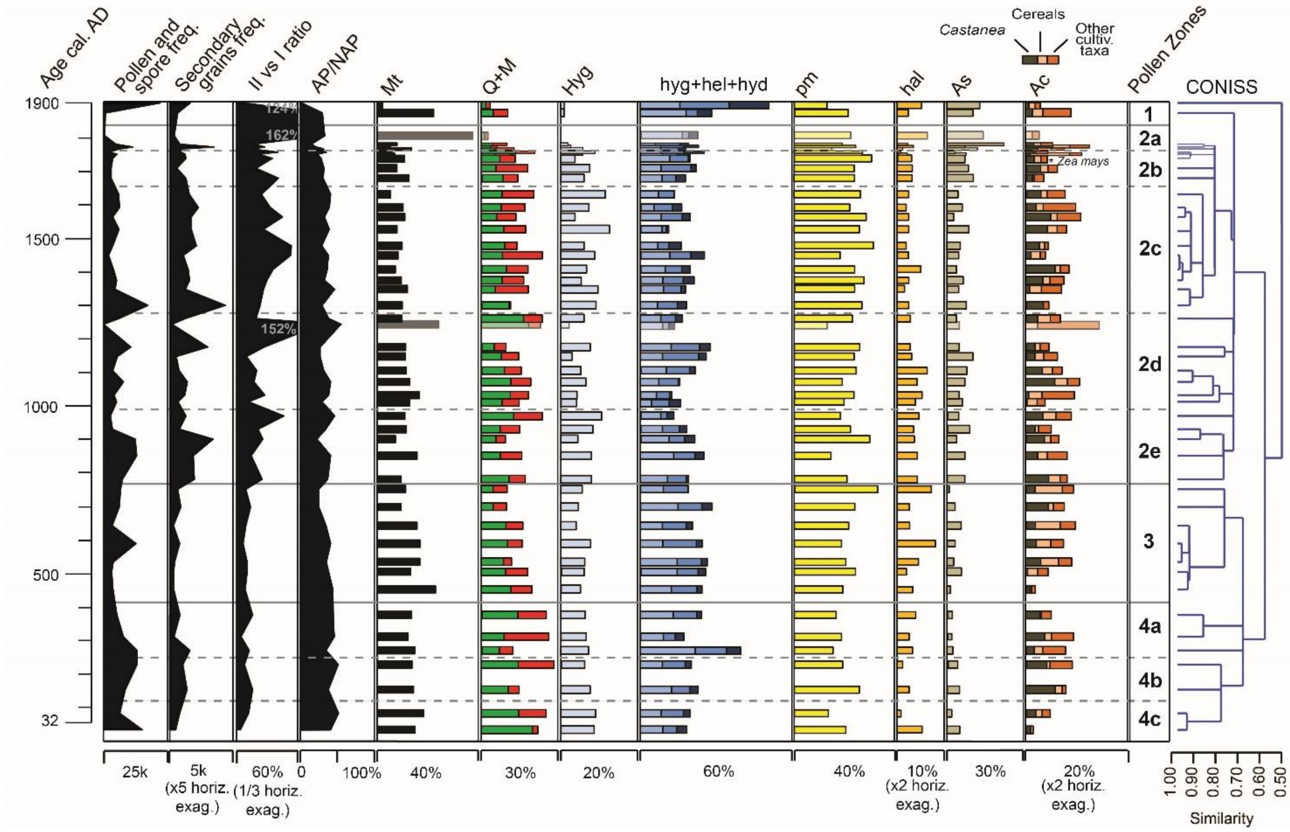
Table 1. List of pollen's ecological groups and associated ecological significance.

Sample depth (m)	Dated material	Radiocarbon age (conventional yrs BP)	Calibrated age BP (2σ interval)	Calibrated age BC/AD (2σ interval)	References
10.90	Shell	840±40	489-652	1298-1461 AD	Amorosi et al. (2017)
17.50	Wood	1060±30	920-1002	948-1030 AD	Amorosi et al. (2017)
22.90	Shell	1900±40	1409-1645	305-541 AD	Amorosi et al. (2017)
25.78	Shell	2220±30	1786-2051	102 BC-164 AD	this study

Table 2. List of radiocarbon ages available for core EM13, recalibrated after Reimer et al. (2020).



Supplemental Figure 1. Age-depth model original graph. Priors: Memory defines how much the accumulation rate of a particular depth in a core depends on the depth above it (Blaauw and Christen, 2011). Acc. rate panel shows the accumulation rate prior as defined per intervals listed bottom-to-top; acc.shape is the shape of the distribution curve of the accumulation rates (1.5 is default). The iteration panel pictures how well the Markov Chain Monte Carlo fits with given priors at an increasing number of iterations (the more uniform the oscillations, the better the model). Boundaries (dotted horizontal lines) in the model were set at 22.45 m (meiofauna-based variation in bottom conditions due to changes in river inputs, following Barbieri et al., 2021), 6.43 m (prodelta – delta front transition/delta front boundary) and 1.31 m (delta front transition/delta front – delta plain boundary).



Supplemental Figure 2. Pollen groups' percentage diagram of EM13 plotted against chronology, including the pollen zonation identified *via* CONISS. The temporal attribution of each sample derives from the age-depth model. The subdivision in terms of centuries AD is also shown (see also Figure 3).

Supplemental Table 1: Percentages of pollen, spores and other NPPs of core EM13. The ecological characterisation of some taxa may be controversial and deserves some explanation: *Castanea*, even though living on the hills, was counted as Anthropic cultivated (Ac) and not as Montane (Mt) because during the last two millennia it was mainly cultivated and, thus, bears no climatic significance. *Beta* was considered halophyte (hal) instead of Ac because its relative abundance is always too low to be considered of anthropic origin. Similarly, other chenopods were also considered hal instead of Anthropic spontaneous (As) due to the proximity of the coast. *Posidonia* and *Ruppia* were assigned to the halophyte group, though strictly hydrophyte (hyd), because they live in saltwater at a few meters of depth in the sea.

DEPTH (m)			**26,17**	25,70	25,10	24,52	24,17	23,83	23,30	22,77	22,20	21,82	21,17	20,61	19,94	19,32	18,88	18,22	17,62	17,20
SAMPLES (n°)			**51**	49	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
TREES		Ecological groups																		
ADOXACEAE	*Sambucus* sp.	sh,DT			0,33					0,33	0,99	0,64			1,24	0,88	0,65		1,85	
BETULACEAE	*Alnus* cf. *glutinosa*	T,Hyg	6,25	7,21	6,33	3,38	3,49	3,00	3,44	3,67	5,92	2,88	2,45	1,42	2,17	3,10	3,23	4,52	1,54	1,56
	Alnus cf. *incana*	T,Mt	5,80	9,40	7,00	3,08	1,59	2,33	4,06	10,33	4,28	5,13	2,86	4,84	1,86	4,42	4,52	2,41	4,31	3,74
	Alnus cf. *viridis*	T,Mt	2,23	4,39	2,00	2,46		2,00	1,56	4,67	0,33	2,88	1,63	1,42		0,44	0,97	1,20	0,62	1,25
	Betula	T,Mt	0,89	0,63	1,00	0,92	0,32	0,67	1,56	1,33	0,33	1,60		0,85			0,65	0,90		
	Carpinus betulus	T,Q		0,63	1,33	1,23	0,95		0,63	2,00	0,99		0,41	0,57	0,31	0,44	0,97	0,60	0,92	0,31
	Corylus avellana	sh,Q	4,91	5,02	3,00	4,31	0,32	3,33	2,81	1,33	1,97	1,28	0,41	1,14	0,93	0,44	3,23	2,41	0,62	3,43
	Ostrya carpinifolia / Carpinus orientalis	T,Q	7,59	0,63	2,33	1,54	0,63	1,33	2,50	2,00	1,97	0,96	1,63	1,99		0,44	0,97	1,20	0,92	1,25
	Betulaceae undiff.	T,Q	1,79				0,32			0,33		0,96	0,41	0,28		0,88	0,65			0,31
CANNABACEAE	*Celtis australis*	T,DT				0,62		1,00										0,60		0,31
	Humulus lupulus	L,DT		0,94	0,33	0,62	0,32	1,33	0,63	0,33	1,97	0,64	0,41	0,85	0,62		1,94	0,60	1,54	1,25
CISTACEAE	*Cistus*	sh,M																	0,62	
	Helianthemum	sh										0,64			0,31					
CORNACEAE	*Cornus mas*	T,Q				0,31		1,33	0,94	1,67	0,66	0,64		1,99	0,93	0,44	0,32	0,90	1,23	
ERICACEAE	*Erica arborea*	sh,M			0,33			0,33	0,31		0,33			1,71					0,31	0,31
EUPHORBIACEAE	Euphorbiaceae undiff.	sh,DT																		
FAGACEAE	*Castanea sativa*	T,Ac	0,89	1,88	5,67	4,00	1,59	3,67	2,81	0,67	0,33	2,88	2,04	1,71	4,35	1,77	4,52	2,41	3,38	1,87
	Fagus sylvatica	T,Mt	0,89		0,67	2,15	2,22	0,33	1,88	1,67	1,97	0,96	1,22	0,85	1,55		0,97	4,22	0,92	0,62
	Quercus cerris + petraea + robur	T,Q	1,34	0,63		0,92	0,63	0,33	0,31		0,99				0,31	0,44		0,30		
	Quercus ilex	T,M	2,23	10,97	4,00	14,77	5,40	16,33	11,25	8,33	8,55	3,21	5,71	5,13	5,59	4,42	5,81	8,73	2,77	7,48
	Quercus pubescens	T,Q	0,89	2,19	1,67	2,46	0,95	0,67	2,81	1,00	0,99	1,92	1,63	1,42	0,62	0,44	1,61	0,60		1,87
	Quercus sp.	T,Q	2,68	1,57	1,00	0,62	1,90		2,50	1,33	0,99		0,82		0,93		0,65	0,30	0,92	1,25
JUGLANDACEAE	*Juglans regia*	T,Ac		0,63		1,54		0,67			0,66	0,64		0,57	0,62	0,44	0,32	2,11		0,62
MALVACEAE	*Tilia* spp.	T,Q		0,31		0,31	0,32				0,33	0,64		0,28	0,31	0,44	0,32		0,31	
MORACEAE	*Morus alba*	T,Ac				1,54							0,82							1,25
OLEACEAE	*Fraxinus* spp.	T,Q	1,34	0,63	1,00				0,31	0,67		1,60	2,86	1,42		0,44	1,61	0,60	0,62	
	Olea europaea	T,Ac																		
	Phillyrea angustifolia	sh,M															0,65			
PINACEAE	*Abies + Picea*	T,Mt	2,23		1,00	0,31	5,71	0,67	0,63	1,33	2,96	1,28	0,82	1,14	0,93	0,44	0,32	2,11	0,31	0,93
	Larix decidua	T,Mt		0,31																
	Pinus mugo + sylvestris	T,Mt		0,31			1,27	0,67		0,33			1,22	1,42				0,90		0,93
	Pinus sp.	T,Mt	2,23	2,51	2,00	2,77	2,54	3,67	1,88	1,67	3,95	2,88	3,67	3,13	2,17	6,64	1,29	3,01	0,62	3,12
	Pinacee undiff.	T,Mt	0,45	0,63		1,23	0,95	1,67	1,56	1,33	0,33	1,60	1,63	1,71	0,31	0,88	0,65	0,60	0,31	0,62
RHAMNACEAE	*Frangula alnus*	sh,Q																		
ROSACEAE	*Prunus*	T,Ac																		
	Pyrus	T,Ac										0,32		1,71						0,31
	Rosa	sh,DT																		
	Rubus	sh,DT							0,63	1,00										
SALICACEAE	*Populus*	T,Hyg				0,92		0,33					1,22			1,77				0,31
	Salix	T,Hyg	3,57	3,13	2,33	2,15	4,76	4,00	3,75	2,00	0,66	4,17	2,45	3,13	3,11	4,87	5,81	4,52	3,38	6,54
SAPINDACEAE	*Acer campestre* type	T,Q		0,31											0,31					

