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Plants, Wet Environments and Agrarian Landscape in the Roman Period. An Integrated Archaeological and Palynological Study at Rivanazzano Terme (Northern Italy)

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ABSTRACT

This integrated archaeological and palynological study of the site of Cascina Isola Felice at Rivanazzano Terme (Staffora Valley, northern Italy) provides a case study illustrating the potential of interdisciplinary approaches to reconstruct complex interactions between plants, wet environments and agrarian practices from the Roman period to Late Antiquity. Palynological analyses were carried out on sediment samples from an artificial water basin structure and from adjacent stratigraphic contexts, complemented by modern pollen rain data. The results indicate an open agrarian landscape dominated by herbaceous communities, with limited woodland cover and a persistent presence of wet environments. Cereal cultivation emerges as a major component of the local agrarian system, accompanied by evidence for textile plants, namely hemp, and in Late Antiquity, flax, suggesting fibre-processing activities such as retting within the basin. Differences between the basin and surrounding areas highlight both local activity-related pollen inputs and regional environmental signals. Diachronic patterns point to a general continuity of the agrarian landscape, accompanied by stronger evidence of agricultural practices during Late Antiquity. By integrating archaeological and palynological evidence, the Rivanazzano study demonstrates how botanical data can be used to reconstruct site function, identify plant-processing activities, and evaluate the ecological role of water-related infrastructures in Roman rural landscapes.

1. Introduction

Understanding how rural communities managed natural resources, water-related environments and agricultural infrastructures during the transition from the Roman period to Late Antiquity is central to reconstructing the long-term resilience of Mediterranean agrarian landscapes (Bowes, 2021). Recent archaeobotanical research has increasingly demonstrated that plant remains contribute not only to the reconstruction of past environments and agriculture, but also to the interpretation of settlement organisation, land use and economic practices (Lodwick and Rowan, 2022; Mercuri *et al.*, 2019). In this context, the present study was conducted within the framework of the project *RuRES – Rural Resilience. Decentralised Landscapes and Ecological Strategies of Non-elite Groups in Cisalpine Gaul*, which investigates the dynamics of rural landscapes in northern Italy through the combined analysis of archaeological and environmental data. Particular attention is devoted to the strategies adopted by non-elite communities for managing natural resources under changing ecological conditions.

From the late Republican period onwards, the incorporation of northern Italy into the Roman state was accompanied by an expansion and reorganisation of rural settlement, planned land division, and the development of road and market networks (Haeussler, 2013; Roncaglia, 2018). In the Po Plain,

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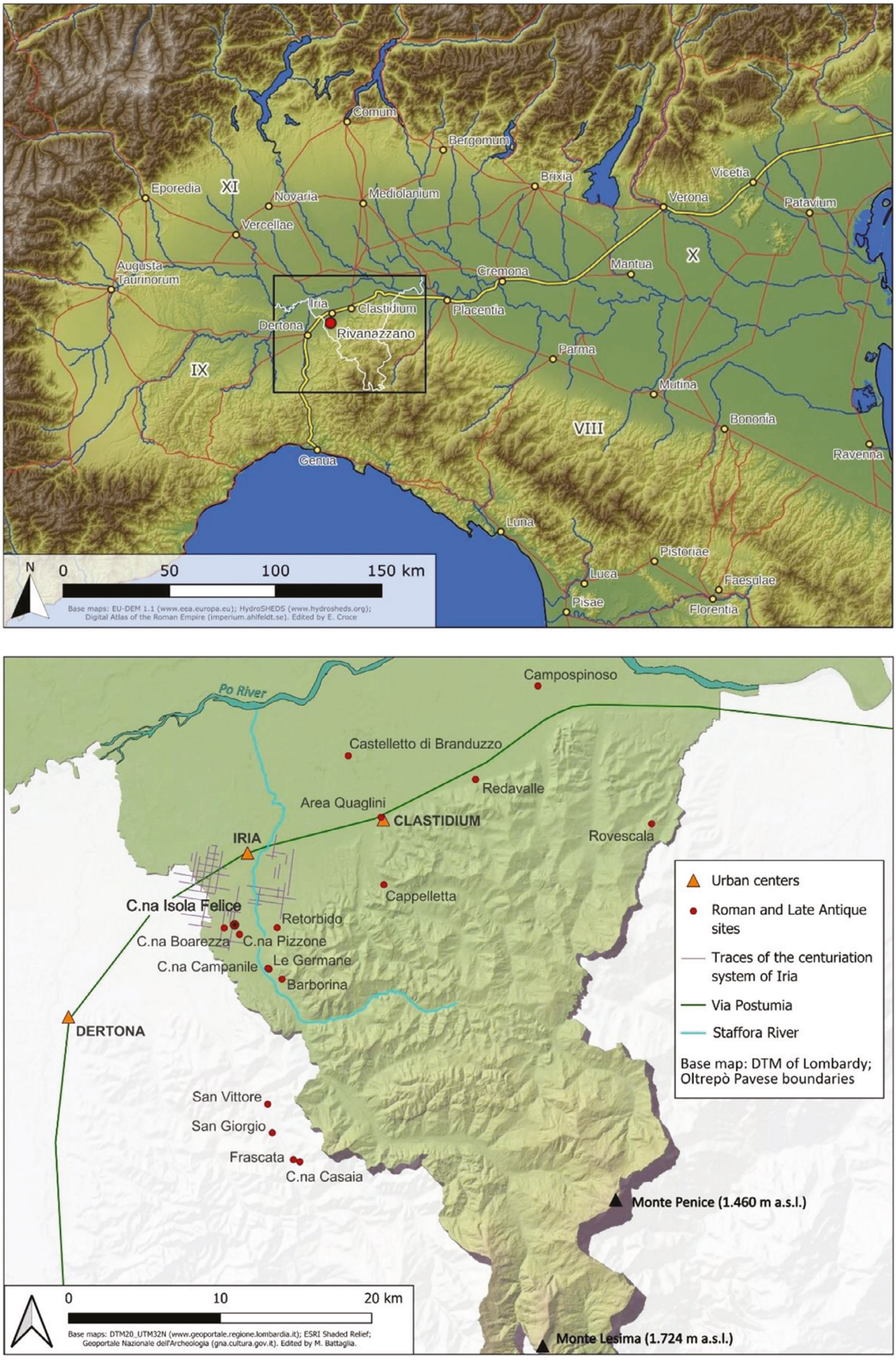


Figure 1. Location of the study area and distribution of the main archaeological evidence in the micro-region of Rivanazzano Terme (Province of Pavia, Italy).

extensive centuriated landscapes supported hierarchically structured settlement systems comprising urban centres, villas, farmsteads, minor rural agglomerations, and specialised productive infrastructures. These components formed integrated agrarian systems in which agricultural production, processing, storage, exchange, and water management were connected at the micro-regional scale (De Haas and Tol, 2017; Bowes, 2021).

The Rivanazzano area reflects this broader pattern (Figure 1), forming part of a structured rural micro-region south of the Roman centre of *Iria*. Archaeological investigations have revealed a dense and functionally differentiated settlement pattern, including villas, farmsteads, roads, centuriated land divisions and specialised infrastructures (Maggi *et al.*, 2019; Zamboni, 2022; Battaglia and Godino, in press). From the later Imperial period into Late Antiquity, this system underwent differentiated transformations rather than uniform decline, with some settlements and facilities being abandoned and others remaining in use, being repurposed or acquiring new productive functions. This makes the period particularly relevant for assessing whether changes in vegetation and land use reflect agricultural contraction, continuity or a reorganisation of rural production and resource management. Within this broader perspective, the case study of Cascina Isola Felice at Rivanazzano Terme (Staffora Valley) provides an opportunity to investigate the interaction between human activities, wetland environments, and hydraulic infrastructures, which have long played a crucial role in shaping agrarian systems in the Po Plain region. By integrating archaeological evidence with palynological data, this study aims to reconstruct patterns of vegetation history, environmental exploitation, and land use. It further aims to contribute to the interpretation of economic practices and site functionality, particularly where the significance of archaeological layers and plant-related contexts remain ambiguous, while shedding light on the resilience and adaptability of rural communities in marginal and dynamic landscapes. The study area is situated at the margins of a more extensive settlement network, encompassing the countryside between the Roman centres of Dertona and Iria, and features a centuriation system. Archaeological investigations have revealed a settlement pattern of significant density and complexity, characterised by *villae*, farms, and rural infrastructures with continuous occupation from the late Republican period through Late Antiquity (Zamboni, 2022; Battaglia and Godino, in press; Figure 1). Such stratigraphic continuity provides a rare opportunity to trace the diachronic evolution of a rural landscape over several centuries.

Against this broader historical and archaeological background, the present palaeoenvironmental study integrates archaeological data with pollen and non-pollen palynomorph evidence to investigate the relationships between human activities, wetland environments and agrarian practices at Rivanazzano Terme. More specifically, the study aims: i) to assess the contribution of pollen analysis to the functional interpretation of archaeological water-related infrastructures, ii) to distinguish local activity-related signals from the surrounding environmental background, and iii) to reconstruct changes in land use and rural resource management between the Roman period and Late Antiquity. Palynology represents a key tool in archaeological research, as it allows the identification of anthropogenic transformations of natural environments as well as the environmental constraints that influenced past societies (Faegri *et al.*, 1989; Mercuri *et al.*, 2010; Mercuri, 2008; 2014; Clò *et al.*, 2024). In the present study, archaeobotanical evidence is integrated with the archaeological record to reconstruct vegetation dynamics, the management of wet environments and agrarian practices. By combining archaeological and palaeoenvironmental evidence, the Rivanazzano case study provides an example of how integrated approaches can refine the functional interpretation of water-related archaeological structures and contribute to a broader understanding of rural landscape organisation and resource management in Roman and Late Antique northern Italy.

2. Study area

2.1 Geomorphology and climate

The Cascina Isola Felice site at Rivanazzano Terme lies within the Oltrepò Pavese, the southwestern extremity of Lombardy, bounded by the right bank of the Po River to the north and the slopes of the Ligurian-Emilian Apennines to the south. The area exhibits a varied topography, characterised by a gradient ranging from alluvial plains to medium and high-hill systems, with peaks attaining an altitude of 1,700 meters.

Located at the transition between the Po Plain and the first Apennine foothills, Rivanazzano Terme sits along the course of the Staffora river, which flows for 64 km before reaching its confluence with the Po river. The upper valley, carved into the resistant Monte Antola Limestones, features steep slopes covered by dense forest and a narrow valley floor almost entirely occupied by the stream. As the valley opens onto the plain, the morphology is dominated by the distal spread of the Staffora alluvial fan (Carta Geomorfologica, 1997), which, in its southern sector, is characterised by a gravelly core overlain by a 60–80 cm layer of fine-textured soil, except where incised palaeochannels cause the gravelly substrate to outcrop directly at the surface. Palaeochannels and alluvial ridges attest to a highly dynamic hydrographic system, characterised by the progressive eastward migration of fluvial axes across the southwestern sector of the fan (Maggi *et al.*, 2019). This shift directly influenced the territory of Rivanazzano Terme through successive ancient depositional phases. Furthermore, extensive tectonic fracturing allows for the ascent of deep, mineral-rich waters (bromine and iodine), which are further enriched by sulfates and bicarbonates from superficial rock formations. These thermal resources are systematically exploited at the modern thermal baths of Salice and Rivanazzano Terme (Pellegrini, 2024).

The region's orographic and lithological variety, combined with a subcontinental climate, shapes present-day local land use: the alluvial plain is dedicated to meadows and cereal

cultivation, the marly-clayey hillslopes are predominantly used for viticulture, while the more resistant mountain lithologies support pastures and dense woodland forests, also present in the middle valley (Pellegrini, 2024).

2.2 Flora and vegetation

Regional palaeoclimatic reconstructions based on speleothem and lacustrine isotope records indicate that climatic conditions during the Roman period were characterised by recurrent hydrological variability at regional scale, without evidence for abrupt climatic disruptions affecting northern Italy (Bernard *et al.*, 2023). Natural pollen records from the central Po Plain indicate that during the Late Holocene the regional vegetation was characterised by mixed deciduous oak woodlands associated with extensive hygrophilous forests, while progressive human impact increasingly shaped the landscape through forest clearance and agricultural expansion (Accorsi *et al.*, 2004; Mercuri *et al.*, 2012; 2026). The present-day vegetation of the study area represents the outcome of this long-term evolution.

The vascular flora of the Oltrepò Pavese is remarkably rich and diverse, representing one of the most floristically varied areas in north-western Italy. Recent floristic inventories document nearly 1,870 taxa of vascular plants in the region, including both native and non-native (neophyte and archaeophyte) species, reflecting a long history of natural diversity and human influence on vegetation patterns (Ardenghi and Polani, 2016). This environmental setting supports the potential natural vegetation referable to the *Carpinion betuli* alliance, whose presence is today inferred mainly from a few relict forest fragments. The remaining patches of lowland woodland attributable to this alliance are typically dominated by *Quercus petraea* (Matt.) Liebl., *Carpinus betulus* L. and *Quercus robur* L., with associated species such as *Prunus avium* (L.) L., *Prunus padus* L., *Fraxinus excelsior* L., *Tilia cordata* Mill., *Alnus glutinosa* (L.) Gaertn., and *Quercus cerris* L. (Blasi, 2010). In areas subjected to significant anthropogenic disturbance, invasion by *Robinia pseudoacacia* L. is frequent, often leading to a partial or even complete transformation of the floristic composition and a marked reduction in species richness (Blasi, 2010; Ardenghi and Polani, 2016). Moving upslope into the foothill and lower montane zones, the vegetation is characterised by mixed oak-dominated forests (on sandstone substrates, the tree layer is dominated by *Quercus cerris*, accompanied by *Quercus pubescens* Willd., *Fraxinus ornus* L., and *Sorbus torminalis* (L.) Crantz) and chestnut woodlands (*Castanea sativa* Mill.). At higher elevations, the environmental setting traditionally supports mesophilous broadleaved woodlands dominated by beech forests (*Fagus sylvatica* L.) often interspersed with semi-natural pastures and coppice woodlands (Ardenghi and Polani, 2016). Across the entire gradient from plain to mountain, the present-day vegetation results from the combined influence of natural ecological factors and long-term land use. Agricultural practices, including viticultural terraces, cereal fields, and other crops, are closely integrated with woodlands, resulting in a heterogeneous landscape where anthropogenic and spontaneous plant communities coexist and contribute to local biodiversity.

2.3 Archaeological context

The archaeological site selected for palynological sampling is located at Cascina Isola Felice, in the northern sector of the municipality of Rivanazzano Terme (44°57′1.42″N, 8°59′56.51″E), at an elevation of 126 m a.s.l. Previous archaeological investigations coordinated by Stefano Maggi (University of Pavia) focused on the exploration of large *villae* (Cascina Pizzone) and small rural sites (Cascina Boarezza, as synthesised in Zamboni, 2022). The archaeological potential of the area of Cascina Isola Felice was first identified in 2017 through the analysis of satellite imagery (Google Earth). The flat morphology of the plain, combined with favourable soil conditions and the cultivation of alfalfa (*Medicago sativa* L.), enabled the detection of crop marks corresponding to the footprint of a rectangular structure. Subsequent field surveys confirmed the presence of a complex and chronologically heterogeneous deposit, although its integrity has been partially affected by long-term agricultural activity (Battaglia and Godino, in press).

Since 2021, extensive stratigraphic excavations have uncovered a large rectangular structure (22×11 m) built from dry-laid river cobbles (Figure 2). This structure features a three-sided perimeter that remains open toward the northeast, where a significant access ramp (SU115) was identified. This ramp, which overlies the sterile substrate (SU138 and SU411), consists of a compact gravel layer sloping inward to provide a managed entrance to the area; the associated walls, measuring 60–70 cm in thickness with a preserved height of up to one meter, were likewise founded directly upon the sterile natural units (SU404 and SU412). Together, the construction of both the walls and the ramp appears designed to offset a marked topographic gradient, levelling the transition between the interior and exterior of the complex. Based on the integration of stratigraphic and sedimentological data, the structure is interpreted as an artificial basin, likely created by reinforcing the banks of a pre-existing body of water.

Numerous small finds were recovered along the internal perimeter and across the ramp, including a significant concentration of oil lamps, coins, twisted glass rods and ornamental items – such as rings and fibulae – alongside both fine tableware and coarseware. The specific typology, density and spatial distribution of these artefacts suggest episodes of intentional deposition, potentially associated with votive or ritual practices.

Built during the Augustan era (late 1st century BC – early 1st century AD), the artificial basin exhibits an initial phase of use continuing into the 2nd century AD, with various structural reinforcements of its banks aimed at maintaining water access and functionality. Within the enclosed area, two substantial clay layers (SU407, SU402) overlying the gravel flooring attest to prolonged sedimentation in a wetland