			26,17	25,70	25,10	24,52	24,17	23,83	23,30	22,77	22,20	21,82	21,17	20,61	19,94	19,32	18,88	18,22	17,62	17,20
ULMACEAE	*Ulmus minor*	T,Q		3,13	0,67	3,69	0,95	1,00	1,56	1,67	0,66	0,96	0,82	0,85			0,97	0,60	0,31	0,62
VITACEAE	*Vitis*	L,Ac		0,94	0,67	1,23	4,44	3,00	1,25	0,33	1,32	0,96	1,63		0,93	1,33	0,32	1,81	0,62	0,31
HERBS																				
ALISMATACEAE	*Sagittaria*	hyd																	1,54	
AMARANTHACEAE	*Beta*	hal	4,91	0,31	1,00	0,31	0,95	0,33	1,25	1,67	1,32	1,28	1,63	1,71	0,31	3,10	1,94	2,11	0,62	1,25
	Chenopodiaceae other	hal	0,45	0,31	0,33	0,62	0,95	1,00	2,50	2,33	0,33	1,92	1,22	0,28	1,24		1,61	0,90	2,15	0,93
AMARYLLIDACEAE	*Allium* type			0,63		0,62			0,31		0,99	0,32	1,63		1,24	1,33		1,20	1,85	0,31
APIACEAE	Apiaceae tot.	pm		0,31	1,33	0,31	0,63		0,94	1,00	0,66	0,96	0,82	0,57	3,42			0,30	0,31	0,93
ARACEAE	*Arum*																			
	Lemna	hyd		0,31			0,32				0,33				0,62				0,62	
ASTERACEAE	*Artemisia*	hal	0,89	0,31	1,33	0,92	1,59	1,33	0,94		0,66	2,24	2,04	1,14	1,24	2,65	1,29	1,81	0,92	1,25
	Aster tripolium type	hal					0,32	0,33					2,04		0,31	0,88		0,30	0,62	0,31
	Centaurea spp.	As	0,45					0,33		0,67		0,32			0,62	0,44		0,60	0,31	0,31
	Asteroideae undiff. + *Bellis* + *Tussilago*	pm	0,45	0,63	0,33	0,62	0,32		1,88	1,00	0,66	0,64	1,22	1,71	0,31		0,65		0,92	0,62
	Cichorioideae tot.	pm		1,57	1,33	2,46	0,95	2,67	0,63	1,33	2,96	2,88	6,12	4,27	3,42	6,64	3,87	1,20	4,62	3,74
BORAGINACEAE	Boraginaceae tot.			0,31			0,63				0,99		0,41		0,93					0,31
BRASSICACEAE	Brassicaceae tot.		1,79	0,94	1,33	0,31	2,86		2,81	0,33	1,64			1,14	1,55		0,97	2,11	1,85	0,62
BUTOMACEAE	*Butomus umbellatus*	hel					0,32				0,33				1,86					
CANNABACEAE	*Cannabis sativa*	Ac						0,67	0,63	0,33		0,64		0,57	0,62	0,44	0,65		0,92	
CARYOPHYLLACEAE	*Corrigiola*	hal									0,66		0,41						0,62	0,31
	Sagina + *Spergula*	As		0,63	0,67	0,31	0,32					0,32		0,28						
	Caryophyllaceae other			2,51		1,54	0,63	3,67	1,56	2,00	0,33	0,96	0,82	2,28	2,17	0,44	1,61	0,60	3,69	1,56
CONVOLVULACEAE	*Convolvulus arvensis*																			
CRASSULACEAE	Crassulaceae tot.			0,63			0,32	0,33	1,88	1,00	0,33	2,56		0,85	1,24		1,94		0,62	3,43
CYPERACEAE	*Carex* type	hyg	0,45	1,57	1,33	4,00	2,86	3,67	2,81	1,33	1,32	3,85	2,45	2,56	3,11	5,31	2,26	5,12	1,54	2,18
	Schoenoplectus + *Schoenus* types	hel	0,45	2,19	1,33	4,92	4,13	2,67	3,44	3,67	1,32	4,81	6,94	6,27	3,73	5,75	3,55	4,52	2,15	4,98
	Cyperaceae undiff.	hyg	4,46	2,82	5,00		9,52	1,00	4,06	4,00	4,61	2,88	1,63	1,71	8,39	0,88	3,55	0,60	6,15	0,93
FABACEAE	*Medicago*	pm						0,33					0,82			0,44	0,65	0,30		0,62
	Fabaceae other	pm		0,63				1,00	0,94	1,33		0,96	0,41	0,85		1,33	0,65	1,20	1,23	0,31
GERANIACEAE	Geraniaceae undiff.	As																		
HALORHAGACEAE	*Myriophyllum* spp.	hyd	0,89		0,67	0,31	0,63				0,66							0,30	0,62	
HYDROCHARITACEAE	*Hydrocharis morsus-ranae*	hyd	0,45	0,31		0,31				1,00			0,41	0,28		0,44			0,31	0,31
HYPERICACEAE	*Hypericum perforatum type*		0,45	0,31	0,33	0,31	0,63		0,31					0,85	2,17	0,44	0,32	0,60	1,54	
LAMIACEAE	Lamiaceae tot.		0,45	0,94	0,67			0,67	0,31	0,67		1,28	0,82	0,85		0,44	0,65	0,30	0,31	
LILIACEAE	*Fritillaria* type	pm																	0,92	
LINACEAE	Linum sp.																			
LYTHRACEAE	*Peplis portula*	Mt																		
NYMPHAEACEAE	*Nymphaeaceae tot.*	hyd		0,31			0,63												0,31	0,62
PAPAVERACEAE	Papaveraceae tot.	As													0,31					
PLANTAGINACEAE	*Callitriche* spp.	hyd	1,34		0,67			0,33					0,41	0,28	0,31		0,32	0,30		0,31
	Litorella uniflora	hyd																		
	Plantago spp. + *Linaria*	As			0,33	0,31		0,33			1,64		0,41	0,85	0,93		3,55	1,81	0,92	3,43
POACEAE	*"Avena-Triticum"* group	ce			0,67	0,31				0,33	0,33	0,96	0,41	1,14	0,31	0,88	0,32	0,60	0,62	0,31
	"Hordeum" group	ce	0,45	1,25	0,67		1,59		0,31		1,64	2,24	1,22	2,56	0,62	1,77	0,32	0,60	0,62	
	Panicum miliaceum cf.	ce				0,31		1,33				0,32	1,22	1,14		2,65	1,61	0,60		0,31

			26,17	25,70	25,10	24,52	24,17	23,83	23,30	22,77	22,20	21,82	21,17	20,61	19,94	19,32	18,88	18,22	17,62	17,20
	Phragmites australis cf.	hel	0,45	2,82	2,67		4,44	1,00	2,81	2,33	2,30	3,21	0,41	0,85	2,17	0,44	1,61	0,90	1,23	0,31
	Secale cereale	ce																		
	Zea mays	ce																		
	Poaceae wild group	pm	21,88	11,60	25,33	16,62	14,92	17,33	14,06	16,67	21,38	16,99	17,55	16,24	19,88	24,78	17,10	13,25	25,54	19,00
POLYGALACEAE	*Polygala vulgaris* ***type***	hyg																		
POLYGONACEAE	Polygonaceae tot.	As	0,89		1,33	1,23	1,59	0,33		1,00	1,64	0,64	0,82	1,14	1,24			1,20	0,31	1,25
POSIDONIACEAE	*Posidonia oceanica*	hal			0,33												0,32			
POTAMOGETONACEAE	*Potamogeton* type	hyd	0,45		0,33		0,32	1,33		0,33	1,32	0,64	0,41	0,85				0,30		0,62
PRIMULACEAE	*Primula* sp.										0,99									
RANUNCULACEAE	*Caltha palustris* type	hyg	0,45				1,27	1,00		1,67		0,96	1,22			1,33	0,32			
	Ranunculaceae other		4,02	1,57	1,00	0,62	0,32	0,33		0,67	1,32		0,41		0,31	0,88	0,65	1,51	0,92	1,56
ROSACEAE	Rosaceae herb. tot.																			
RUBIACEAE	Rubiaceae tot.				0,67					1,00				0,57	0,93				0,62	
RUPPIACEAE	*Ruppia maritima* type	hal																		
SCHEUCHZERIACEAE	*Scheuchzeria palustris*	Mt (hel)									0,33									
SCROPHULARIACEAE	Scrophulariaceae tot.														1,24				0,62	
SMILACACEAE	*Smilax aspera*																			
TYPHACEAE	*Sparganium emersum* type	hyd	0,89	1,88	1,67	1,54	3,81	1,33	1,88	0,67	0,66	1,60	1,63	1,14	3,11	0,44	0,65	2,41	2,15	1,25
	Sparganium erectum type	hel	0,45	1,88	0,33			0,33	0,31	0,33	0,33	0,64	0,82	0,28			0,65		0,62	
	Typha spp.	hel		0,31	0,33	0,31	0,32	0,33			0,33		0,41		0,31			0,30		
URTICACEAE	Urticaceae tot.	As	4,02	1,25	2,33	1,85	0,32	1,00	1,88	0,33	2,30	1,28	2,04	3,13	0,62	0,88	3,23	3,92	3,08	3,43
VALERIANACEAE	Valerianaceae undiff.							0,33												
ZYGOPHYLLACEAE	*Tribulus terrestris*	As										0,32								
MONILOPHYTA/LYCOPODIOPHYTA (% PS+themsel		P																		
DRYOPTERIDACEAE	*Polystichum* type	hyg																		
ASPLENIACEAE	*Asplenium* type	hyg		0,30	0,94		1,74		0,29	1,25			0,38				0,31	0,56	0,30	0,30
CYSTOPTERIDACEAE	*Cystopteris fragilis*	hyg	0,86			0,58	1,16	0,96	0,88	0,31	0,30	0,60		1,09	0,30			0,56		
DENNSTAEDTIACEAE	*Pteridium aquilinum*	hyg																		
ISOETACEAE	*Isoetes* sp.	hel		0,89			0,58			0,63	0,60		0,38							
OPHIOGLOSSACEAE	*Botrychium lunaria* type	hyg						0,32		0,31										
POLYPODIACEAE	*Polypodium vulgare* type	hyg									0,60									
PTERIDACEAE	*Pteris*	hyg									0,30					0,43		0,56		0,30
SELAGINELLACEAE	*Selaginella*	hyg																		
FILICALES MONOLETES		hyg	3,00	3,87	4,38	3,51	5,22	2,88	4,99	3,75	6,61	6,55	5,73	3,53	3,58	2,16	4,29	4,76	3,26	4,44
FILICALES TRILETES		hyg			0,94	0,88					0,30						0,31	0,56		
MONILOPHYTA/LYCOPODIOPHYTA TOTALS			3,86	5,06	6,25	4,97	8,70	4,15	6,16	6,25	8,71	7,14	6,49	4,62	3,88	2,59	4,91	7,00	3,56	5,03
NPPs (% PS+themselves)																				
ALGAE	*Pseudoschizaea circula*			0,31	1,64	1,22	0,63	2,60	1,54	1,32	4,10	1,58	5,04	3,84	1,83	2,59	0,32	3,49	2,69	3,02
DINOFLAGELLATES			2,18	0,31					0,31	0,66	0,65	0,32				0,44	0,64	1,78		0,31
FUNGI	*Glomus*		1,75		1,32		0,63				0,33			0,28	0,31		0,32		0,31	
BRYOPHYTA	*Bryophyta undeterminable*		2,04													0,86				
ANTHOCEROTACEAE	*Phaeoceros laevis*	hyg					0,31		0,30		0,32							0,87		
BRYACEAE	*Bryum marratii*	hel	2,45		0,65															

			26,17	25,70	25,10	24,52	24,17	23,83	23,30	22,77	22,20	21,82	21,17	20,61	19,94	19,32	18,88	18,22	17,62	17,20
DICRANACEAE	*Aongstroemia longipes + Saelania glaucescens*																			
FISSIDENTACEAE	*Fissidens rufulus*																			
FUNARIACEAE	*Funaria*								0,30											
	Physcomitrium pyriforme	hyg																		
JUNGERMANNIACEAE	*Mylia taylori*	Mt																		
MNIACEAE	*Plagiomnium + Rhzomnium*		2,04																	
ORTOTRICHACEAE	*Ulotha crispa*		0,41						1,19	0,64										
POTTIACEAE	*Pterygoneum ovatum*																			
RADULACEAE	*Radula complanata*																			
SPHAGNACEAE	*Sphagnum* spp.	hel	1,63	0,62	1,95	4,41	2,77	0,99	2,98	3,21	3,17	1,27	2,78	2,23	1,53	2,15	1,59	2,90	2,11	1,23
	BRYOPHYTA TOTAL		8,57	0,62	2,60	4,41	3,08	0,99	4,76	3,85	3,49	1,27	2,78	2,23	1,53	3,00	1,59	3,77	2,11	1,23
SECONDARY DEPOSITION (% PS+themsemves)																				
	Acer																			
	Alnus			3,13	1,33	1,23	2,22		2,81	0,33	1,64	1,28			1,86		1,94		1,23	0,62
	Apiaceae																		0,31	
	Artemisia																			
	Asteraceae undiff.											0,32					0,32			
	Beta						0,63													
	Betula								0,63											
	Betulaceae undiff.													0,57			1,29			0,31
	Carpinus betulus				0,33															
	Caryophyllaceae																			
	Carya		0,89		2,00		1,27		1,56	0,33	1,32	0,64		0,28	0,62	0,44		1,51		
	Castanea sativa														0,31					
	Chenopodiaceae undiff.				0,67		0,32		0,31		0,33				0,62		0,97	0,60		
	Cichorioideae				0,33				0,31			0,32								
	Corylus																		0,31	
	Cyperaceae														0,31					
	Engelhardia						0,63													
	Ephedra			0,31							0,33									
	Ericaceae																			
	Fabaceae																			
	Glomus				1,00						0,66									
	Hystricosphaeridium						0,95													0,31
	Juglandaceae undiff.																		0,31	
	Myrica				0,33															
	Myriophyllum								0,31											
	Nyssa			0,63																
	Ostrya carpinifolia / Carpinus orientalis				1,00						0,33								0,62	
	Pinus sylvestris/mugo																			
	Pinaceae undiff. + *Pinus* sp.			0,31	1,33	2,46	0,32	0,67	0,63	0,33	0,99	0,32	2,86	2,56	0,62	0,88	2,26	2,41	1,23	7,48
	Poaceae						0,63		0,63			0,32	0,82						0,62	
	Pteris										0,33									
	Pterocarya		0,45		2,00		2,54				0,66				0,31					
	Quercus sp.										0,33								0,31	
	Sequoiadendron														0,31					
	Tilia														0,62					

			26,17	25,70	25,10	24,52	24,17	23,83	23,30	22,77	22,20	21,82	21,17	20,61	19,94	19,32	18,88	18,22	17,62	17,20
	Tsuga				0,33															
	Ulmus										0,33									
	Urticaceae																			
	Zelkova			0,31																
	Undeterminable grains		1,79	7,21	5,00	3,38	3,17	3,67	9,06	7,67	2,96	7,05	5,31	5,13	8,39	4,87	19,03	9,94	21,54	12,15
	Monolete spores																			
	Trilete spores				0,67	0,31								0,28			0,65	0,30	0,31	0,62
SECONDARY DEPOSITION - TOTAL		II/I ratio	3,13	11,91	16,33	7,38	12,70	4,33	16,25	8,67	10,20	10,26	8,98	8,83	13,98	6,19	26,45	14,76	26,77	21,50
ECOLOGICAL GROUPS		SAMPLES	51	49	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32
Physiognomy																				
WOODY		**T+sh+L**	48,21	58,93	44,67	59,08	41,59	53,67	51,56	51,33	44,41	42,31	38,78	41,60	30,43	35,84	43,87	48,19	28,92	42,37
Trees		**T**	41,07	47,65	38,00	50,46	36,51	43,67	44,38	43,33	37,50	35,26	34,69	36,47	26,40	32,74	36,13	42,17	22,77	35,83
Shrubs		**sh**	7,14	9,40	5,67	6,77	0,32	5,67	5,31	7,33	3,62	5,45	2,04	4,27	2,48	1,77	5,48	3,61	4,00	4,98
Lianas		**L**		1,88	1,00	1,85	4,76	4,33	1,88	0,67	3,29	1,60	2,04	0,85	1,55	1,33	2,26	2,41	2,15	1,56
HERBS		**H**	51,79	41,07	55,67	40,92	58,41	46,67	48,44	49,00	56,58	58,65	61,22	58,40	70,81	65,04	56,77	51,81	74,46	57,63
Ecology																				
Deciduous trees		**DT**		0,94	0,67	1,23	0,32	2,33	1,25	1,67	2,96	1,28	0,41	0,85	1,86	0,88	2,58	1,20	3,38	1,56
Montane taxa		**Mt**	14,73	18,18	13,67	12,92	14,60	12,00	13,13	22,67	14,47	16,35	13,06	15,38	6,83	12,83	9,35	15,36	7,08	11,21
Broadleaved mesic forest		**M+Q**	22,77	26,02	15,33	30,15	12,38	24,67	25,94	20,33	18,42	12,18	14,69	16,81	10,25	8,85	17,74	16,27	9,54	16,82
Mixed-oak forest		**Q**	20,54	15,05	11,00	15,38	6,98	8,00	14,38	12,00	9,54	8,97	8,98	9,97	4,66	4,42	11,29	7,53	5,85	9,03
Mediterraneans		**M**	2,23	10,97	4,33	14,77	5,40	16,67	11,56	8,33	8,88	3,21	5,71	6,84	5,59	4,42	6,45	8,73	3,69	7,79
Woody hygrophytes		**Hyg**	9,82	10,34	8,67	6,46	8,25	7,33	7,19	5,67	6,58	7,05	6,12	4,56	5,28	9,73	9,03	9,04	4,92	8,41
Herbaceous hygrophytes		**hyg**	9,22	9,45	12,58	8,97	22,65	9,82	13,33	13,25	14,95	14,84	11,79	8,89	15,37	10,11	11,04	13,60	11,25	8,14
Helophytes		**hel**	5,42	8,73	7,26	9,64	12,56	5,32	9,54	10,16	8,38	9,92	11,73	9,64	9,60	8,34	7,39	8,62	6,11	6,53
Hydrophytes		**hyd**	4,02	2,82	3,33	2,15	5,71	3,00	1,88	2,00	2,96	2,24	2,86	2,56	4,04	0,88	0,97	3,31	5,54	3,12
Other cultivated		**Ac-Cast-ce**		1,57	0,67	4,31	4,44	4,33	1,88	0,67	1,97	2,56	2,45	2,85	2,17	2,21	1,29	3,92	1,54	2,49
Cereals		**ce**	0,45	1,25	1,33	0,62	1,59	1,33	0,31	0,33	1,97	3,53	2,86	4,84	0,93	5,31	2,26	1,81	1,23	0,62
Anthropic spontaneous		**As**	5,36	1,88	4,67	3,69	2,22	2,00	1,88	2,00	5,59	2,88	3,27	5,41	3,73	1,33	6,77	7,53	4,62	8,41
Halophytes		**hal**	6,25	0,94	3,00	1,85	3,81	3,00	4,69	4,00	2,96	5,45	7,35	3,13	3,11	6,64	5,16	5,12	4,92	4,05
Pastures and meadows		**pm**	22,32	14,73	28,33	20,00	16,83	21,33	18,44	21,33	25,66	22,44	26,94	23,65	27,02	33,19	22,90	16,27	33,54	25,23
Anthropic cultivated tot		**Ac**	1,34	4,70	7,67	8,92	7,62	9,33	5,00	1,67	4,28	8,97	7,35	9,40	7,45	9,29	8,06	8,13	6,15	4,98
COUNTED GRAINS																				
TRACHEOPHYTA		**S+M**	254	338	328	357	355	316	357	332	344	340	269	376	340	239	331	370	344	342
SPERMATOPHYTA (pollen sum)		**S**	224	319	300	325	315	300	320	300	304	312	245	351	322	226	310	332	325	321
MONILOPHYTA+LYCOPODIOPHYTA		**M**	30	19	28	32	40	16	37	32	40	28	24	25	18	13	21	38	19	21
SECONDARY DEPOSITION			7	38	49	24	40	13	52	26	31	32	22	31	45	14	82	49	87	69
Absolute Pollen Frequency (grains/g)																				
APF TRACHEOPHYTA			16253	6761	9005	13891	13998	7678	5444	3807	3350	3993	9489	3451	6421	5693	7757	13851	13429	3737
APF SPERMATOPHYTA			14333	6381	8236	12646	12421	7289	4880	3440	2961	3664	8643	3222	6081	5384	7265	12428	12687	3507
APF MONILOPHYTA+LYCOPODIOPHYTA			1920	380	769	1245	1577	389	564	367	390	329	847	229	340	310	492	1423	742	229
APF SECONDARY GRAINS			448	760	1345	934	1577	316	793	298	302	376	776	285	850	334	1922	1834	3396	754