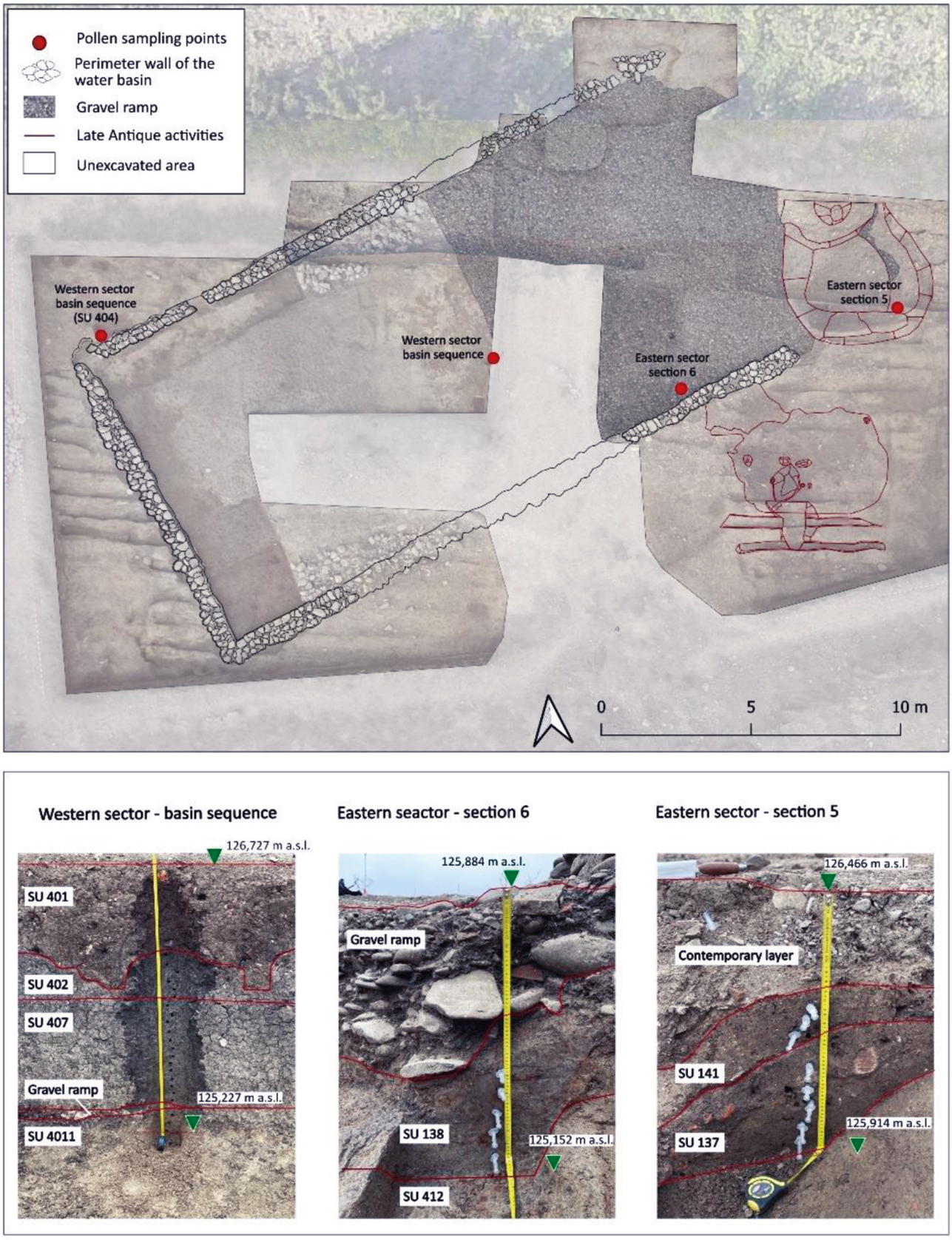


Figure 2. Rivanazzano Terme – Cascina Isola Felice, general map of the excavations with location of the palynological sampling and detail of the stratigraphic sequences studied for pollen.

environment, confirming the reservoir's primary hydraulic function.

Material evidence indicates that the basin remained a significant feature of the landscape into Late Antiquity. Between the second half of the 4th century and the early 5th century AD, the area outside the complex was used for productive activities, as indicated by carbonaceous layers, a decommissioned pyrotechnological structure, and a circular pit cut into the gravel ramp, whose earliest infills correspond to SU137 and SU141. These activities, though yet to be fully identified, are associated with several large circular pits located shortly to the north, which contain secondary deposits from the systematic spoliation of a nearby high-status residence. The building's prestige is evidenced by fragments of stone floor paving, painted plasters, and architectural elements – most notably a marble lintel retaining traces of blue pigment. Furthermore, the discovery of Kerbschnitt-style military belt fittings suggests that a high-ranking official was likely associated with the complex during this phase (Battaglia and Godino, in press).

On archaeological and stratigraphic grounds, the sedimentary sequence can therefore be divided into three main phases: a pre-basin phase predating the late 1st century BC; the construction and principal use of the basin from the Augustan period to the 2nd century AD; and a Late Antique phase (4th–5th century AD), when the structure remained a recognizable feature of the site and was reused within a different functional context.

The Cascina Isola Felice site was selected for palynological sampling as it lies within a sector where the alluvial fan transitions into fine-grained, clay-rich deposits that favour anaerobic conditions and good pollen preservation. Sampling focused on two main areas: the western sector, corresponding to the stratified deposits of the artificial basin spanning the late 1st century BC to Late Antiquity, and the eastern sector, including a Late Antiquity waste pit.

3. Material and methods

In 2024, pollen samples were collected at different stages of the fieldwork from multiple areas of the site. Sampling focused on the basin area in the western sector and on stratigraphic units exposed in the eastern sector. Overall, 35 sediment samples were selected for palynological analysis as representative of the main archaeological contexts investigated (Figure 2; Table 1). Of these, 28 samples derive from the western sector, corresponding to a basin sequence, while 7 are from the eastern sector. In addition, two moss cushions were collected to provide a reference for the modern pollen rain (M1 = 44°57′03.8″N, 8°59′54.9″E; M2 = 44°57′01.6″N, 8°59′54.1″E). All selected sediment samples and moss cushions were processed and analysed for pollen, allowing a comparative assessment of archaeological and modern pollen assemblages and supporting the interpretation of vegetation dynamics and land use at the site.

Sediments were processed following standard palynological procedures, including heavy-liquid enrichment (Florenzano *et al.*, 2012). *Lycopodium* spores were added to calculate the concentration of pollen, expressed as pollen/gram. Chemical treatment comprised deflocculation, removal of carbonates and silicates, acetolysis, and permanent mounting of the residues in glycerine jelly for microscopic observation. Moss samples were boiled with NaOH 10% and then filtered and washed several times with distilled water (Zappa *et al.*, 2026).

Table 1. Rivanazzano Terme – Pollen samples analysed. Samples were generally collected at approximately 5 cm intervals whenever continuous stratigraphic sequences were available. Stratigraphic units, archaeological chronology and main sedimentological descriptions are reported for the western sector (basin sequence) and the eastern sector (waste pit).

Western sector				
Sample	**Depth (cm)**	**Stratigraphic unit**	**Chronology**	**Sedimentological description**
1–6	50–72	SU 402	4th–5th AD	Dark grey clayey layer
7–19	76–130	SU 407	late 1st BC–2nd AD	Grey/light green clayey layer
20–22	140–150	SU 411	<late 1st BC	Clayey layer, with a sandy fraction
23–24	137–142	SU 411	<late 1st BC	Light green clayey layer
25–26	148–153	SU 412	<late 1st BC	Soil with evident iron-rich veins
27–28	11–20	SU 404	<late 1st BC	Yellowish clayey layer
Eastern sector – section 6				
1–5	41–65	SU 138	< late 1st BC	Light green clayey layer
4th AD Eastern sector – section 5				
2	24	SU 141	4th AD	Brown silty-clayey fill with small brick fragments, a few charcoal flecks and traces of mortar
6	44	SU 137	4th AD	Brown clayey fill with abundant centimetre-sized charcoal and brick fragments

Pollen identification was carried out under transmitted light microscopy (at 1000× magnification) using standard keys and atlases (Moore *et al.*, 1991; Reille, 1992; 1998; van Geel, 2001; van Geel *et al.*, 2003). Following Florenzano *et al.* (2015), fenestrate pollen grains were assigned to Cichorieae rather than Cichorioideae, as the diagnostic pollen morphology characterises the tribe rather than the entire subfamily. Cereal pollen types were distinguished according