DEPTH (m)			16,75	16,10	15,80	15,25	14,85	14,22	13,80	13,06	12,77	12,20	11,63	11,15	10,75	10,20	9,82	9,30	8,77	8,34
SAMPLES (n°)			31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14
TREES		Ecological groups																		
ADOXACEAE	*Sambucus* sp.	sh,DT							0,33			0,55					0,98			0,33
BETULACEAE	*Alnus* cf. *glutinosa*	T,Hyg	5,57	2,56	1,89	5,07	2,96	1,67	2,00		3,75	3,87	3,13	1,67	3,67	2,75	1,97	3,77	1,62	4,28
	Alnus cf. *incana*	T,Mt	4,26	4,17	7,57	6,87	5,38	3,00	3,00	2,38	3,75	4,97	2,73	4,00	3,33	2,75	3,28	1,89	3,90	2,63
	Alnus cf. *viridis*	T,Mt	1,31	2,56	2,84	0,90	2,15	2,33	1,00	2,38	0,94	0,55	1,56	2,33	0,67		1,31	0,47	1,62	0,66
	Betula	T,Mt	0,33		0,32	1,19	0,27	0,67	2,67					0,67	0,33		0,66		0,65	0,66
	Carpinus betulus	T,Q	0,33	0,32	0,32	0,30		0,33		2,38	0,63			0,67			0,33		0,32	0,33
	Corylus avellana	sh,Q	3,93	1,92	4,10	3,28	2,96	0,67	0,33	7,14	4,38	2,21	1,17	2,00	2,33	1,83		1,42	1,62	1,97
	Ostrya carpinifolia / Carpinus orientalis	T,Q	1,97	0,96	0,95	0,90	1,34	1,00	1,00		2,50	0,55	1,17	0,33	1,00	2,75	1,64	2,83	0,97	0,99
	Betulaceae undiff.	T,Q	0,98		0,63	0,60	0,27				0,31		0,39	0,33	0,33	0,92		0,47	0,32	
CANNABACEAE	*Celtis australis*	T,DT									0,31		1,17	0,33	0,33			0,47		
	Humulus lupulus	L,DT	1,31	0,64	1,89	1,19	0,81	1,00	1,00		0,94		3,13	1,00	3,00	0,92	0,98	0,94	1,30	
CISTACEAE	*Cistus*	sh,M																		
	Helianthemum	sh																		
CORNACEAE	*Cornus mas*	T,Q	0,33	0,32	0,32		1,08				1,25	1,66		1,33	0,67		0,33			0,99
ERICACEAE	*Erica arborea*	sh,M	0,66				0,27	1,00	0,33		0,31			0,33	1,00		0,66			
EUPHORBIACEAE	Euphorbiaceae undiff.	sh,DT																		
FAGACEAE	*Castanea sativa*	T,Ac	3,28	0,32	0,63	5,67	3,23	1,67	1,67		2,19	3,31	0,78	3,33	5,67	0,92	2,62	4,25	4,87	1,97
	Fagus sylvatica	T,Mt	1,31	0,96	2,21	1,49	0,54	0,33	0,67		1,25	1,66		0,67	1,00				0,65	1,32
	Quercus cerris + petraea + robur	T,Q		0,64		1,19	0,54	0,67			1,56	0,55		0,33	0,33		1,31			0,33
	Quercus ilex	T,M	10,82	6,41	7,26	8,06	6,45	6,33	4,33	4,76	6,56	1,10	5,08	7,67	6,33	15,60	4,26	5,66	6,82	9,54
	Quercus pubescens	T,Q	1,31	1,28	0,95	2,09	0,81	2,00		2,38	1,88	0,55	1,17	0,67	1,67	0,92	0,98	2,36	0,65	0,33
	Quercus sp.	T,Q	1,97	0,32	0,63		0,27		1,33		0,94	2,21			1,00	1,83	3,28	0,47		1,97
JUGLANDACEAE	*Juglans regia*	T,Ac	1,31	0,64	1,26	0,90	0,27	0,67		7,14	0,94		0,39	0,67				0,94	1,62	0,33
MALVACEAE	*Tilia* spp.	T,Q	0,33	0,64															0,32	
MORACEAE	*Morus alba*	T,Ac		0,32				0,67					1,95			0,92			0,65	0,66
OLEACEAE	*Fraxinus* spp.	T,Q			2,21	2,09	0,27	0,67	2,00		1,25	2,21	1,56	0,33			0,98		0,65	0,33
	Olea europaea	T,Ac											0,39							
	Phillyrea angustifolia	sh,M									0,63			0,67	1,33				0,97	
PINACEAE	*Abies + Picea*	T,Mt	0,66	0,64	0,32			0,33	1,00		0,31	1,10	0,39	0,33	0,33		0,66		0,97	0,99
	Larix decidua	T,Mt	0,33																	
	Pinus mugo + sylvestris	T,Mt		0,96	0,32			0,67	0,33				0,78				0,98		0,32	0,66
	Pinus sp.	T,Mt	1,31	2,24	2,21	1,79	2,15	3,67	2,00	16,67	2,50	0,55	1,17	0,67	0,67	3,67	2,30	4,72	1,95	2,96
	Pinacee undiff.	T,Mt	0,66	0,96	0,63	0,30	0,81	0,67	0,33	2,38	0,63	0,55	0,39	0,33	0,67	1,83	0,33	0,47	0,65	
RHAMNACEAE	*Frangula alnus*	sh,Q										1,10					0,33			
ROSACEAE	*Prunus*	T,Ac							0,33											
	Pyrus	T,Ac			1,26					4,76	0,31			1,67	1,00			0,47	2,27	0,99
	Rosa	sh,DT																		0,66
	Rubus	sh,DT																		1,32
SALICACEAE	*Populus*	T,Hyg		0,32				0,33	0,33	2,38			1,17	0,33		1,83		0,47	0,32	0,33
	Salix	T,Hyg	6,56	3,85	2,84	2,39	2,96	2,33	6,33		3,13	6,08	7,03	4,00	4,00	5,50	4,92	7,55	2,27	3,62
SAPINDACEAE	*Acer campestre* type	T,Q						0,33					0,39							0,33

			16,75	16,10	15,80	15,25	14,85	14,22	13,80	13,06	12,77	12,20	11,63	11,15	10,75	10,20	9,82	9,30	8,77	8,34
ULMACEAE	*Ulmus minor*	T,Q	1,97		1,58	1,49	1,61	1,67	0,33	7,14	2,19		0,78	2,33	2,67		0,33	0,47	1,30	0,33
VITACEAE	*Vitis*	L,Ac	0,66	0,64		0,30	1,08	1,00	1,00			1,10	0,78	0,33			0,66	0,47		4,28
HERBS																				
ALISMATACEAE	*Sagittaria*	hyd																		
AMARANTHACEAE	*Beta*	hal	0,98	0,96	1,89	0,90	0,54	1,00	1,67		0,63	1,10	1,56	0,67	1,00		0,66	1,89	0,32	0,66
	Chenopodiaceae other	hal	1,97	1,28	0,95	0,60	1,34	0,33	0,67		0,94	1,10		0,67	1,67	1,83	0,33	0,47	0,97	0,33
AMARYLLIDACEAE	*Allium* type			0,96	0,32	0,30		0,33	1,00	2,38		0,55			0,33	0,92	0,66	0,47		
APIACEAE	Apiaceae tot.	pm	1,64	0,64	2,21	0,90	0,81		1,00		0,94	0,55	0,78	1,33	1,67	0,92	1,64	0,47	1,95	0,66
ARACEAE	*Arum*																			
	Lemna	hyd		0,32					2,00			0,55		0,67			0,66			0,33
ASTERACEAE	*Artemisia*	hal	2,30	1,60	2,84	3,58	4,30	1,67			1,56	0,55	1,17	1,33	1,33		0,33	0,47	0,65	0,66
	Aster tripolium type	hal	0,33	0,64	0,63		0,81		0,33		0,31			0,33	2,00	0,92	0,98		0,97	0,66
	Centaurea spp.	As		0,32			0,81	0,67	0,33			0,55	0,39			1,83				0,66
	Asteroideae undiff. + *Bellis* + *Tussilago*	pm	0,66		2,52	0,30	1,34	1,00	1,00		0,94	0,55	1,17	2,33	1,00	0,92	1,31	0,47	1,62	0,66
	Cichorioideae tot.	pm	5,25	4,81	5,05	2,09	5,65	4,33	4,33	7,14	5,63	2,76	11,72	5,00	5,33	6,42	3,61	4,25	11,69	7,89
BORAGINACEAE	Boraginaceae tot.								0,33			1,66			0,33				0,32	0,33
BRASSICACEAE	Brassicaceae tot.		1,64	0,96	0,32			0,67	1,67	2,38	0,94		0,39		0,67		1,31	0,94	1,30	0,99
BUTOMACEAE	*Butomus umbellatus*	hel																		0,33
CANNABACEAE	*Cannabis sativa*	Ac	0,98		3,79	1,19	0,54	0,33	0,33		0,63		0,39		0,67					
CARYOPHYLLACEAE	*Corrigiola*	hal						0,33	0,33			1,66	0,39							
	Sagina + *Spergula*	As	0,33	0,32	0,63	1,19	1,61				0,31	0,55		1,67	0,33		2,62	0,47	0,97	0,99
	Caryophyllaceae other		0,66	3,53	0,95	1,79	0,81	1,67	0,67	2,38	0,63	3,31	1,56	2,33	1,00		2,62	0,47	0,65	1,32
CONVOLVULACEAE	*Convolvulus arvensis*																	0,47		
CRASSULACEAE	Crassulaceae tot.		1,64	1,28	1,26	2,69	0,54	0,67	1,33		1,88	0,55		2,00			0,66	0,94	2,27	
CYPERACEAE	*Carex* type	hyg	1,64	3,53	0,32	0,60	2,15	2,00	2,00	2,38	1,25	1,10	2,73	1,00	1,67	3,67	0,98	3,30	1,30	1,97
	Schoenoplectus + *Schoenus* types	hel	1,31	5,45	1,89	2,69	4,03	8,00	5,67		3,44	3,87	3,52	4,33	1,33	6,42	1,64	6,13	3,57	5,26
	Cyperaceae undiff.	hyg	1,97	0,96	1,26	1,49	1,34		4,67		0,94	3,31	1,56	0,67	0,33	0,92	4,59	2,36	2,27	2,30
FABACEAE	*Medicago*	pm	0,98	0,32	0,63	0,60	0,27				0,31		1,17		0,33	0,92			0,65	
	Fabaceae other	pm	1,31	0,64	0,63	0,60		0,67	1,33	2,38	0,63	4,42	1,95		0,67	1,83	0,66			2,30
GERANIACEAE	Geraniaceae undiff.	As																		
HALORHAGACEAE	*Myriophyllum* spp.	hyd									0,31	1,10	0,39	0,33			0,66			
HYDROCHARITACEAE	*Hydrocharis morsus-ranae*	hyd		1,92	0,32		0,54		1,00		0,31	0,55		1,00	1,00		1,64	0,47	0,65	1,32
HYPERICACEAE	*Hypericum perforatum type*		0,66	0,96	0,32		0,27		1,33		0,63	0,55		0,33	2,00		0,66		1,30	
LAMIACEAE	Lamiaceae tot.			0,64	1,26	0,30		0,67	0,33		0,31			0,67		1,83	0,33			1,64
LILIACEAE	*Fritillaria* type	pm																		
LINACEAE	Linum sp.						0,27													
LYTHRACEAE	*Peplis portula*	Mt																		
NYMPHAEACEAE	*Nymphaeaceae tot.*	hyd		0,64				0,67	0,33				0,39			1,83	0,33	0,47	0,65	0,33
PAPAVERACEAE	Papaveraceae tot.	As																		
PLANTAGINACEAE	*Callitriche* spp.	hyd					0,54				0,31		0,39	0,67	1,00	1,83	0,66		0,65	
	Litorella uniflora	hyd																		
	Plantago spp. + *Linaria*	As		1,60	1,58	2,09	0,54	3,33	0,67		1,56	1,66	0,78	1,67	1,00		0,33	0,94	0,97	1,97
POACEAE	*"Avena-Triticum"* group	ce	0,66		0,32	0,30	0,81		0,33				0,39				0,33			
	"Hordeum" group	ce	0,66	1,60	0,63	0,60	0,27	0,67	0,67	2,38				0,67	0,33		0,33	0,47	0,32	0,99
	Panicum miliaceum cf.	ce	1,31	0,32	1,58	1,49	0,81	1,00			2,50		1,95	0,67	0,67	1,83	0,33	1,42	0,97	0,33

			16,75	16,10	15,80	15,25	14,85	14,22	13,80	13,06	12,77	12,20	11,63	11,15	10,75	10,20	9,82	9,30	8,77	8,34
	Phragmites australis cf.	hel	0,66	1,60	1,26	1,49	2,15	2,00	3,00	2,38	1,56	1,66	0,39	1,67	2,00	0,92	1,64		1,95	0,99
	Secale cereale	ce																		
	Zea mays	ce																		
	Poaceae wild group	pm	10,49	16,99	14,51	16,72	18,82	19,67	21,33	4,76	17,50	22,10	16,41	21,67	18,00	9,17	27,21	18,87	15,26	13,16
POLYGALACEAE	*Polygala vulgaris* ***type***	hyg																		
POLYGONACEAE	Polygonaceae tot.	As	1,64	1,28	1,58	0,90	2,69		2,00		0,63	2,21	1,17	1,67			0,33		0,65	0,99
POSIDONIACEAE	*Posidonia oceanica*	hal					0,54													
POTAMOGETONACEAE	*Potamogeton* type	hyd		0,64			0,27	0,67	0,67		0,63		0,39		0,67	0,92	0,66	0,47	0,65	
PRIMULACEAE	*Primula* sp.											0,55								
RANUNCULACEAE	*Caltha palustris* type	hyg				0,30		0,33			0,94		3,91	0,33	1,00	2,75		4,25		
	Ranunculaceae other			3,85	1,26	1,19	0,54	3,00	0,33	2,38	2,19		0,39	0,67	1,33		0,33	1,89	2,92	0,33
ROSACEAE	Rosaceae herb. tot.					0,30							0,39	0,33	0,33		0,66	0,47		
RUBIACEAE	Rubiaceae tot.			0,64				0,33	0,33			0,55		0,33			0,33			
RUPPIACEAE	*Ruppia maritima* type	hal							0,67											
SCHEUCHZERIACEAE	*Scheuchzeria palustris*	Mt (hel)																		
SCROPHULARIACEAE	Scrophulariaceae tot.										0,31		0,39							
SMILACACEAE	*Smilax aspera*																			0,33
TYPHACEAE	*Sparganium emersum* type	hyd	2,62	1,28	0,63	0,90	0,81	1,33	0,33	2,38	1,25	1,10		1,67	0,67	0,92	0,33	0,47	0,65	1,64
	Sparganium erectum type	hel		0,32	0,32	0,90	1,61	1,33	0,33		0,63	0,55		0,67	1,33		0,66	0,47	1,30	
	Typha spp.	hel			0,32	0,30	0,27		0,33				0,39		1,33	0,92		0,47		0,33
URTICACEAE	Urticaceae tot.	As	2,30	2,56	0,95	2,69	2,96	5,67	2,00	4,76	1,25	2,76	2,73	1,33	2,33	4,59	1,97	4,72		1,64
VALERIANACEAE	Valerianaceae undiff.																			
ZYGOPHYLLACEAE	*Tribulus terrestris*	As						0,33				0,55								0,33
MONILOPHYTA/LYCOPODIOPHYTA (% PS+themsel		P																		
DRYOPTERIDACEAE	*Polystichum* type	hyg	0,31																	
ASPLENIACEAE	*Asplenium* type	hyg		0,62	0,30		0,25	0,62			0,30			0,93	0,31	0,88	0,32		0,31	
CYSTOPTERIDACEAE	*Cystopteris fragilis*	hyg	0,31		0,30		0,25				0,89				0,62					
DENNSTAEDTIACEAE	*Pteridium aquilinum*	hyg			0,30															
ISOETACEAE	*Isoetes* sp.	hel						0,31	0,31				0,38							
OPHIOGLOSSACEAE	*Botrychium lunaria* type	hyg																		
POLYPODIACEAE	*Polypodium vulgare* type	hyg																		
PTERIDACEAE	*Pteris*	hyg	0,31																0,31	
SELAGINELLACEAE	*Selaginella*	hyg																		
FILICALES MONOLETES		hyg	2,82	2,48	3,90	4,83	5,76	5,61	4,70	6,67	3,26	2,16	3,02	5,30	5,90	2,63	0,65	2,28	4,01	0,98
FILICALES TRILETES		hyg	0,63				0,50		0,94		0,59			0,31		0,88	0,32	0,91	0,31	
MONILOPHYTA/LYCOPODIOPHYTA TOTALS			4,39	3,11	4,80	4,83	6,77	6,54	5,96	6,67	5,04	2,16	3,40	6,54	6,83	4,39	1,29	3,20	4,94	0,98
NPPs (% PS+themselves)																				
ALGAE	*Pseudoschizaea circula*		0,97	3,41	3,35	2,05	1,59	1,96	1,96		2,44	0,55	1,54	1,64	1,96	2,68	1,93	4,93	1,91	0,65
DINOFLAGELLATES			0,33	1,58	0,63		0,27	0,33	3,23	16,00		1,63	0,78		0,66	0,91	0,65		0,65	0,98
FUNGI	*Glomus*		0,33	0,32	0,31				0,33		0,31	1,09					0,33			0,33
BRYOPHYTA	*Bryophyta undeterminable*																			
ANTHOCEROTACEAE	*Phaeoceros laevis*	hyg				0,29		0,65						0,33			0,33			
BRYACEAE	*Bryum marratii*	hel																		