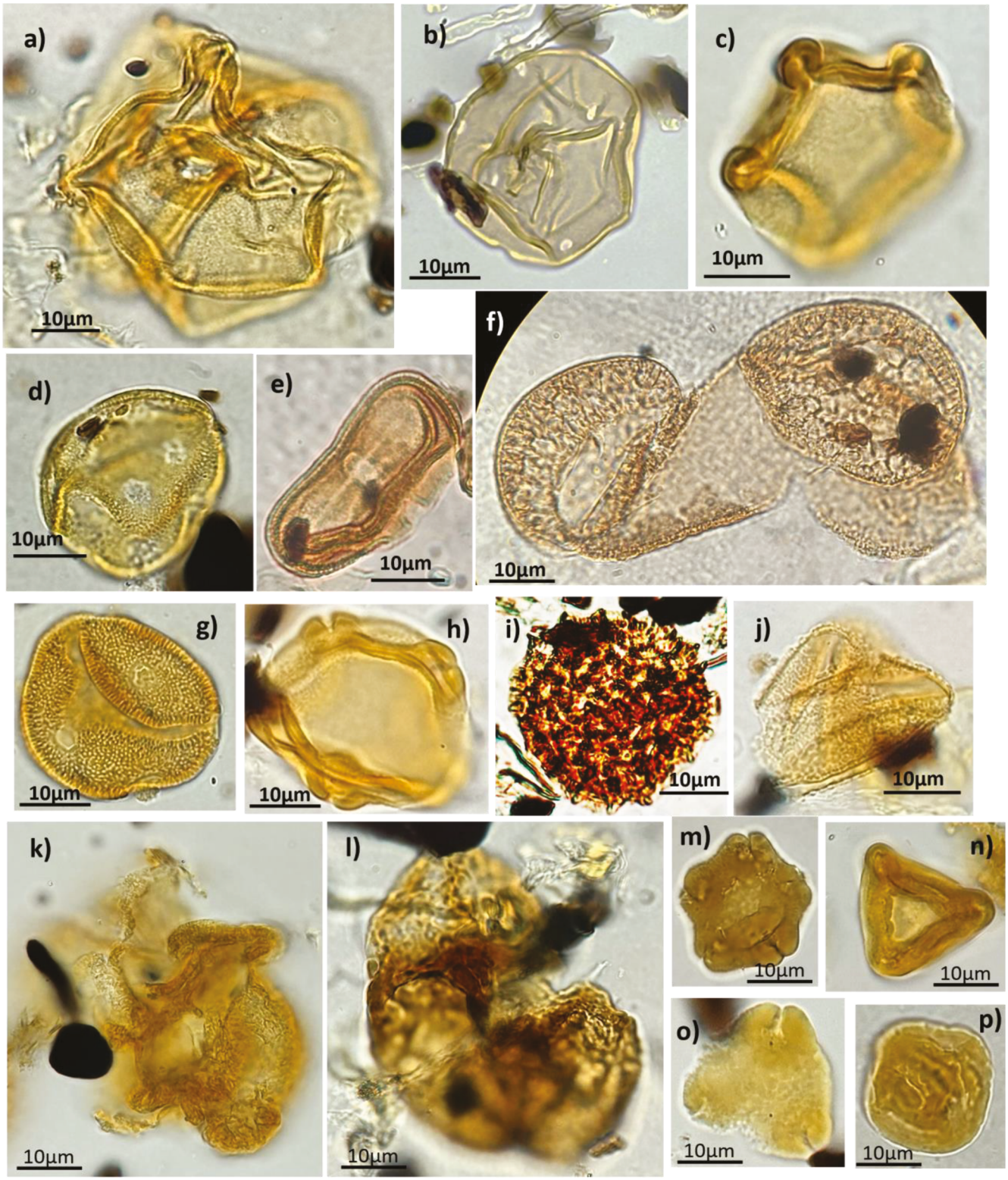


Figure 3. Rivanazzano Terme – Pollen grains from the western sector: a) *Avena/Triticum* group; b) *Juglans regia*; c) *Alnus*; d) *Alisma*; e) *Peucedanum palustre* type; f) *Pinus*; g) *Dianthus*; h) *Myriophyllum spicatum*; i) *Persicaria maculosa* type; j) *Sparganium emersum* type. Secondary pollen grains: k), l) *Pinus*; m) Alnipollenites; n), o) Normapolles group; p) Indeterminate.

to the morphological criteria proposed by Faegri *et al.* (1989) and Beug (2004). Secondary pollen grains, *i.e.* reworked pollen derived from older deposits and recognised by their altered preservation state (typically darker colour, corrosion and/or abrasion), were recorded separately and excluded from the pollen sum (Faegri *et al.*, 1989; Moore *et al.*, 1991). Non-pollen palynomorphs (NPPs) and microcharcoal were observed during pollen counting but were not systematically counted.

Pollen percentages were calculated on the pollen sum (PS) including all pollen grains considered coeval with the deposit. The percentage of secondary pollen was calculated on the total pollen count, including both PS and secondary pollen grains. The site data have been archived in the BRAIN database (Mercuri *et al.*, 2024), where the Rivanazzano Terme site is recorded under the identifier NLO93.

The arboreal/non-arboreal pollen ratio (AP/NAP) was calculated as a general indicator of the relative representation of woody and herbaceous vegetation. To facilitate the interpretation of vegetation dynamics and land-use patterns, selected ecological and functional pollen sums were calculated by grouping taxa according to their ecological affinity or anthropogenic significance.

Woody vegetation was represented by Mediterranean and sub-Mediterranean taxa (*Cistus*, *Erica*, *Fraxinus ornus*, *Ilex aquifolium*, *Myrtus communis*, *Olea europaea, Pistacia*, *Quercus ilex* type), conifers (*Abies*, *Picea*, *Pinus*), mixed deciduous oak woodland taxa (*Acer campestre* type, *Carpinus betulus*, *Corylus avellana*, *Fraxinus excelsior* type, *Ostrya carpinifolia/Carpinus orientalis* type, deciduous *Quercus*, *Tilia*, *Ulmus*), and hygrophilous trees (*Alnus*, *Populus*, *Salix*).

Additional pollen sums were calculated for hygrophilous herbs (Cyperaceae undiff. with *Carex* and *Scirpus*, *Phragmites australis*, *Sparganium emersum* type, *Typha latifolia* type) and aquatic plants (*Alisma*, *Myriophyllum*, *Nuphar*, *Nymphaea alba* type, *Potamogeton lucens*), as well as for cultivated plants, including cereals (*Avena/Triticum* group, *Hordeum* group, *Panicum*, *Secale cereale*, *Triticum*, and undifferentiated cereals).

Anthropogenic pollen indicators (API; *sensu* Mercuri *et al.*, 2013b) and Local Pastoral Pollen Indicators (LPPI; *sensu* Mazier, 2007), both including Cichorieae, and the OJC group (*Olea europaea*, *Juglans regia*, *Castanea sativa*; Mercuri *et al.*, 2013a) were used as established indicators of human impact, pastoral activity and cultivated woody resources, respectively. These ecological and functional pollen sums were used as interpretative tools but did not replace the analysis of individual pollen taxa.

4. Results

The results are presented first for the western sector (basin sequence), followed by the eastern sector (waste pit), and finally by the modern moss samples. Within each dataset, pollen preservation, concentration and floristic richness are first described, followed by the main palaeoenvironmental and land-use indicators, including woody vegetation, wet environments, cultivated plants, and non-pollen palynomorphs (NPPs).

4.1 Western sector – basin sequence (28 samples)

4.1.1 Pollen count, concentration, preservation state, and floristic richness

A total of 9,360 pollen grains was counted across the analysed samples, with an average of 334 grains per sample. In most cases, a pollen sum exceeding 320 grains was achieved; lower counts were recorded only in sample 8 (circa 300 grains) and in samples 22 and 24 (circa 120 grains each), owing to their very low pollen concentration. All samples contained pollen and generally showed good to very good preservation (Figures 3 a–j), indicating that the lower pollen sums achieved in a few samples mainly reflect low pollen concentration rather than poor preservation. Pollen concentration was overall high (circa 54,000 p/g, on average) but varied markedly along the sequence, with the lowest values in the bottom part (min. 2,996 p/g in sample 24) and substantially higher concentrations towards the upper part (max. 142,328 in sample 7). Secondary pollen grains (Figures 3k–p) were identified in approximately 60% of the samples, occurring sporadically in the upper part of the sequence and more frequently in the lower part. Pollen assemblages show high taxonomic diversity, with dominance of herb pollen taxa over woody taxa. Overall, 140 pollen types were identified, including 36 arboreal taxa (trees, shrubs, and lianas) and 104 non-arboreal taxa.

4.1.2 Woody vegetation composition

The arboreal component is dominated by deciduous *Quercus* and *Pinus*, showing contrasting trends between the two main parts of the sequence, with *Pinus* more abundant in the lower part and *Quercus* increasing upwards. Other recurrent woody taxa include *Ulmus*, *Corylus avellana* and *Alnus*, the latter displaying relatively stable values throughout the sequence. Arboreal pollen can be grouped into four main vegetation units: montane woodland elements (conifers, *Fagus*, *Castanea*), Mediterranean and sub-Mediterranean woody taxa, mixed deciduous oak woodlands, and hygrophilous trees. Among these, mixed deciduous oak woodland increases towards the upper part of the sequence, whereas montane woodland is more represented in the lower samples (Table 2). Overall, woody taxa are consistently present throughout the sequence, although clear changes in their relative abundance are observed. Accordingly, the AP/NAP ratio indicates a marked dominance of non-arboreal pollen throughout the sequence, averaging approximately 25/75 and showing a decreasing trend towards the uppermost samples, where values reach a minimum of 10/90 (Figure 4). Notable among the woody plants are the traces of *Olea europaea* (<1% in P5, P15, P17), *Vitis vinifera* (in nine samples, and 0.2% on average) and *Morus nigra* (1.9% in P20), which indicate potential tree cultivation.