			16,75	16,10	15,80	15,25	14,85	14,22	13,80	13,06	12,77	12,20	11,63	11,15	10,75	10,20	9,82	9,30	8,77	8,34
DICRANACEAE	*Aongstroemia longipes + Saelania glaucescens*																			
FISSIDENTACEAE	*Fissidens rufulus*																			
FUNARIACEAE	*Funaria*																			
	Physcomitrium pyriforme	hyg																		
JUNGERMANNIACEAE	*Mylia taylori*	Mt																		
MNIACEAE	*Plagiomnium + Rhzomnium*																			
ORTOTRICHACEAE	*Ulotha crispa*																			
POTTIACEAE	*Pterygoneum ovatum*																			
RADULACEAE	*Radula complanata*																			
SPHAGNACEAE	*Sphagnum* spp.	hel	0,65	0,95	1,55	2,33	1,33	2,58	1,64		0,31	1,63	2,29	1,63	0,66		0,33	0,93	1,60	0,65
	BRYOPHYTA TOTAL		0,65	0,95	1,55	2,62	1,33	3,23	1,64		0,31	1,63	2,29	1,96	0,66		0,65	0,93	1,60	0,65
SECONDARY DEPOSITION (% PS+themsemves)																				
	Acer																			
	Alnus		0,33	0,32	1,26	1,49		0,33	2,67				1,17		0,67		1,64	0,94		0,33
	Apiaceae								0,67											
	Artemisia																			
	Asteraceae undiff.										0,31						0,66	0,47		
	Beta																			
	Betula																			
	Betulaceae undiff.		0,66			0,30		0,67				2,21			0,33		0,66		0,32	
	Carpinus betulus																			
	Caryophyllaceae																			
	Carya								0,33			0,55					2,62			0,66
	Castanea sativa																			
	Chenopodiaceae undiff.		0,98	0,32	0,32	0,30	0,54		0,67		0,31				0,33		0,33		0,32	
	Cichorioideae																			
	Corylus								0,33								0,66			
	Cyperaceae																			0,33
	Engelhardia																			
	Ephedra		0,33		0,32												0,98			0,33
	Ericaceae																			
	Fabaceae																1,64			0,66
	Glomus											0,55					0,66			0,99
	Hystricosphaeridium									9,52			0,39							
	Juglandaceae undiff.																			
	Myrica								0,33											
	Myriophyllum																			
	Nyssa																			
	Ostrya carpinifolia / Carpinus orientalis																			
	Pinus sylvestris/mugo																			
	Pinaceae undiff. + *Pinus* sp.		6,56	1,60	8,20	2,99	6,72	1,33	6,33	28,57	4,38	1,10	3,13	6,33	3,67	14,68	6,23	2,83	12,34	2,96
	Poaceae								0,67		0,31	0,55			0,67		0,98	0,94		
	Pteris							0,67												
	Pterocarya																			
	Quercus sp.											0,55	0,39					0,94	0,97	
	Sequoiadendron											0,55								
	Tilia																	0,94		

			16,75	16,10	15,80	15,25	14,85	14,22	13,80	13,06	12,77	12,20	11,63	11,15	10,75	10,20	9,82	9,30	8,77	8,34
	Tsuga										0,31									
	Ulmus																			
	Urticaceae			0,32																
	Zelkova					0,30														
	Undeterminable grains		39,67	8,97	18,93	12,54	13,44	7,33	15,00	114,29	14,38	16,57	13,28	25,00	31,67	38,53	38,03	25,94	33,77	26,97
	Monolete spores																	0,47		0,33
	Trilete spores			0,32					1,00			0,55	0,39		0,33	2,75	1,31	0,47		0,99
SECONDARY DEPOSITION - TOTAL		II/I ratio	48,52	11,86	29,02	17,91	20,70	10,33	28,00	152,38	20,00	23,20	18,75	31,33	37,67	55,96	56,39	33,96	47,73	34,54
ECOLOGICAL GROUPS		SAMPLES	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14
Physiognomy																				
WOODY		**T+sh+L**	53,44	34,62	45,11	48,06	38,44	35,67	33,67	61,90	45,31	36,46	38,67	39,33	43,33	44,95	36,07	40,57	39,61	46,05
Trees		**T**	45,57	28,85	36,28	42,39	31,18	29,67	29,67	52,38	38,13	30,94	31,64	32,67	35,00	42,20	31,15	37,26	34,09	36,84
Shrubs		**sh**	5,90	4,49	6,94	4,18	5,38	4,00	2,00	9,52	6,25	4,42	2,73	5,33	5,33	1,83	3,28	1,89	4,22	4,93
Lianas		**L**	1,97	1,28	1,89	1,49	1,88	2,00	2,00		0,94	1,10	3,91	1,33	3,00	0,92	1,64	1,42	1,30	4,28
HERBS		**H**	46,56	65,38	54,89	51,94	61,56	64,67	66,67	38,10	54,69	64,64	61,33	60,67	56,67	55,05	64,92	59,43	60,39	54,61
Ecology																				
Deciduous trees		**DT**	1,31	0,64	1,89	1,19	0,81	1,00	1,33		1,25	0,55	4,30	1,33	3,33	0,92	1,97	1,42	1,30	2,30
Montane taxa		**Mt**	10,16	12,50	16,40	12,54	11,29	11,67	11,00	23,81	9,38	9,39	7,03	9,00	7,00	8,26	9,51	7,55	10,71	9,87
Broadleaved mesic forest		**M+Q**	24,59	12,82	18,93	20,00	15,86	14,67	9,67	23,81	24,38	12,15	12,11	17,00	18,67	23,85	14,43	13,68	13,96	17,43
Mixed-oak forest		**Q**	13,11	6,41	11,67	11,94	9,14	7,33	5,00	19,05	16,88	11,05	6,64	8,33	10,00	8,26	9,51	8,02	6,17	7,89
Mediterraneans		**M**	11,48	6,41	7,26	8,06	6,72	7,33	4,67	4,76	7,50	1,10	5,47	8,67	8,67	15,60	4,92	5,66	7,79	9,54
Woody hygrophytes		**Hyg**	12,13	6,73	4,73	7,46	5,91	4,33	8,67	2,38	6,88	9,94	11,33	6,00	7,67	10,09	6,89	11,79	4,22	8,22
Herbaceous hygrophytes		**hyg**	8,00	7,59	6,38	7,51	10,26	9,52	12,62	9,05	8,17	6,58	11,60	8,87	9,83	11,73	7,19	13,10	8,51	5,25
Helophytes		**hel**	2,62	8,32	5,34	7,70	9,39	14,23	11,29	2,38	5,94	7,71	6,96	8,30	6,66	8,26	4,26	8,01	8,42	7,56
Hydrophytes		**hyd**	2,62	4,81	0,95	0,90	2,15	2,67	4,33	2,38	2,81	3,31	1,56	4,33	3,33	5,50	4,92	1,89	3,25	3,62
Other cultivated		**Ac-Cast-ce**	2,95	1,60	6,31	2,39	1,88	2,67	1,67	11,90	1,88	1,10	3,91	2,67	1,67	0,92	0,66	1,89	4,55	6,25
Cereals		**ce**	2,62	1,92	2,52	2,39	1,88	1,67	1,00	2,38	2,50		2,34	1,33	1,00	1,83	0,98	1,89	1,30	1,32
Anthropic spontaneous		**As**	4,26	6,09	4,73	6,87	8,60	10,00	5,00	4,76	3,75	8,29	5,08	6,33	3,67	6,42	5,25	6,13	2,60	6,58
Halophytes		**hal**	5,57	4,49	6,31	5,07	7,53	3,33	3,67		3,44	4,42	3,13	3,00	6,00	2,75	2,30	2,83	2,92	2,30
Pastures and meadows		**pm**	20,33	23,40	25,55	21,19	26,88	25,67	29,00	14,29	25,94	30,39	33,20	30,33	27,00	20,18	34,43	24,06	31,17	24,67
Anthropic cultivated tot		**Ac**	8,85	3,85	9,46	10,45	6,99	6,00	4,33	14,29	6,56	4,42	7,03	7,33	8,33	3,67	4,26	8,02	10,71	9,54
COUNTED GRAINS																				
TRACHEOPHYTA		**S+M**	321	325	338	361	404	331	324	45	338	188	271	327	324	114	311	221	329	309
SPERMATOPHYTA (pollen sum)		**S**	305	312	317	335	372	300	300	42	320	181	256	300	300	109	305	212	308	304
MONILOPHYTA+LYCOPODIOPHYTA		**M**	16	13	21	26	32	31	24	3	18	7	15	27	24	5	6	9	21	5
SECONDARY DEPOSITION			148	37	92	60	77	31	84	64	64	42	48	94	113	61	172	72	147	105
Absolute Pollen Frequency (grains/g)																				
APF TRACHEOPHYTA			2749	5514	4273	8236	3771	5554	11457	114	6307	19503	3840	5409	4107	1993	3746	3691	3723	6556
APF SPERMATOPHYTA			2612	5293	4008	7643	3472	5034	10608	107	5972	18776	3628	4963	3803	1906	3674	3541	3485	6450
APF MONILOPHYTA+LYCOPODIOPHYTA			137	221	266	593	299	520	849	8	336	726	213	447	304	87	72	150	238	106
APF SECONDARY GRAINS			1267	628	1163	1369	719	520	2970	163	1194	4357	680	1555	1432	1066	2072	1203	1663	2228