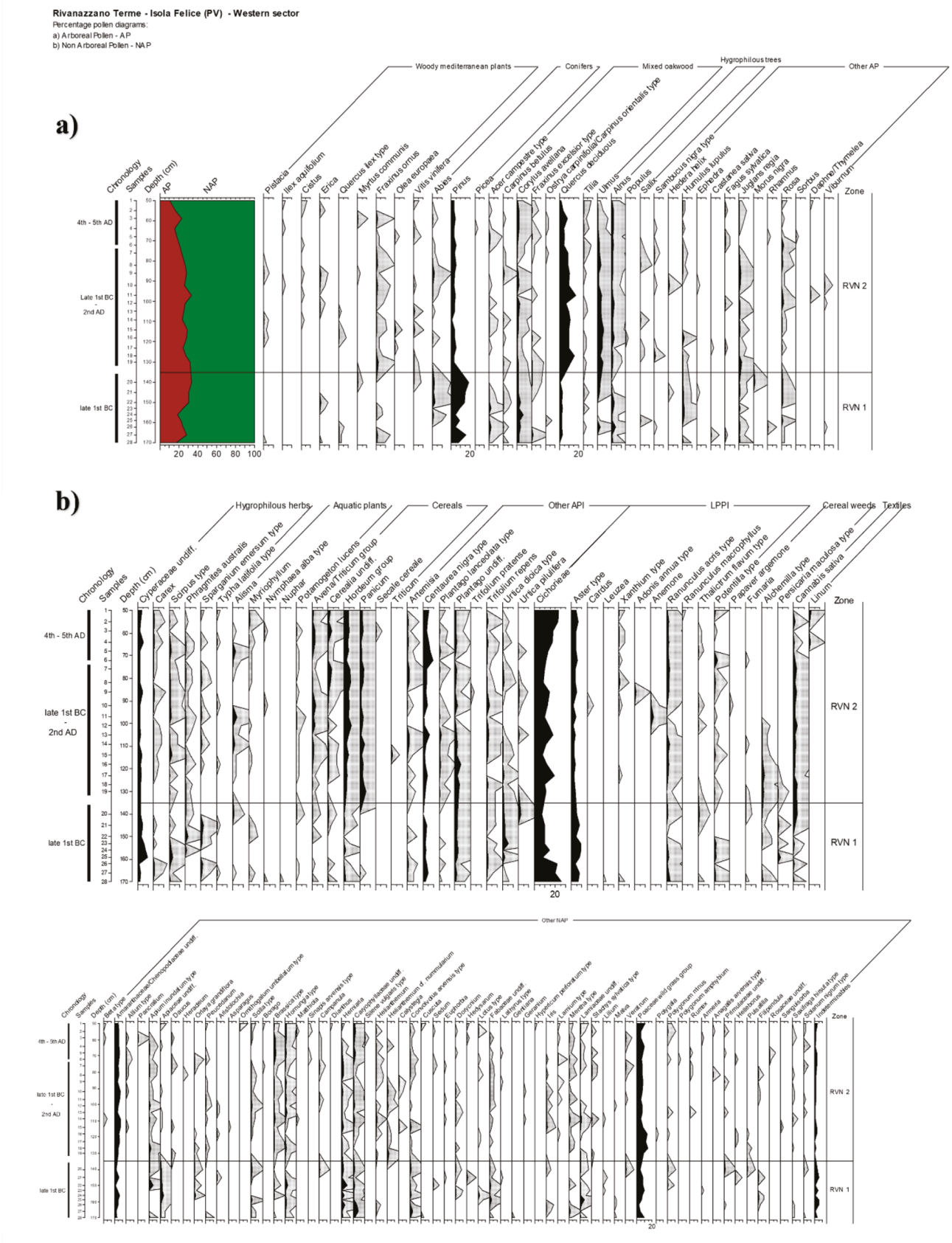


Figure 4. Rivanazzano Terme – Percentage pollen diagram of the western sector (basin sequence), showing the main pollen taxa, with a) Arboreal taxa and b) Non Arboreal taxa. The pollen zonation (RVN1–RVN2) is based on the overall composition of the pollen assemblages.

4.1.3 Wet environments

Hygrophilous herbs and hydrophytes are well represented in the pollen assemblages, including Cyperaceae undiff., *Carex*, *Scirpus*, *Phragmites australis*, *Typha latifolia* type and *Sparganium emersum* type, as well as aquatic taxa such as *Myriophyllum*, *Potamogeton lucens*, *Alisma* and *Nymphaea alba* type. These taxa occur throughout most of the sequence, indicating the persistent presence of wet environments associated with the basin, although their relative abundance shows moderate fluctuations along the sequence.

4.1.4 Cereals and textile plants

Cereal pollen is present in nearly all samples and includes *Hordeum* group, *Avena/Triticum* group, *Triticum*, *Panicum* and undifferentiated cereals, with an overall mean value of approximately 7% and higher percentages in the upper part of the sequence. Pollen of textile plants is also recorded (Figure 5), with *Linum* occurring in a limited number of samples and *Cannabis sativa* present throughout most of the sequence, with significant values in several samples (mean 1.6%; Figure 4).

4.1.5 Pastoral and anthropogenic indicators

Pastoral indicators are mainly represented by Asteraceae, together with Ranunculaceae and *Potentilla* type, resulting in consistently expressed LPPI values throughout the sequence. Anthropogenic pollen indicators (API) are also continuously recorded, indicating the persistent presence of taxa associated with human activities and disturbed environments.

4.1.6 Non-pollen palynomorphs and microcharcoal

Non-pollen palynomorphs (NPPs) were observed during pollen analysis. They are generally scarce and mainly consist of fungal spores, including *Glomus*, *Sordaria*

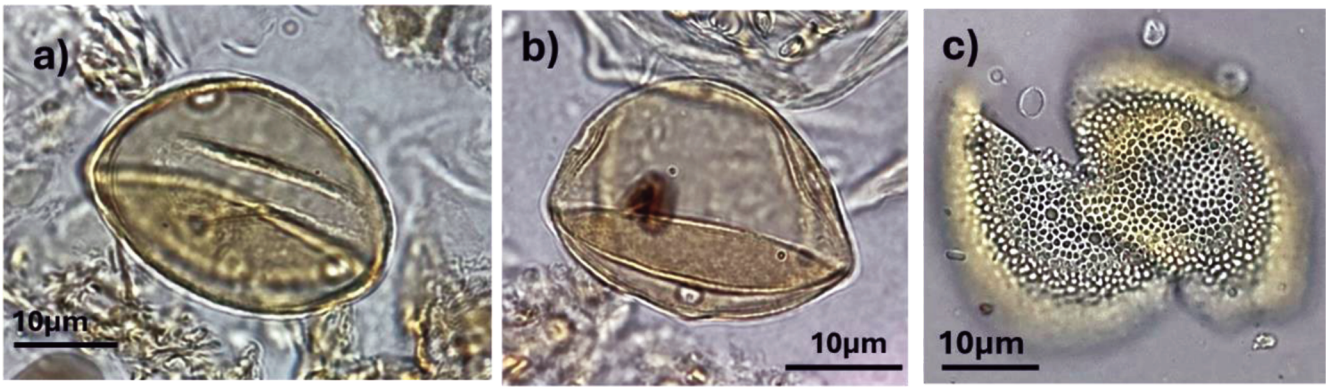


Figure 5. Rivanazzano Terme – Pollen of textile plants: a, b) *Cannabis sativa* and c) *Linum*.