DEPTH (m)			7,84	7,15	6,86	6,43	5,17	4,80	4,10	3,69	3,19	1,59	0,83	0,57
SAMPLES (n°)			13	12	11	10	9	8	7	6	5	4	3	2
TREES		Ecological groups												
ADOXACEAE	*Sambucus* sp.	sh,DT				1,27	0,33							
BETULACEAE	*Alnus* cf. *glutinosa*	T,Hyg	2,37	3,13	1,38	2,23	3,00	3,67	4,67	0,97	1,98		0,68	0,32
	Alnus cf. *incana*	T,Mt	1,19	5,94	2,76	1,91	3,00	0,33		1,94	0,33		2,04	
	Alnus cf. *viridis*	T,Mt	1,19	0,63	1,84	3,50	1,33	0,33	0,93	1,29	1,98		0,68	
	Betula	T,Mt	0,40	0,31	1,38				0,62					
	Carpinus betulus	T,Q				0,32								
	Corylus avellana	sh,Q	1,58	0,94	1,38	1,27	1,33	1,67	1,25	0,32	0,33		0,68	0,65
	Ostrya carpinifolia / Carpinus orientalis	T,Q	0,79	2,19	1,38	0,64	0,67	2,33	0,62	0,32	0,99	1,25		0,65
	Betulaceae undiff.	T,Q				0,64		0,33	0,31				0,68	
CANNABACEAE	*Celtis australis*	T,DT	0,40		0,92	1,27		0,33					0,68	
	Humulus lupulus	L,DT		0,31	0,92	1,27	1,33	0,67		3,56	0,66		0,68	0,32
CISTACEAE	*Cistus*	sh,M												
	Helianthemum	sh												
CORNACEAE	*Cornus mas*	T,Q	0,40	0,63		0,32	0,33							
ERICACEAE	*Erica arborea*	sh,M	0,40		0,46		0,67				0,66			
EUPHORBIACEAE	Euphorbiaceae undiff.	sh,DT		0,31										
FAGACEAE	*Castanea sativa*	T,Ac	2,77	1,25	2,76	1,59	0,67	1,67	2,49	5,18	1,65		1,36	0,65
	Fagus sylvatica	T,Mt	0,79	0,63	1,84	0,32		1,33	0,62		0,99			
	Quercus cerris + petraea + robur	T,Q		0,94	0,46	0,32		0,33	0,93		0,99			
	Quercus ilex	T,M	9,88	5,94	10,60	5,41	5,00	9,67	7,79	2,59	6,27	1,25	7,48	1,62
	Quercus pubescens	T,Q	2,37	0,31	1,84	0,64	0,33	2,00	0,31	0,97	1,32		2,72	
	Quercus sp.	T,Q	1,19	1,88	1,38	0,64	0,67	0,33		0,32	0,66			
JUGLANDACEAE	*Juglans regia*	T,Ac	0,79	0,31	0,92	0,64	0,33	1,33	2,18	0,65	0,66	1,25	2,72	0,65
MALVACEAE	*Tilia* spp.	T,Q				0,32	0,33		0,31					
MORACEAE	*Morus alba*	T,Ac	0,79	0,31	0,46					2,27	0,33			
OLEACEAE	*Fraxinus* spp.	T,Q		0,31		0,64	1,00	0,67	0,31	0,65	0,33		0,68	
	Olea europaea	T,Ac												
	Phillyrea angustifolia	sh,M				0,32								
PINACEAE	*Abies + Picea*	T,Mt			0,46	0,96	0,33		2,49	1,29		2,50		0,32
	Larix decidua	T,Mt								0,32				
	Pinus mugo + sylvestris	T,Mt	0,79	1,25	2,30	0,64	0,67	1,67	1,56	0,32	0,66	11,25	2,72	0,32
	Pinus sp.	T,Mt	2,37	3,13	0,92	2,55	2,33	2,33	5,92	0,97	2,64	20,00	12,24	0,97
	Pinacee undiff.	T,Mt	0,79	0,31	0,92	0,64		0,67	0,62	0,32	0,33	1,25	0,68	0,32
RHAMNACEAE	*Frangula alnus*	sh,Q												
ROSACEAE	*Prunus*	T,Ac												
	Pyrus	T,Ac	0,40			0,32			0,31				0,68	
	Rosa	sh,DT		0,31										
	Rubus	sh,DT		0,63			0,33		0,31					
SALICACEAE	*Populus*	T,Hyg	0,79		3,23	0,96	0,33	3,00	0,93	0,32	0,66			0,65
	Salix	T,Hyg	7,91	3,75	3,23	2,23	3,00	4,00	0,93	1,62				
SAPINDACEAE	*Acer campestre* type	T,Q		0,94	0,46				0,31					0,32

			7,84	7,15	6,86	6,43	5,17	4,80	4,10	3,69	3,19	1,59	0,83	0,57
ULMACEAE	*Ulmus minor*	T,Q	0,79	0,31	0,92	1,27	0,67	2,67	0,93	0,97			0,68	
VITACEAE	*Vitis*	L,Ac	1,58	0,94	0,46		1,67	0,67			0,33		1,36	
HERBS														
ALISMATACEAE	*Sagittaria*	hyd												
AMARANTHACEAE	*Beta*	hal	0,40	0,63	0,92	0,64	0,33	0,67	0,62	0,32	0,66	1,25	0,68	1,30
	Chenopodiaceae other	hal	0,40		0,92	0,96		0,67		0,65	0,33	6,25	2,04	3,57
AMARYLLIDACEAE	*Allium* type		1,19	0,31			0,67	0,33	1,56	0,32	0,99		2,04	
APIACEAE	Apiaceae tot.	pm		0,63	0,46	1,27		0,33	0,62	1,94	2,31	1,25	0,68	
ARACEAE	*Arum*		0,40							1,29				
	Lemna	hyd		0,63						0,65				
ASTERACEAE	*Artemisia*	hal	3,16	2,50	1,38	1,91	0,33	1,33	0,31	2,27	0,66		0,68	
	Aster tripolium type	hal		0,63			1,67		0,31	0,65	0,99			0,97
	Centaurea spp.	As	0,40	0,31	1,84	0,64		0,67	0,93	0,32	0,99		1,36	
	Asteroideae undiff. + *Bellis* + *Tussilago*	pm	0,40	0,31	0,46	2,55	0,67	1,00	0,62	1,29	0,66		0,68	
	Cichorioideae tot.	pm	7,11	7,50	7,37	8,92	6,33	7,67	1,25	3,88	4,29	12,50	19,73	2,92
BORAGINACEAE	Boraginaceae tot.			0,31				0,67		0,32				
BRASSICACEAE	Brassicaceae tot.			0,94	0,46	0,32	1,67	0,67	4,67	0,65	1,65		0,68	0,65
BUTOMACEAE	*Butomus umbellatus*	hel												1,62
CANNABACEAE	*Cannabis sativa*	Ac		0,31		0,32	0,33	0,33		0,97	0,99		0,68	0,32
CARYOPHYLLACEAE	*Corrigiola*	hal	0,40				0,33			0,97				
	Sagina + Spergula	As		2,19	0,92	0,64	3,33	0,33	0,62	0,32	3,30	1,25	0,68	3,57
	Caryophyllaceae other		1,19	4,38	0,92	1,59	2,33	4,33	1,25	5,18	2,64		2,04	2,27
CONVOLVULACEAE	*Convolvulus arvensis*													
CRASSULACEAE	Crassulaceae tot.		1,19	1,88		0,64	0,67		2,80	3,24	5,61			1,30
CYPERACEAE	*Carex* type	hyg	3,16	0,63	2,30	2,87	2,33	3,33	3,43	3,56	0,99	2,50	4,76	11,04
	Schoenoplectus + Schoenus types	hel	1,58	1,56	4,61	2,23	2,33	1,33	3,12	3,56	4,95	1,25	1,36	9,74
	Cyperaceae undiff.	hyg	1,58	3,75	0,92	1,27	4,33	0,67	0,62	2,27	0,99	1,25	1,36	2,27
FABACEAE	*Medicago*	pm			1,38	0,64			0,93	0,32	0,66			
	Fabaceae other	pm	1,58	0,63	0,92	0,32	1,33	1,33	0,93	0,97				0,65
GERANIACEAE	Geraniaceae undiff.	As										1,25		0,32
HALORHAGACEAE	*Myriophyllum* spp.	hyd		0,63	0,46		1,00	0,33	0,31	0,97	0,66			
HYDROCHARITACEAE	*Hydrocharis morsus-ranae*	hyd	0,40	0,31	0,46		0,33	1,67	0,31	0,97	0,99	1,25		0,32
HYPERICACEAE	*Hypericum perforatum type*		0,79	0,31	0,46	1,27		0,67		0,32	0,99			0,65
LAMIACEAE	Lamiaceae tot.		0,79	0,63	1,38	0,32	0,33	0,33	0,62	0,32				
LILIACEAE	*Fritillaria* type	pm												
LINACEAE	Linum sp.				0,92									
LYTHRACEAE	*Peplis portula*	Mt							0,62					
NYMPHAEACEAE	*Nymphaeaceae tot.*	hyd		0,63			0,67	0,67		1,62		1,25	3,40	0,97
PAPAVERACEAE	Papaveraceae tot.	As		0,31			0,33			0,32				
PLANTAGINACEAE	*Callitriche* spp.	hyd					0,33	0,33		0,97	0,33	1,25	0,68	1,30
	Litorella uniflora	hyd								0,32				
	Plantago spp. + *Linaria*	As	1,58	0,63	1,38	3,50		0,33	4,05	1,29	5,61			0,32
POACEAE	*"Avena-Triticum"* group	ce			0,46		0,33		0,93					
	"Hordeum" group	ce		0,31		0,32	2,33		0,93	1,29	0,66	1,25	2,04	
	Panicum miliaceum cf.	ce	1,19		0,92	0,64	4,67	0,33	0,62	1,94	0,66			1,30

			7,84	7,15	6,86	6,43	5,17	4,80	4,10	3,69	3,19	1,59	0,83	0,57
	Phragmites australis cf.	hel	0,79	1,88	1,84	2,87	2,00	0,67	2,18	3,88	1,65	1,25		
	Secale cereale	ce					0,33							
	Zea mays	ce				0,32								
	Poaceae wild group	pm	17,00	16,88	14,29	19,75	21,67	16,67	12,77	17,48	11,88	10,00	4,76	9,74
POLYGALACEAE	*Polygala vulgaris* ***type***	hyg								0,32				
POLYGONACEAE	Polygonaceae tot.	As	0,40	3,44	0,46	0,64	1,00	0,33	1,56	2,91	2,31	3,75	2,72	1,95
POSIDONIACEAE	*Posidonia oceanica*	hal												
POTAMOGETONACEAE	*Potamogeton* type	hyd	0,40	0,31	0,46			1,33	0,62		1,32	1,25		3,25
PRIMULACEAE	*Primula* sp.													
RANUNCULACEAE	*Caltha palustris* type	hyg	2,77			1,59		1,00						
	Ranunculaceae other		1,19		1,84	2,23	1,67	3,33	4,05		3,96	2,50	2,72	1,95
ROSACEAE	Rosaceae herb. tot.										0,33	1,25		
RUBIACEAE	Rubiaceae tot.					1,27					0,33		0,68	
RUPPIACEAE	*Ruppia maritima* type	hal												
SCHEUCHZERIACEAE	*Scheuchzeria palustris*	Mt (hel)												
SCROPHULARIACEAE	Scrophulariaceae tot.			0,31		0,32								
SMILACACEAE	*Smilax aspera*													
TYPHACEAE	*Sparganium emersum* type	hyd	1,58	1,25	0,46	0,64	2,00	2,33	1,87	0,32	0,66			9,42
	Sparganium erectum type	hel	0,79	0,63		0,96		0,33	0,31					12,66
	Typha spp.	hel							0,31					
URTICACEAE	Urticaceae tot.	As	3,56	3,75	2,76	1,91	2,67	1,67	5,61	1,62	9,24	7,50	4,08	5,84
VALERIANACEAE	Valerianaceae undiff.												0,68	
ZYGOPHYLLACEAE	*Tribulus terrestris*	As								0,32				
MONILOPHYTA/LYCOPODIOPHYTA (% PS+themsel		P												
DRYOPTERIDACEAE	*Polystichum* type	hyg												
ASPLENIACEAE	*Asplenium* type	hyg				0,30								
CYSTOPTERIDACEAE	*Cystopteris fragilis*	hyg		0,30	0,44									
DENNSTAEDTIACEAE	*Pteridium aquilinum*	hyg							0,30					
ISOETACEAE	*Isoetes* sp.	hel		0,30	0,44	0,30		0,32		0,63				
OPHIOGLOSSACEAE	*Botrychium lunaria* type	hyg										2,25	0,57	
POLYPODIACEAE	*Polypodium vulgare* type	hyg												
PTERIDACEAE	*Pteris*	hyg	0,38								0,32		0,57	
SELAGINELLACEAE	*Selaginella*	hyg	0,38									2,25		
FILICALES MONOLETES		hyg	2,30	3,87	3,95	4,82	1,63	2,59	3,28	1,89	2,56	2,25	13,22	1,91
FILICALES TRILETES		hyg		0,30			0,33		0,60		0,32	3,37	1,15	
MONILOPHYTA/LYCOPODIOPHYTA TOTALS			3,07	4,76	4,82	5,42	1,96	2,91	4,18	2,52	3,19	10,11	15,52	1,91
NPPs (% PS+themselves)														
ALGAE	*Pseudoschizaea circula*		3,44	1,54	1,36	0,95	0,33	3,23	1,83	1,59	1,30	6,98	10,91	1,28
DINOFLAGELLATES			0,39	0,31	0,46	0,95		2,60	3,02	1,90	1,94	20,00	9,82	0,96
FUNGI	*Glomus*			1,54			0,33					3,61		
BRYOPHYTA	*Bryophyta undeterminable*												0,64	
ANTHOCEROTACEAE	*Phaeoceros laevis*	hyg										1,18		
BRYACEAE	*Bryum marratii*	hel												

			7,84	7,15	6,86	6,43	5,17	4,80	4,10	3,69	3,19	1,59	0,83	0,57
DICRANACEAE	*Aongstroemia longipes + Saelania glaucescens*												1,91	
FISSIDENTACEAE	*Fissidens rufulus*				0,44									
FUNARIACEAE	*Funaria*													
	Physcomitrium pyriforme	hyg										1,18		
JUNGERMANNIACEAE	*Mylia taylori*	Mt										1,18	0,64	
MNIACEAE	*Plagiomnium + Rhzomnium*													
ORTOTRICHACEAE	*Ulotha crispa*													
POTTIACEAE	*Pterygoneum ovatum*		0,38											
RADULACEAE	*Radula complanata*											1,18		
SPHAGNACEAE	*Sphagnum* spp.	hel	4,51	1,23	3,54	1,57	0,66	4,46	1,23	0,96	4,11	1,18	3,18	
	BRYOPHYTA TOTAL		4,89	1,23	3,98	1,57	0,66	4,46	1,23	0,96	4,11	5,88	6,37	
SECONDARY DEPOSITION (% PS+themsemves)														
	Acer												1,36	
	Alnus		0,40	0,63		0,64				0,32				
	Apiaceae													
	Artemisia												0,68	
	Asteraceae undiff.					0,32								
	Beta													
	Betula									0,32				
	Betulaceae undiff.		0,79				0,67	0,67						
	Carpinus betulus													
	Caryophyllaceae												1,36	
	Carya			0,94						1,29				
	Castanea sativa													
	Chenopodiaceae undiff.			0,63		0,32								0,32
	Cichorioideae					0,32				0,32				
	Corylus		0,40											
	Cyperaceae													
	Engelhardia													
	Ephedra			0,31			0,67	0,33		0,32				
	Ericaceae													
	Fabaceae													
	Glomus											7,50		
	Hystricosphaeridium		0,40		0,46	1,59		1,33					3,40	
	Juglandaceae undiff.													
	Myrica													
	Myriophyllum													
	Nyssa													
	Ostrya carpinifolia / Carpinus orientalis		0,40											
	Pinus sylvestris/mugo											28,75		
	Pinaceae undiff. + *Pinus* sp.		3,95	5,94	3,23	5,10	4,00	12,33	6,85	4,53	4,62	71,25	62,59	0,97
	Poaceae			0,94			0,67			0,97				
	Pteris								0,31		0,33		0,68	
	Pterocarya												2,04	
	Quercus sp.		1,98											
	Sequoiadendron													
	Tilia					0,32			0,31					

			7,84	7,15	6,86	6,43	5,17	4,80	4,10	3,69	3,19	1,59	0,83	0,57
	Tsuga			0,31				0,33		0,32		1,25		
	Ulmus													
	Urticaceae													
	Zelkova				0,46			0,33		0,32				
	Undeterminable grains		13,83	32,50	14,29	24,20	15,67	26,00	6,85	18,45	10,89	36,25	63,27	4,22
	Monolete spores							0,33						
	Trilete spores		0,40	1,25	0,46		0,33	0,33	0,31	0,97	0,33	5,00	2,72	0,97
SECONDARY DEPOSITION - TOTAL		II/I ratio	22,53	43,44	18,89	32,80	22,00	42,00	14,64	28,16	16,17	150,00	136,73	6,49
ECOLOGICAL GROUPS		SAMPLES	13	12	11	10	9	8	7	6	5	4	3	2
Physiognomy														
WOODY		**T+sh+L**	42,69	37,81	45,62	35,03	29,67	42,00	37,69	27,18	24,75	38,75	39,46	7,79
Trees		**T**	37,94	33,75	40,55	27,39	22,67	38,67	35,20	22,01	20,79	38,75	36,05	6,82
Shrubs		**sh**	3,16	2,81	3,69	6,37	4,00	2,00	2,49	1,62	2,97		1,36	0,65
Lianas		**L**	1,58	1,25	1,38	1,27	3,00	1,33		3,56	0,99		2,04	0,32
HERBS		**H**	57,31	62,19	54,38	66,24	70,67	58,00	62,31	73,14	75,25	61,25	61,22	92,21
Ecology														
Deciduous trees		**DT**	0,40	1,56	1,84	3,82	2,00	1,00	0,31	3,56	0,66		1,36	0,32
Montane taxa		**Mt**	7,51	12,19	12,44	10,51	7,67	6,67	13,40	6,47	6,93	36,18	19,00	1,95
Broadleaved mesic forest		**M+Q**	17,39	14,38	18,89	12,74	11,00	20,00	13,08	6,15	11,55	2,50	12,93	3,25
Mixed-oak forest		**Q**	7,11	8,44	7,83	7,01	5,33	10,33	5,30	3,56	4,62	1,25	5,44	1,62
Mediterraneans		**M**	10,28	5,94	11,06	5,73	5,67	9,67	7,79	2,59	6,93	1,25	7,48	1,62
Woody hygrophytes		**Hyg**	11,07	6,88	7,83	5,41	6,33	10,67	6,54	2,91	2,64		0,68	0,97
Herbaceous hygrophytes		**hyg**	10,58	9,14	8,05	11,15	8,63	7,91	8,23	8,67	5,18	16,22	21,64	15,22
Helophytes		**hel**	7,67	5,59	10,43	7,92	5,00	7,12	7,15	9,04	10,71	3,68	4,55	24,03
Hydrophytes		**hyd**	2,37	3,75	1,84	0,64	4,33	6,67	3,12	5,83	3,96	5,00	4,08	15,26
Other cultivated		**Ac-Cast-ce**	3,56	1,88	1,84	1,27	2,33	2,33	2,49	3,88	2,31	1,25	5,44	0,97
Cereals		**ce**	1,19	0,31	1,38	1,27	7,67	0,33	2,49	3,24	1,32	1,25	2,04	1,30
Anthropic spontaneous		**As**	5,93	10,63	7,37	7,32	7,33	3,33	12,77	7,12	21,45	13,75	8,84	12,01
Halophytes		**hal**	4,35	3,75	3,23	3,50	2,67	2,67	1,25	4,85	2,64	7,50	3,40	5,84
Pastures and meadows		**pm**	26,09	25,94	24,88	33,44	30,00	27,00	17,13	25,89	19,80	23,75	25,85	13,31
Anthropic cultivated tot		**Ac**	7,51	3,44	5,99	4,14	10,67	4,33	7,48	12,30	5,28	2,50	8,84	2,92
COUNTED GRAINS														
TRACHEOPHYTA		**S+M**	274	340	237	337	308	323	339	320	326	94	184	314
SPERMATOPHYTA (pollen sum)		**S**	253	320	217	314	300	300	321	309	303	80	147	308
MONILOPHYTA+LYCOPODIOPHYTA		**M**	21	20	20	23	8	23	18	11	23	14	37	6
SECONDARY DEPOSITION			57	139	41	103	66	126	47	87	49	120	201	20
Absolute Pollen Frequency (grains/g)														
APF TRACHEOPHYTA			5455	3091	3363	3774	5550	2787	6471	12615	5226	263	586	25142
APF SPERMATOPHYTA			5037	2909	3079	3516	5406	2588	6128	12181	4858	224	469	24662
APF MONILOPHYTA+LYCOPODIOPHYTA			418	182	284	258	144	198	344	434	369	39	118	480
APF SECONDARY GRAINS			1135	1264	582	1153	1189	1087	897	3430	786	336	641	1601