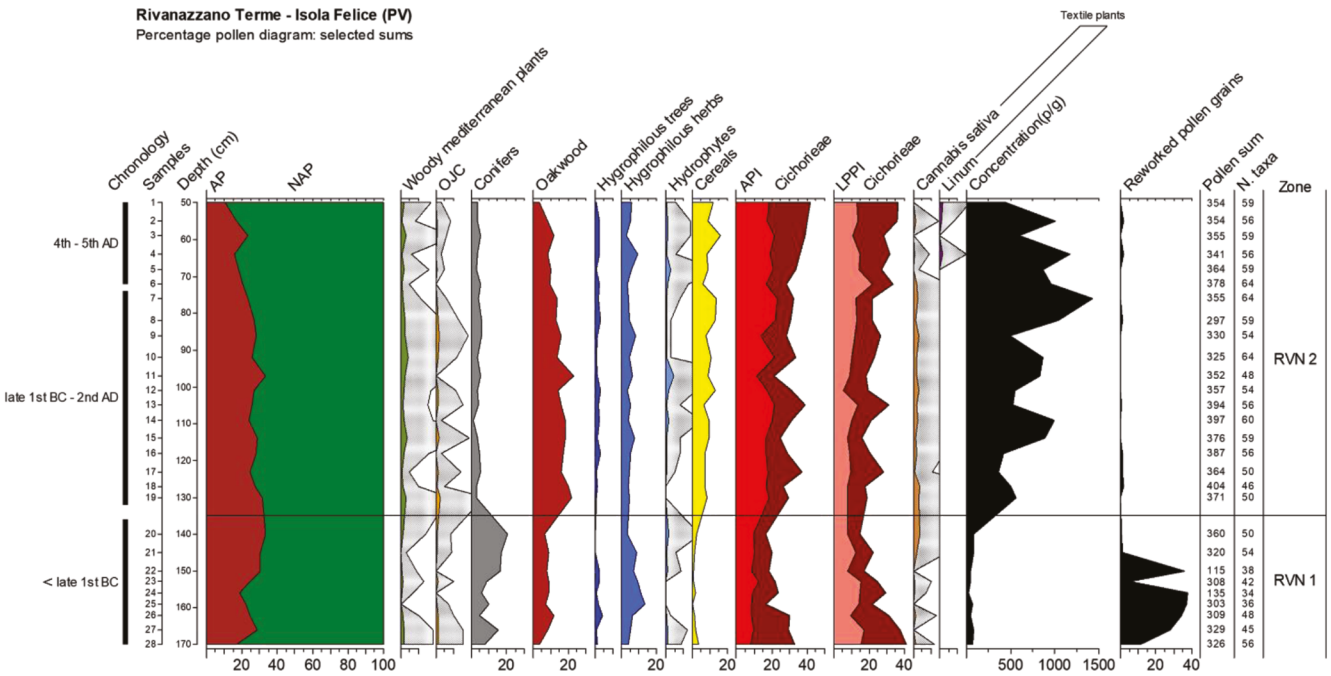


Figure 6. Rivanazzano Terme – Simplified pollen diagram showing ecological and functional pollen sums and selected pollen taxa derived from the pollen sequence of the artificial basin pollen sequence. These curves are used to facilitate environmental and land-use reconstruction. Cichorieae are represented within the relevant ecological and functional pollen sums, as they are included in both API (=Anthropogenic Pollen Indicators) and LPPI (Local Pastoral Pollen Indicators) sums. Grey curves represent a ×10 the amplification.

Table 2. Rivanazzano Terme – Summary of the main woody vegetation groups characterising the two pollen zones (RVN1 and RVN2) of the western basin sequence.

Vegetation group	Main taxa included	Pollen zones		
		RVN1	RVN2	Notes
Montane woodland elements	*Pinus*, *Abies*, *Fagus sylvatica*, *Castanea sativa*	Higher values (11.8%)	Lower values (4.1%)	Dominated by conifers; more represented in the bottom zone
Mediterranean woody taxa	*Quercus ilex*, *Fraxinus ornus*, *Olea/Fraxinus*, *Ilex*, *Cistus*, *Erica*, *Pistacia*, *Myrtus*, *Viburnum*	Low values (1%)	Slightly higher values (1.9%)	Always minor component
Mixed deciduous oak woodland	Deciduous *Quercus*, *Acer campestre* type, *Carpinus betulus*, *Corylus avellana, Ostrya carpinifolia*, *Fraxinus excelsior* type, *Ulmus*, *Tilia*	Moderate values (8.0%)	Higher values (14.3%)	Increasing trend towards the upper zone
Hygrophilous trees	*Alnus*, *Salix*, *Populus*	Low and stable	Low and stable	Minor component throughout the sequence

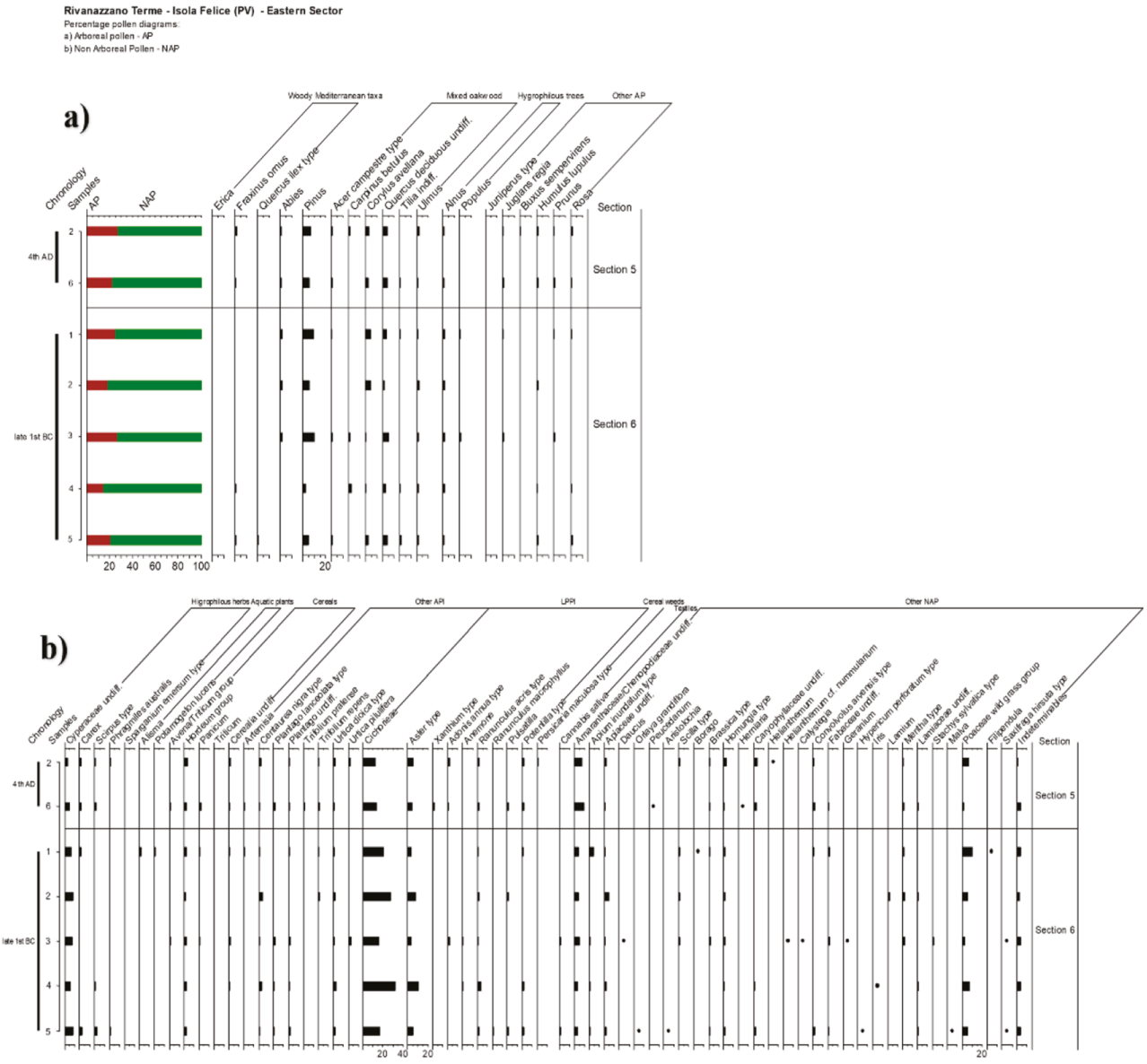


Figure 7. Rivanazzano Terme – Pollen percentage diagram of the eastern sector (Sections 5 and 6), showing the main pollen taxa.

type, *Thecaphora* and algal remains including cysts of *Concentricystes* (*Pseudoschizaea*), and occasional records of the protozoan *Arcella*. Microcharcoal fragments were also sporadically observed in several samples.

4.1.7 Pollen Zones

Based on the overall pollen assemblage composition, two main pollen zones were identified within the basin sequence (Figure 6):

RVN1, the older zone corresponding to samples 28–20, is characterised by lower pollen concentration, a higher contribution of montane woodland elements, including conifers, a greater representation of hygrophilous and aquatic herbs (8.1%), together with a greater occurrence of secondary pollen grains (21.8%);

RVN2, the younger zone corresponding to samples 19–1, is characterised by increased pollen concentration, higher representation of mixed deciduous oak woodland taxa, higher cereal pollen values (1.9% *vs* 0.3% on average), lower values of hygrophilous and aquatic herbs (6.3%), and a reduced incidence of secondary pollen (0.5%), reflecting more stable depositional conditions.

4.2 Eastern sector (waste pit) – sections 5 and 6 (7 samples)

4.2.1 Pollen count, concentration, preservation state, and floristic richness

A total of 2,354 pollen grains was counted in the seven analysed samples, with an average of approximately 336 grains per sample. All samples contained pollen, although the preservation ranged from poor to moderate. Secondary pollen grains were only occasionally recorded (0.8% on average). Pollen concentration was high (circa 51,000 p/g, on average), with a maximum value recorded in the deepest sample (174,265 p/g in sample 5 – section 6), whereas the remaining samples displayed lower and more homogeneous values. The pollen assemblages show good taxonomic diversity, with a total of 80 pollen types identified, including 19 arboreal taxa (trees, shrubs and lianas) and 61 non-arboreal taxa. The AP/NAP ratio indicates a clear dominance of non-arboreal pollen (Figure 7), with an average value of 21/79 and values ranging from 27/73 to 14/86, confirming the prevalence of open environments in the surroundings of the site.

4.2.2 Woody vegetation composition

The arboreal pollen assemblage is broadly comparable to that recorded in the basin sequence, although with different relative proportions. Mixed deciduous oak woodland taxa and conifers represent the main arboreal groups, with mean values of 8.6% and 7.6%, respectively, and relatively stable percentages across the samples. Mediterranean and sub-Mediterranean woody taxa are scarce (0.9%) and restricted to the upper samples, whereas hygrophilous trees are consistently represented (mean 3.5%).

4.2.3 Wet environments

Hygrophilous herbs and hydrophytes are also well represented in the pollen assemblages, accounting for 9.3% (12.8% when hygrophilous trees are added). Hygrophilous herbs are represented by a more limited number of taxa than in the western sector, mainly including Cyperaceae (with *Carex* and *Scirpus*), *Phragmites australis* and *Sparganium emersum* type, but occur at higher percentages. Rooted aquatic plants such as *Alisma* and *Potamogeton lucens* are also present.

4.2.4 Cereals and textile plants

Cereal pollen occurs at lower percentages than in the basin sequence (mean 3.5%) and includes *Hordeum* group, *Avena/Triticum* group, *Panicum* and undifferentiated cereals. Textile plants are absent or only sporadically recorded in this sector, with *Cannabis sativa* occurring in trace amounts and *Linum* not recorded.

4.2.5 Pastoral and anthropogenic indicators

Pastoral indicators are mainly represented by Asteraceae, which account for more than half of the herbaceous component and include *Aster* type, *Centaurea nigra* type, *Xanthium*, and Cichorieae. Ranunculaceae are also present, with LPPI values reaching 12.6% (Cichorieae excluded). Anthropogenic indicators (API) reach a mean value of 7.7% and are represented throughout the analysed samples. Only the two samples from Section 5, coeval with the upper part of the basin sequence (4th–5th century AD), show pollen assemblages broadly comparable to those recorded in the western sector, particularly with respect to woody vegetation, wetland indicators and cereal pollen.

4.2.6 Non-pollen palynomorphs and microcharcoal

Non-pollen palynomorphs (NPPs) are scarce and are mainly represented by fungal spores (*Glomus*, *Thecaphora*) and algal remains, including cysts of *Concentricystes* (*Pseudoschizaea*). Microcharcoal fragments, occasionally exceeding 100–125 μm, were observed in several samples.

4.3 Moss samples

A pollen count of 500 grains was achieved for each of the two analysed moss samples. A total of 60 pollen taxa (28 arboreal and 32 non-arboreal) were identified in sample M1, and 56 taxa (22 arboreal and 34 non-arboreal) in sample M2. Pollen concentration was very high in both samples, reaching circa 180,000 p/g in M1 and 390,000 p/g in M2. The arboreal pollen assemblage is dominated by deciduous *Quercus*, followed by *Pinus*, *Ostrya carpinifolia/Carpinus orientalis* type, *Corylus avellana*, *Alnus*, and *Fraxinus excelsior* type. Other woody taxa, including *Castanea sativa*, *Populus* and *Ulmus*, are present at lower percentages. Among non-arboreal taxa, wild Poaceae, Cyperaceae and Chenopodiaceae/Amaranthaceae are the most abundant, together with *Mentha* type, *Artemisia* and *Hornungia* type. Cereal pollen (*Avena/Triticum* group and *Hordeum* group) occurs at low percentages, whereas *Urtica dioica* type is

recorded only in sample M1. Overall, the moss samples are characterised by a predominance of taxa associated with the present-day agricultural landscape.

5. Discussion

Palynological results, integrated with archaeological data, provide a coherent framework for reconstructing both the environmental setting and human activities associated with the two main sampling areas at Cascina Isola Felice at Rivanazzano Terme, namely the western sector (basin sequence) and the eastern sector (waste pit). Their comparison provides an opportunity to distinguish local activity-related signals from the broader environmental background and to evaluate the contribution of palynological evidence to the functional interpretation of the archaeological contexts.

The stratigraphic and chronological distribution of the samples identifies two main temporal blocks within the palynological record: an earlier phase spanning the late Republican to early Imperial period (1st century BC – 1st century AD), and a later phase dated to Late Antiquity (4th–5th century AD). These two chronological horizons provide the temporal framework within which palynological similarities and differences between the western and eastern sectors can be interpreted, allowing both spatial and diachronic patterns in environmental conditions and agrarian practices to be assessed. The following sections discuss the paleoenvironmental setting, agrarian landscape, human activities and their diachronic development within the broader archaeological context.

5.1 Key aspects of the palaeoenvironmental reconstruction

Secondary pollen grains, excluded from the pollen sum, provide important insights into deposit formation. Their occurrence indicates that the lower part of the basin sequence, RVN1 (Figure 6), predating the construction of the basin, was affected by episodes of flooding or fluvial sediment input, particularly at the base of SU411. These alluvial inputs, which diluted organic matter with large amounts of mineral sediment, are also reflected by the markedly reduced pollen concentration observed in the lower units of the sequence (SU411, SU412, SU404). By contrast, the low percentages of secondary pollen recorded in the eastern sector suggest only limited post-depositional reworking and indicate that the pollen assemblages largely reflect the local depositional environment.

Forest cover around the basin was generally limited, with open and discontinuous woodlands that appear to have been more developed during the earlier phases of the sequence. The modern moss samples indicate that the present pollen rain is likewise dominated by an open agricultural landscape, with deciduous oak and pine representing the main arboreal components. Comparison with the archaeological pollen record suggests the long-term persistence of an open landscape, while also highlighting changes in the relative importance of individual woody and cultivated taxa.

Montane and upland areas were characterised by conifers, while the lowlands were characterised by sparse mixed deciduous oak woodlands associated with Mediterranean and sub-Mediterranean woody taxa (Figure 4). A marked change in woodland composition occurred at the transition from RVN1 to RVN2 zone of the western sequence, with a decrease in conifers and a relative increase in mixed deciduous oak and hygrophilous woodland elements, broadly corresponding to the stratigraphic horizon associated with SU407.

Beyond evidence for cereal cultivation, the woody vegetation indicates the availability of a diversified range of plant resources within the surrounding agrarian landscape. Hazelnut, walnut and elderberry may have contributed edible products, while the frequent occurrence of *Vitis vinifera* and the presence of *Olea europaea* pollen suggest the possible local cultivation of grapevine and olive. The occasional occurrence of *Morus nigra* pollen, although limited to a single sample, is noteworthy because it points to the presence of an additional cultivated or managed woody resource within the local agrarian system, possibly reflecting the presence of cultivated areas or other managed spaces around the basin.

Wet environments formed a persistent component of the landscape surrounding the basin, as indicated by pollen taxa associated with small ditches, ponds and stagnant or slow-flowing water bodies. Their continuous occurrence provides an environmental context fully consistent with the archaeologically documented artificial basin and suggests that wet habitats were maintained throughout the occupation of the site. High pollen values of Cyperaceae, together with some *Ranunculus acris* type, further suggest the development of wet meadows, whereas rooted aquatic plants point to shallow pools or standing water.

5.2 The agrarian landscape and human activities

Cereal cultivation appears to have been a major component of the agrarian landscape at the site, as indicated by the frequent occurrence and relatively high percentages of cereal pollen throughout the sequence. Pollen of different cereal types suggests their cultivation in the surrounding area, while the occurrence of pollen from arable weeds such as *Papaver* and *Fumaria* further supports local cereal farming. Although cereal indicators are already present in the pre-basin phase (RVN1), their marked increase in RVN2 (Figure 4) points to an intensification of cereal-related activities during the more recent period. This pattern may reflect an expansion of cultivated areas and related activities in the immediate vicinity of the basin. The likely proximity of cereal fields is suggested by the transport of pollen into the basin during harvesting or soil disturbance, as well as by the possible introduction of crop residues such as straw, which may have contributed to the enhanced cereal pollen representation recorded in the later phase. Archaeological evidence documents repeated structural interventions aimed at maintaining the accessibility and water-retaining function of the basin, although no discrete

episodes of sediment removal or complete emptying have been identified stratigraphically. The possible introduction of straw or other crop residues should therefore be regarded as an interpretation of the palynological evidence rather than as an archaeologically documented cleaning practice. Interestingly, evidence for textile plants suggests that fibre processing was among the possible uses of the basin.

The presence of hemp (*Cannabis sativa*) pollen, together with flax (*Linum*) in the later phase, supports the interpretation of *in situ* retting activities, which typically involve the immersion of plant stems in water to facilitate fibre extraction. High values of *Cannabis* pollen in wet depositional environments are, in fact, regarded as a diagnostic indicator of retting, due to the localised over-representation produced during fibre processing (*e.g.* Behre, 1981). Archaeobotanical signals of hemp retting have been documented in central Italy, particularly in lacustrine contexts such as Lago di Nemi and Lago Albano, where high percentages of *Cannabis* pollen have been interpreted as evidence of hemp cultivation and processing during the Roman period (Mercuri *et al.*, 2002). Despite its generally low pollen representation, broader historical and archaeobotanical evidence indicates that hemp cultivation was widespread in the Emilia Romagna region (northern Italy) – especially in the provinces of Bologna and Ferrara – from the Roman period until the modern era (Bandini Mazzanti *et al.*, 2005; Bosi *et al.*, 2015; 2019). Within the western basin sequence, evidence for flax becomes more prominent in the later phases, whereas hemp is attested throughout most of the use-life of the basin, suggesting long-term continuity in fibre-related activities.

The presence of Asteraceae and other herbaceous taxa associated with open environments indicates that grassland areas were likely present in the surrounding landscape. However, the scarcity of coprophilous fungi in both sectors suggests limited or non-intensive pastoral activity (Cugny *et al.*, 2010; Florenzano, 2019). Although livestock husbandry does not seem to have been a dominant activity locally, open areas were probably used for grazing within a system of crop rotation involving cereal fields. The sporadic presence of microcharcoal further suggests that fire was not systematically used and may instead reflect localised burning activities, for example to eliminate the accumulation of organic residues related to agricultural practices.

5.3 Regional context: Late Roman and Late Antique rural landscapes

The palaeoenvironmental reconstruction obtained at Rivanazzano is broadly consistent with the framework emerging from archaeobotanical investigations of Roman rural sites in Italy. Studies carried out on small Roman farmsteads in southern Tuscany describe comparable open agrarian landscapes characterised by cereal cultivation, grazing areas, limited woodland cover and diversified woody resources, reflecting intensive land use by skilled non-elite rural communities (Rattighieri *et al.*, 2013; Bowes *et al.*, 2015; Mercuri *et al.*, 2022). Small rural settlements were embedded within the agrarian systems rather than representing marginal components of the agricultural economy. Collectively occupied between the 1st century BC and the 5th century AD, these sites provide valuable evidence for reconstructing site function, land use and the organisation of agrarian landscapes over the long term (Bowes, 2021).

A similarly structured rural landscape has also been documented in the Po Plain, where archaeobotanical investigations at Roman Mutina (Modena, Emilia Romagna) indicate that landscape fragmentation was already well established during the Roman period, with remnants of natural vegetation persisting alongside intensively managed agricultural and anthropogenic areas (Bosi *et al.*, 2015). Regional archaeobotanical records indicate that the transition between the Roman period and Late Antiquity was accompanied by important environmental transformations, including repeated flood events and the local expansion of wetlands and hygrophilous woodlands, while cultivated landscapes continued to characterise this territory (Bosi *et al.*, 2019). Archaeological evidence from the Oltrepò Pavese similarly indicates that, between the late 3rd and 5th centuries AD, several rural settlements underwent transformation and partial reoccupation rather than uniform abandonment, suggesting the persistence of an active, although reorganised, rural landscape (*e.g.*, this was observed in the area at Cascina Boarezza, Cascina Pizzone, Le Germane, Castelletto di Branduzzo, Rovescala, Campospinoso and Casteggio – Area Quaglini; Godino, 2025).

Within this regional framework, the Rivanazzano sequence does not indicate a major shift from cultivated to abandoned landscapes. Rather it records continuity in the exploitation of an open agrarian environment, accompanied by changes in the organisation of agricultural activities and in the use of the artificial basin. These results further support the view that Roman rural landscapes operated as integrated agrarian systems, in which agricultural production, managed woody resources and water-related infrastructures interacted over the long term.

5.4 Water-related infrastructures and their interpretation

Artificial water infrastructures have represented a recurrent component of the rural landscapes of the Po Plain since prehistoric times. In northern Italy, the close relationship between settlement organisation, water management and agricultural production is already well documented from the Bronze Age Terramare culture, where hydraulic works formed an integral part of highly structured agrarian systems (Cremaschi *et al.*, 2016; Mercuri *et al.*, 2026). The best-known example is the Middle Bronze Age wooden basin of Noceto, interpreted as a ritual rather than a productive structure, but demonstrating the long-standing importance of artificial water reservoirs within the agrarian landscapes of the central Po Plain.

Although artificial water structures fulfilled a wide range of agricultural and productive functions during the Roman period, palaeoenvironmental studies of archaeological

reservoirs have shown that these structures preserve highly localised pollen records, providing valuable information on vegetation history, land use, crop-processing and other human activities in the immediate surroundings of archaeological sites (Petr and Vařeka, 2019). In this respect, the Rivanazzano basin provides one of the few archaeobotanically documented examples from Roman northern Italy in which the integration of archaeological and palynological evidence allows both the local environmental setting and the probable productive function of an artificial water structure to be reconstructed. The Rivanazzano record therefore contributes to the broader archaeobotanical picture of the Italian landscape, where the interaction between cultural practices and plant diversity has shaped the long-term bio-cultural diversity of the peninsula (Mercuri *et al.,* 2015).

5.5 Diachronic patterns in environment and land use

The palynological record suggests a broadly consistent agrarian setting across the two main chronological blocks represented in the pollen dataset, although with changes in the intensity and organisation of land use practices at Cascina Isola Felice at Rivanazzano Terme. The two temporal blocks represented in the pollen dataset intersect with, but do not directly reproduce, the three archaeological phases described above (see paragraph 2.3): the earlier pollen record includes the transition from the pre-basin context to the establishment and Roman use of the basin, while the later pollen record documents the Late Antique phase.

During the earlier phase (1st century BC – 1st century AD), the pollen assemblages indicate an open landscape dominated by herbaceous communities, with limited woodland cover and a persistent presence of wet environments and local alluvial inputs. Cereal pollen is already documented in this phase, together with anthropogenic indicators, pointing to established agricultural activities in the area. Woodland cover, mainly represented by mixed deciduous oak and conifers, appear to have played a minor role, suggesting that cultivated fields, grasslands and wetlands were the dominant components of the local landscape.

In the later phase (4th–5th century AD), the general paleoenvironmental framework remains comparable, but the palynological signal shows clearer evidence of activity-related processes associated with the artificial basin. Archaeologically, SU402 indicates that the basin remained a recognisable wet feature or was reused, although there is no evidence for the uninterrupted continuation of its original hydraulic function. Comparison between the two samples from the eastern sector (Section 5) and the coeval samples from the basin sequence highlights a largely consistent paleoenvironmental signal, characterised by an open landscape with sparse mixed oak woodland and non-forested wet environments. While cereal pollen is present in both sectors, its higher representation in the basin sequence supports the interpretation of activity-related accumulation within the structure. This is consistent with archaeological evidence for continued productive activities in the area, although it does not demonstrate that the basin retained its earlier Roman function. Similarly, the pasture and ruderal indicators, particularly Asteraceae, recorded again with higher values inside the basin, may reflect the introduction of plant material such as straw during agricultural activities, rather than differences in surrounding land use.

Within this Late Antiquity phase, however, the upper part of the RVN2 pollen record shows lower arboreal values accompanied by a greater representation of anthropogenic indicators, including cereals and pastoral indicators. Given the chronological discontinuity between SU407 and SU402, these differences should not be interpreted as a gradual, uninterrupted trend. They nevertheless suggest that the Late Antique reorganisation of the site did not entail abandonment of the surrounding agrarian landscape, but rather continued cultivation and plant-related activities within a predominantly open environment. At the same time, the enhanced representation of anthropogenic indicators within the basin sequence further supports the interpretation of the structure as a focal point for plant-related activities, where both primary plant-processing residues and secondary inputs contributed to the pollen assemblage.

6. Conclusion

Taken together, the palynological data indicate that the site of Cascina Isola Felice at Rivanazzano Terme was embedded within a well-structured agrarian landscape primarily oriented towards plant cultivation, with a marked emphasis on cereals and textile plants. A diachronic perspective further suggests a general continuity of this agrarian system between the earlier pollen record (1st century BC – 1st century AD) and Late Antiquity, although the later phase is characterised by lower arboreal cover and an increase of anthropogenic indicators.

To our knowledge, the Rivanazzano basin represents one of the few archaeobotanically documented water-related infrastructures from Roman northern Italy. The integration of stratigraphic, archaeological and palynological evidence makes it a particularly informative case for investigating how water management and plant-processing activities were embedded within Roman rural economies. Within this framework, the artificial basin can be interpreted as a multifunctional feature integrated into the agrarian system, most plausibly associated with plant-processing activities, including the retting of hemp and, in later phases, flax. The palynological signal suggests repeated episodes of use, the introduction of plant residues such as straw, and controlled water circulation for processing or irrigation-related purposes. The limited development of aquatic vegetation is consistent with management of the structure, even during periods of reduced activity. Comparison with the present-day pollen rain indicates that the open character of the landscape has persisted to the present, although the archaeological record suggests a more diversified exploitation of plant resources and a greater intensity of

agricultural activities during the Roman and Late Antique phases. From an archaeological perspective, this continuity should not be understood as the uninterrupted survival of the Roman-period functions of the basin, but as evidence for the reorganisation of the rural landscape around existing structures and resources. During Late Antiquity, the basin persisted as a recognisable wet feature within an area characterised by new productive activities. The site therefore documents neither straightforward continuity nor wholesale abandonment, but a selective reconfiguration of the Roman agrarian system, in which earlier infrastructures were retained or adapted within new forms of production and resource management. These results provide further evidence for the close integration between plants, wet environments and agrarian practices at Rivanazzano Terme, highlighting the effectiveness of an interdisciplinary archaeological and palynological approach not only for reconstructing past environments, but also for interpreting the function of archaeological structures and the organisation of Roman rural landscapes.

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